THE UNIVERSITY

GEOLOGICAL SURVEY

OF

KANSAS.

CONDUCTED UNDER AUTHORITY OF THE BOARD OF ADMINISTRATION OF THE
UNIVERSITY OF KANSAS, AS AUTHORIZED BY
STATE LEGISLATION.

BULLETIN No. 1.

SPECIAL REPORT ON WELL WATERS IN KANSAS.

BY

ERASMUS HAWORTH, *State Geologist.*

The Geological Survey publications are distributed from the University of Kansas, Lawrence.

STATE PRINTING OFFICE,
TOPEKA, 1913.
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LETTER OF TRANSMITTAL.

Dr. Frank Strong, Chancellor of the University of Kansas:

SIR—I have the honor to submit to you herewith a special report on Well Waters in Kansas, prepared by myself principally. The information herein contained has been gathered gradually throughout the entire period of the existence of this Survey and is here summarized and put into a readable form for the first time. It is prepared hurriedly as an emergency report, due to the great and unparalleled scarcity of water in Kansas this season, particularly in the eastern part of the state, with a desire that it may be distributed throughout the state at the earliest possible moment. It is written expressly for the layman, rather than the scientist, although it is hoped it may not be entirely uninteresting to the latter.

This report will constitute Bulletin No. 1 of the reports of the Geological Survey of Kansas.

Most respectfully submitted.

ERASMUS HAWORTH,
State Geologist.

LAWRENCE, KANSAS, October 1, 1913.

CONTENTS.

PREFACE.

THIS BULLETIN is written for the layman rather than the scientist, and therefore elementary explanations are given with frequency. The present summer, 1913, has been the dryest summer known for many years. The rainfall has been unusually light. Surface streams of water, springs and wells have gone dry, even to a greater extent than in the unusually dry year of 1901. This extraordinary drouth of the ground is due to a combination of dry weather this summer and the approach to drouths during the three preceding years. The drouth of 1901 was followed by a period of unusually rainy weather, which produced the floods of 1903, 1904, and 1905. Throughout this period the ground became thoroughly saturated with water. Then came a few years of about average rainfall, followed by a period of drouth which came on gradually and increased in intensity up to the present time. It is not the drouth of 1913 alone, therefore, which has made ground water so scarce; but the drouth of 1913 is a culmination of a period of dry years, each one being a little more severe than its predecessor, so that the real dearth of ground water became more noticeable than the actual rainfall might imply.

Another feature of the rainfall, particularly in the eastern part of the state, has enhanced the drouth. During the last two years rains which have come have been more precipitous than usual while they lasted and more local in extent. This has resulted in a larger per cent of the rainfall being disposed of by run-off than the general average for Kansas, and much more than one would at first think possible during such dry weather. For example, during the late summer of 1912, a heavy rain fell in the vicinity of Dexter, severe enough to cause miniature floods along Grouse Creek and its tributaries. It was estimated by local residents that more than four inches of rain fell in some places. The ground was dry and parched and would have absorbed all the rainfall had opportunity been afforded. But the water came in such quantities and so rapidly that time was given for the absorption of only a portion of it, and consequently much of it ran away and did but little good. Heavy, rapid showers are characteristic of dry countries, and usually in any given area, during protracted drouths, the small amount of rain which does fall is more intense than the average rains in the same areas during humid years.

The combination of all these conditions has resulted in making Kansas suffer for want of water for domestic purposes, including stock water, more during the present summer than has been known for a long time. It is well known to this Survey that many parts of Kansas are well supplied with ground water readily available for the asking, so that the scarcity of water need not be nearly so acute as it is, should proper arrangements be made for winning water from beneath the surface. It is also well known that in certain other areas ground water is scarce, or entirely unavailable, and false hopes should not be raised for a good supply in those areas. This little volume is brought out hurriedly in a hope of giving proper information on the subject.

It is recognized, the entire question of water supply includes the use of surface water found in rivers and water which may be impounded in ponds. This latter phase of the water problem is largely, if not entirely, engineering work, taking care of the water after impounded on the surface, and in general, is disconnected from obtaining water from the ground. For various reasons it is thought best to confine this report to ground water, leaving to other departments in the public-service work the task of properly propounding to the people of the state correct methods for handling surface water.

ERASMUS HAWORTH,
State Geologist.

CHAPTER I.

GENERAL CONSIDERATIONS.

In order to give an intelligent and understandable discussion of the ground water of Kansas a few fundamental principles should be reviewed. Contrary to popular belief, there is nothing whatever mysterious connected with the entire subject. Ever since the earliest dawn of history we have been dominated, to a greater or less extent, by a belief that there is something mysterious, supernatural, unknowable, about the existence of ground water, and that therefore something more than ordinary intelligence should be called into action when searching for it. Hence the "open sesame" has been more or less everywhere in demand, and is yet, probably, with a majority of people.

I have no doubt that could the question be settled by a vote of the people, as we settle important matters of politics and religion, the vote would be overwhelmingly in favor of the wizard's wand in one form or another. Just last week I visited a well supplying a large amount of good, wholesome water and was told by the owner that he located it with the forked stick, that the well driller did not believe in such a method, but that after the abundant supply of good water was obtained the driller became thoroughly converted to the efficacy of a forked peach-tree limb, and this in face of the fact that almost every neighbor within a radius of three miles, and in some directions from five to ten miles, had an equally good well obtained in the same manner and practically at the same depth, by drilling through the same kinds of rock into the same porous stratum, showing he was in an area underlaid by sheet water substantially everywhere present.

I beg the reader, therefore, to lay aside all his prejudice, if he has any, and ideas of mysteriousness of ground water, and believe with me that there is nothing mysterious connected with the subject; that water underground obeys the same laws that it does above ground; that above ground, in ponds and rivers and lakes and reservoirs and city supply pipes, it is controlled by the power of gravitation, and that likewise water beneath the surface of the ground is controlled by gravitation; that it flows here and there wherever gravity pulls it; that it is held here and there by impervious rock masses, as it is in the bottom of streams and lakes and water tanks; that pressure is set up whenever subsurface conditions are such that a "head" can be produced, as it can in water pipes, water towers, elevated tanks, etc.; and that the wizard's wand, the open sesame, has no more to do with ground-water supply than it has with water supply in lakes, ponds, pipes and other artificial containers on the surface.

It is now desirable to give a brief explanation of the terms "porous" and "impervious," and to show why water may be available from some rocks and not from others. All rocks are porous, and all rocks may contain water. But with some of them the water is entirely unavailable, and with others it is easily obtained. Some rocks may be full of water, but when a hole is drilled into them no water will run into the hole. Other rocks may be full of water and when a hole is drilled into them the water collects in the hole and may be pumped out. Now why this difference? Here is the explanation.

Adhesion is the name by which we express the attraction, or pull, the surface of a solid may have for a liquid in contact with it. Adhesion seems to be the same per unit of surface for all forms of the same solid, regardless of size of the granules. I mean, for example, that adhesion is as great on the surface of a little grain of sand as it is on a big one, so that when a little grain of sand is wet with water it holds the water to its surface as tightly as it does on the surface of a big grain. In this respect it differs from gravity, for gravity varies as the volume of the same kind of materials. Now, whenever water will wet the surface of a solid we have adhesive force greater than gravity. For gravity is all the time pulling at the water which does the wetting in an effort to pull it away from the surface, but adhesion holds onto it and will not let it go.

The force of adhesion, like so many other forces, varies as the square of the distance. This means that a particle of water one-millionth of an inch from the surface of the sand grain is held with a certain force, while a similar particle of water two-millionths of an inch away is held with only a fourth the pull. But gravity gives a constant pull on each particle of water, so that it gets all the water that is not too close to the sand grains, as shown in figure 1, placed as sand grains are in a pile of sand or in a sand rock. Let the broken line around each represent the distance from the surface throughout which adhesion is more powerful than gravity. Water will wet the three grains, therefore, and will crawl all over each in spite of gravity. But the water in the center of the void, at *a*, between the three grains is so far from the surface of each grain that gravity acts on it more powerfully than adhesion does, and therefore will pull it away when opportunity offers, in spite of adhesion, but it will leave a film of water covering the surface of each grain of sand.

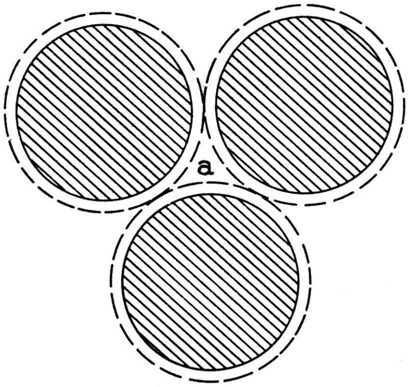

FIGURE 1, representing sand grains wet with water. The broken line around each grain represents the distance from the grain throughout which adhesion surpasses gravity and holds the water to the sand grain in spite of gravity. Beyond the broken line within the area marked "*a*," gravity surpasses adhesion, and water here may be pulled away by gravity. Rocks of this character are called "pervious."

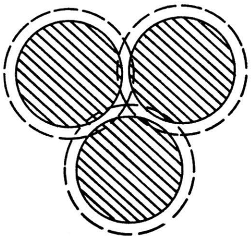

FIGURE 2, representing how granules may be so small that gravity can not pull water away from their surfaces, and thus such granules constitute a rock that can not become a water producer, and therefore it is "impervious" to water.

Now, let us suppose we have a sand rock composed of grains of sand like those just mentioned. We may have two conditions with different results. If the amount of water present is small, adhesion may use all of it in covering each grain of sand with a film shown by the broken lines around each grain in figure 1. In this case there will be no water left to fill the centers of the voids, and therefore none that may be pulled away by gravity. We may drill a hole into such rock, but no water will run into the hole, so of course we can pump none out. And yet we are dealing with a rock that may become very productive. Let us suppose that in a second case water is more abundant, as much as can be forced into the rock. Now, gravity has a chance to control all the water in the voids outside the broken lines in figure 1. It will pull it into a hole, if we drill one into the rock, and we may pump it out. It will pull it down hill if the rock is inclined, and make the water flow through the rock as it would in a river, only slower. It will give the water a pressure or "head" if it is properly held in the porous rock by impervious layers above and below, and we may have an artesian well if we bore a hole down into it.

Let us consider another case in which the sand grains are exceedingly small. Figure 2 may be used to help us. Here are three grains of sand so small that the broken lines surrounding them cut each other in the center of the void between the grains, leaving no space whatever where water may exist which may be pulled away by gravity. Suppose this rock is full of water and we drill a hole into it. No water will run into the hole because all of it is held on the surface of the sand grains by adhesion.

It is not a question of how much water a rock may have within it, therefore, which interests us, but how much can we get out of it. Fine-grained rocks and coarse-grained rocks have about the same per cent of voids. Some very fine-grained soils carry around 50 per cent of moisture. Coarse-grained rocks yield more water than fine-grained rocks do entirely because the voids between the grains are so big a portion of the water is subject to the influence of gravity. We use the term "impervious" to express the thought that no material may enter and pass through the rock mass talked of. Strictly speaking, as will be seen from the above explanation, no rock can be impervious, because all rocks have voids in them. In everyday use the term impervious means that the rock is so fine grained adhesion holds all the water which gets into it. The conditions are as shown in figure 2. A pervious rock, on the other hand, is a rock sufficiently coarse grained so that water filling the voids is partly outside the controlling influence of adhesion and therefore subject to the pull of gravity, as shown on figure 1.

RATE OF FLOW OF GROUND WATER.

The rate of flow of ground water through porous material is exceedingly variable and depends upon two conditions: First, the inclination of the top surface of the ground water, which is called the "water table"; and, second, the size of pores or voids within the material. It is evident that where more resistance is offered to movement the inclination of the water table may be greater. Water in a lake or river has its surface, or water table, substantially level. If a stream has a fall of a foot to a mile an appreciable current, or velocity, is given the water in the stream through the influence of gravity. If the water lies imbedded within a mass of earthy material, the water will flow down stream with a velocity just as it does in an ordinary river, only the hindrance afforded by the earthy material through which it flows makes it flow slower. The coarser such materials, and the larger the voids within, the more rapidly water will flow through them. A pile of rock boulders averaging six inches in diameter will permit a velocity of water through them somewhat approaching the velocity within ordinary streams, and will also be dependent largely upon the inclination of the water table, *i. e.* the water surface within the mass of boulders. Should the material gradually grow finer, passing through various grades of coarse and fine pebbles and then to coarse and fine sand and silt, and finally to fine-grained and compact clay, the velocity through the material will vary accordingly and continuously grow less until it becomes practically zero in well-compacted clay.

In 1904, Doctor Slichter made tests to determine the flow of ground water in the river valley at Garden City. Here the surface of the river flood plain slopes down stream about seven feet to the mile, and the water table slopes about the same, as is shown from the fact that water is found at substantially the same depth up and down the valley near Garden City. The summing up of his results gave an average flow down stream of about eight feet in twenty-four hours. In many places in the state where sheet water is found the water table has a much greater inclination, and flow is correspondingly more rapid.

In the summer of 1908, Mr. H. C. Wolff,[2] of the U. S.

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[2] Wolff, Mr. Henry C., U. S. G. S. Water Supply Papers 258, page 119. Washington, 1911.

Geological Survey, made an investigation of the underflow in the south fork of the Republican River, near St. Francis. He found that the flood plain area and the water table had a slope of 10.7 feet per mile, and that the ground water moved down stream at an average rate of 17 feet per day, and a maximum rate of 56 feet per day in the coarsest sand and gravel. Should the inclination of the water table be increased it is evident the velocity of flow would be correspondingly increased.

POROUS SURFACE MATERIALS RESTING ON AN IMPERVIOUS FLOOR.

According to the foregoing explanations of the action of water within porous material it follows that when rain water falls upon the surface of the ground a portion of it will sink into the ground and will be pulled downward by gravity. We have a right to assume that should nothing intervene to prevent, ultimately this rain water would reach the center of the earth. But the outer portions of the earth are so complex that divers conditions obtain, here and there, which retard, or altogether stop, the downward movement of water.

We have explored the earth down to a distance of something over 6000 feet, in a few places, to which depth we have sunk drill holes, and to something over 5000 feet by sinking shafts and having men go below and operate mines. Usually, the deeper one goes the more abundant and more troublesome the ground water down to a certain dept, which varies greatly at different places, but which upon the average is from 3000 to 4000 feet deep. Beyond these depths water occurs less in quantity and in some places is not present in sufficient quantity to cause trouble in mining.

A careful study of local conditions in each mining area generally will reveal conditions which control the depth at which water may be found. Not infrequently a shaft will pass through different formations alternating wet and dry, showing that it is not so much a question of depth as it is one of structure or texture of rock masses which control ground-water conditions. For example, in sinking the shaft for the salt mine at Lyons, Kan., water was found near the surface, which increased in abundance to a depth of substantially 300 feet, at which depth water was very abundant. It seems that nearly all the material passed through thus far was porous and would let gravity pull the water downward with ease. Here a mass of fine-grained, compact, impervious shale was reached which served as a floor to the water, so that it could sink no further. Salt is mined here a depth of 1000 to 1030 feet, and no water whatever is found in the mine.

At Kanopolis, about twenty-five miles to the north, shafts are also put down through similar surface materials to the underlying salt beds. Conditions here are quite like those at Lyons, excepting that the overlying fine-grained shales have more fissures and crevices in them through which water can slowly work its way. The result is that salt mines here are somewhat bothered with water, although not badly so. We can well imagine a still further change by assuming that some other place could be found where the shale beds are fissured and broken to such an extent that water would work its way through them very readily.

A POROUS BED BETWEEN TWO IMPERVIOUS BEDS.

We often have a porous rock layer resting on an impervious bed and also covered by an impervious bed. Under such conditions water always deports itself strictly in accordance with the laws of gravity. If nature has supplied no opportunity for water to get into the porous rock, then, of course, it will contain none. Such conditions are exceedingly rare, and yet are met with occasionally in drilling deep wells for oil and gas or other purposes. In a few instances in the oil fields of western Arkansas and eastern Oklahoma drillers report finding dry sand rock hundreds of feet beneath the surface, with water-tight beds of shale both above and below. Similar conditions occasionally are reported from the California oil fields. Usually, however, deeply lying sand rocks are filled with water wherever found.

Such a mass of sand rock surrounded above and below with water-tight shales may be compared to a surface water-pipe flattened out so as to cover a wide area. Water will comport itself within such sand rock as it would within a water pipe, excepting that velocity of movement will be greatly reduced and will be comparable to the velocity of movement already discussed for water within surface sand masses. In most cases such sand rocks come to the surface, at least along one margin, so that rainfall may supply them with water. The rock itself does not have to come entirely to the surface, and in fact rarely does. If it underlies a mass of porous material such as soil, sand, or gravel, which in turn is exposed to the surface, then rain water will have an opportunity to work its way down into the porous rock and in between the impervious layers above and below. The areas where rain water enters such rock masses are called "catchment" areas and are important in all considerations of ground water. Catchment areas may be very limited, or very wide. In considering the amount of water which may be furnished by deep-seated porous rocks the extent of the catchment area and the rainfall upon it are of great importance.

We now have the water started downwards in our porous rock which is surrounded above and below by impervious masses. A number of different conditions may obtain. The end or side of the pervious rock, or catchment area, may be exposed to the surface, or it may not. The great Dakota sandstone formation of America has its western area exposed along the foot of the Rocky Mountains from southwards in Mexico far north into Alberta, Canada. This forms a catchment area, therefore, which is a long narrow strip of country crossed by myriads of greater or lesser mountain streams that carry water from rains and melted snows from the entire eastern slope of the Rocky Mountains. A large amount of such water is absorbed by the Dakota sandstone mass along this long ribbon-like catchment area, the elevation of which in the United States averages from five to six thousand feet above sea level. Eastward the sandstones dip faster than the surface and become buried from one to two thousand feet by overlying rocks. Still farther east the dip grows less, so that the surface inclination catches up with it and causes the same Dakota sandstone to outcrop where the elevation is from fifteen hundred to two thousand feet.

Such a condition affords excellent opportunity for the water content from the catchment area to work its way eastward and to escape as spring water where the same rock masses are exposed to the surface. If the escape is sufficiently rapid, it is evident little or no water pressure will be set up within the sandstone because it goes out as fast as it comes in. But if the outflow is checked, or entirely stopped, and the intake is copious, sooner or later the entire rock mass will be full of water and a pressure, or head, will be set up so that when a hole is drilled down into the rock an artesian flow results. Experience shows that all these matters turn out just as we have a right to expect they would, the water being propelled down hill or down stream by gravity just as it is on the surface of the ground.

If our porous rock mass has a sufficient catchment area, but has no outlet lower down, as is often the case, then water can not flow through it. It will flow into it, however, and fill the voids throughout its entire area, and there it will stand. If a stream cuts a channel down into it, seeps and springs result. If a well is drilled into it, artesian water will be obtained. But otherwise the water will remain in the porous rock without having an opportunity to flow out of it.

In many cases substantially the same results are obtained when the rock mass is not very porous, such as ordinary limestone. Limestones invariably are in layers one above another, and more or less space exists between these layers. For convenience we call such spaces bedding planes. They may be filled wholly or partly with clay and therefore the amount of water which could flow down them would vary from place to place in the same rock masses. Limestones generally have vertical fissures, or cracks, in them substantially at right angles to the bedding planes. These cracks, likewise, are variably filled with clay, and hence will have a flow of water through them differing in different places. Suppose we have such a mass of limestone inclined in any given direction, situated so that a catchment area exists in the humid part of the country. Rain water would work its way down from the catchment area into the vertical fissures and from them into the spaces between the rock layers, and would follow the bedding planes downward in the direction of the inclination of the rock masses. Substantially similar conditions would exist here as explained for the more porous sand rock sandwiched between fine-grained, impervious shales.

ON MINERAL WATERS.

Nothing mysterious should be expected in attempting to understand mineral waters. Rain water is substantially free from mineral material, although rarely entirely so. Raindrops are formed in the atmosphere and consequently constitute the purest natural water known to man. Such pure water has a wonderfully strong dissolving power. The atmosphere contains a variable amount of soluble mineral material in the form of fine dust, usually of microscopic dimensions. As soon as a little raindrop comes in contact with the dust particles it begins dissolving them, and in that way the purest of rain water contains a trace of mineral material. Of course rain water always contains portions of the atmosphere, for water holds or dissolves portions of the gases constituting the atmosphere. It has been estimated that rain water before lighting upon the earth never has less than two parts to the million of mineral matter dissolved in it and sometimes as high as ten parts.[3]

When rain water comes in contact with the ground it immediately begins dissolving the ground itself. Naturally, materials easily dissolved will be dissolved in greatest abundance. When rain water falls upon granite rock or pure sandstone it can dissolve but little, and consequently river water and lake water in granitic and sandy areas will have but little material dissolved in them. But if rain water falls on other earth materials more easily dissolved it will dissolve a larger amount. Limestone is quite soluble in water containing carbonic acid gas in solution. Rain water dissolves this gas from the atmosphere and also takes up large quantities of it from decaying vegetation at and near the surface of the ground. As the water travels far beneath the surface it tends to lose its capacity to dissolve limestone because the carbonic acid gas has been used up. Well water, spring water, and river water in limestone countries, therefore, contain a large amount of lime held in solution.

Stratified rocks quite often contain gypsum and salt, each of which is easily soluble in ground water, and therefore such water is salty or gypsiferous as the case may be. Our stratified rocks were formed partly under ocean water and the sediment forming them was saturated with ocean water, just as sand on ocean beaches and mud and other sediments now constituting the delta of the Mississippi and other rivers are at the present time. Ocean salts dissolved in ocean water will remain in such materials until leached out by rain water. If, now, we have a mass of porous rock with a good outlet or subdrainage, as already mentioned in the Dakota sandstone in

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[3] Richards and Woodman, Air, Water and Food, page 197.

Kansas, various soluble materials held in them will have been leached long ago so that the water obtained from such sand rocks at the present time will be comparatively pure. Porous rocks which do not have this subdrainage will have had no chance for the ocean salts to be leached out and consequently may produce water which is substantially the same as ocean water, or even more concentrated. It so happens that the most of our sand rocks reached by the drill in our oil and gas fields of southeast Kansas belong to this latter class, namely, rocks which have no subdrainage. That is the reason why water obtained by such drilling invariably is salt water. A chemical analysis of this water shows that it contains not only salt, but practically every other material found in ocean water. Water produced by such wells is largely the same over wide areas of country although differing sightly in detailed properties.

Later in this volume it will be shown that throughout large portions of Kansas the rock masses rise to the east and dip to the west, thus affording a suitable catchment area on the east. However, they have no outlet for drainage to the west and therefore ocean salts originally in them have not been leached and carried away. This gives us salt water in almost all of our deep wells over a large portion of the state. It should be noted that water obtained from rocks near the catchment area usually is relatively pure. This is just as one might expect. Experience has shown that wells drilled into water-bearing rocks near the catchment area produce good water, and that as we migrate down the dip slopes away from the catchment area, and further from the surface the water accordingly becomes more highly mineralized until ultimately it is unfit for use. Some of the best-watered portions of the state are in just such conditions, along slender zones lying parallel with catchment areas throughout which the water is but slightly mineralized.

APPLICATION.

In applying the general principles above outlined to the conditions of Kansas, in order that they may be used in a prophetic way for the purpose of locating areas throughout which it may be possible to obtain well water, one must know the general geology of the state. This is geology, pure and simple. Searching for ground water is comparable to searching for other mineral materials, and geology is just as applicable as it is in searching for coal, or oil, or gas, or metallic deposits.

We have seen that geologic conditions may be divided into two great classes; first, conditions where the porous material comes immediately to the surface and rests upon an impervious floor; second, where porous material comes to the surface through a part of its existence, producing a catchment area, and elsewhere becomes imbedded between nonporous materials. These two conditions should be kept clearly in mind. While they have some points in common yet they have many points of difference, and in order to discuss them intelligently they should be treated separately.

Water may be found in porous material resting upon an impervious floor in almost all parts of the state. Generally it is present in every river valley and on many hillsides where debris or "slip" of the miner is sufficiently accumulated to hold quantities of water worth consideration. Northeastern Kansas is covered to variable depths by a mass of debris brought southward by glacial processes. It is the glaciated part of the state. This loose material is very heterogeneous in character and contains much soil and silt and rock boulders. It was distributed over the surface of the earth as the surface then existed, so that in places it rests upon the old local porous materials, and in other places upon fine-grained impervious beds of shales. Water conditions therefore are exceedingly variable but always in accordance with the principles above outlined.

Again, in the western part of the state the so-called Tertiary mantle of debris wafted eastward from the Rocky Mountain region forms another area with porous material at the surface resting upon an impervious floor. Here water conditions are a little more regular than throughout the glaciated area. because the upper surface of the floor was not gouged and corroded as excessively as is the floor under the glacial material in northeast Kansas. Generally here and there through the western end of the state water is everywhere abundant, but in some areas no water can be had.

This gives us three general areas in Kansas throughout which well water in large quantities may be found, namely, the river valleys, the glaciated area of northeast Kansas, and the Tertiary area of western Kansas. In other parts of the state many places are available where the soil covering, or the slip of the miner, is sufficient to form a storehouse for water. Consequently these will serve as a catchment area and will produce water wherever it is accumulated in sufficient amount to hold large quantities of water.

The second set of conditions, where porous formations are imbedded with impervious ones above and below, deals with the stratified rocks themselves. Throughout the eastern portion of Kansas the strata dip to the west while the general surface is inclined to the east. This produces north-and-south lines of outcropping of the several formations substantially parallel to each other. The oldest rocks, those lying on the bottom, appear at the surface along the eastern end of the state. Traveling westward one continually passes from the exposed edges of rock masses to those higher up, and hence younger, entirely across the state. Figure 3 is a diagramatical illustration of this and may be looked upon as a vertical section across the surface geological map, plate I.

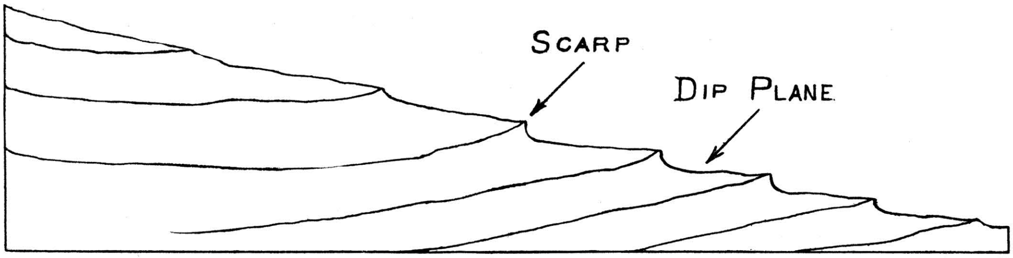

FIGURE 3. This represents a vertical section across Kansas from east to west, showing the surface, or sky line, where scarps are produced by hard rocks, and dip planes in between, where the rocks are soft and wear away easily.

As these rock masses vary in hardness it follows that the surface is worn quite irregularly. A hard limestone will resist erosion more than a soft shale beneath it. Therefore, erosion processes will wear shale away up to the foot of the limestone and thus produce a greater or lesser escarpment, or scarp, along outcropping lines. Such scarps in most instances reach clear across the state and are a permanent feature in the landscape. For example, the Oread limestone forms a scarp which extends from Leavenworth southwest by way of Lawrence and Ottawa and Burlington and Sedan to the Oklahoma state line. Immediately underneath it throughout this distance we find a soft shale bed, the Lawrence shales, two hundred feet in thickness, which on account of their softness wear away as fast as the overlying Oread limestone will permit. This produces a face of a hill, or bluff, or scarp looking eastward which is easily traced as above named entirely across the state. Beneath these shales is another mass of limestone, with shales beneath it, and a scarp facing eastward along their line of outcropping, and so on till the entire state is covered. Figure 3 represents a vertical section across this kind of surface features produced by erosion of this kind of rock masses, alternating hard and soft rocks gently dipping away from the dip of the surface. The surface of such limestone masses dips gently to the west, and if the overlying shales are principally worn away we find a zone or strip of almost level country trending parallel with the outcropping lines, but which slopes gently to the west. The width of such a zone varies from place to place, sometimes being from ten to twenty miles wide. We call such an area a "dip plane," because it is a plane dipping with the rock strata in whatever direction that chances to be.

These dip planes are good catchment areas. The soil covering absorbs the rain and allows it to work downward through the vertical fissures in the limestone below so that it can follow the bedding planes westward, while our rivers flow eastward. Dip plane catchment areas are serviceable for storing water in the fissures and bedding planes of the underlying formations. Such ground waters gradually work their way westward throughout the eastern part of the state and may be had here and there farther to the west in the form of well waters.

CHAPTER II.

RIVER VALLEYS.

In Kansas all our river valleys, excepting the smallest creeks, have great width and the flood plains, or river alluviums, have varying thickness from ten feet to a hundred feet or more. The Kansas River valley from Junction City to the Missouri River averages four or five miles in width. The flood plain material naturally varies in thickness. At Lawrence it is about sixty feet thick, and doubtless in some places is much thicker. The Arkansas River valley varies in width more than a river valley usually does, due to certain combinations of lithologic conditions which need not here be discussed. The thickness of this river alluvial material varies from fifteen or twenty feet in some places to three hundred or more in others. Similar statements may be made of the Marais des Cygnes River, of the Neosho River, and the Verdigris River, although exact figures for width of channel and thickness of alluvial material can not be given for all of them.

Much misunderstanding exists in the public mind regarding water conditions in river valleys. It may be well, therefore, to give a brief explanation of facts as they actually obtain.

A river valley is a channel or ditch chiseled into the upper surface of the rock mass. Flowing water has done the chiseling. If the rock masses vary in character then the depth and width of the valley may vary accordingly. Water flowing through such a valley wears away the rock masses and carries the products of erosion down stream. The walls of the valley, the bluffs, as they are commonly called, being thus subject to erosion, tend to grow farther and farther apart so that the valley grows ever wider. Rivers and their valleys are creatures of circumstances. There was a time in the history of the world when ocean water covered the western end of Kansas and Cretaceous rocks were forming. The eastern end of the state was drained westward, so that our rivers in those days flowed west. Subsequently, the great Rocky Mountain area was elevated and the ocean water driven out from western Kansas and the Great Plains were lifted so that surface water was forced to flow to the east. That was the beginning of our present drainage system. Each individual stream passed through various vicissitudes, and doubtless many of the earlier ones were destroyed and new ones created to take their places. It is not my purpose here to discuss Nature's mode of forming rivers and river valleys. It is important, however, to know that valleys have been formed slowly, with more or less irregularity, and that in the course of time these same river valleys in a measure have been refilled with sand and soil and other surface materials. The immediate water channel of each river valley migrates from place to place across the valley, and builds up the so-called flood plains with materials held in suspension and carried along during times of flood. In general this material is washed down from the uplands. A great flood of a large river usually results in filling up the valley upon an average of one to three inches with materials brought down from the uplands.

The bottom of the river valley proper is the stratified rock masses and will or will not form a floor through which water can not pass, depending upon the degree of porosity of such rocks. Usually this floor may be looked upon as water tight throughout the greater part of the course of a stream, because much of the rock masses primarily are water tight and the mud of the river fills up and chokes up the pores in the porous rocks.

A river valley, therefore, is a greater or lesser ditch cut into the rocks, with a floor substantially water tight. Piled upon this floor is a mass of loose, porous material which allows rain water to soak down into it and flow through it in accordance with the laws of ground water movements already discussed in chapter I. If rains are copious throughout the drainage area of the river the river valley will be substantially full of water. The immediate river channel is a portion of the valley, from which the alluvial material is constantly carried away by the flowing water, so that a lesser ditch is made in the soft material filling the greater ditch. This is represented in figure 4. Rain water falling upon the uplands works its way down into the river valley. Only a small portion of it actually enters the river channel because such large portions are absorbed by the loose material of the river flood plain. The water thus absorbed has its velocity checked and can work its way toward the river channel by very slow paces. Gradually it moves down stream and ultimately much of it seeps out into the river channel itself. The ground water in a river valley, therefore, is rain water which has not yet gotten into the river channel, but is working its way toward the channel, and is not water which has been in the channel working its way outward. Here is where so many people have wrong ideas. It is thought by many people that the water in a river valley has worked its way outward from the channel itself. It is fortunate for us that this idea is erroneous, because, were it correct, we would have but a small part of the water within our river valleys which we actually do have. How much better it is for us that nature has kindly filled the river valley full of water and permits the river slowly to carry it away, rather than to have the river valley with no water in it except what might work its way out from the river channel. As it is the river valley becomes a great storehouse for water.

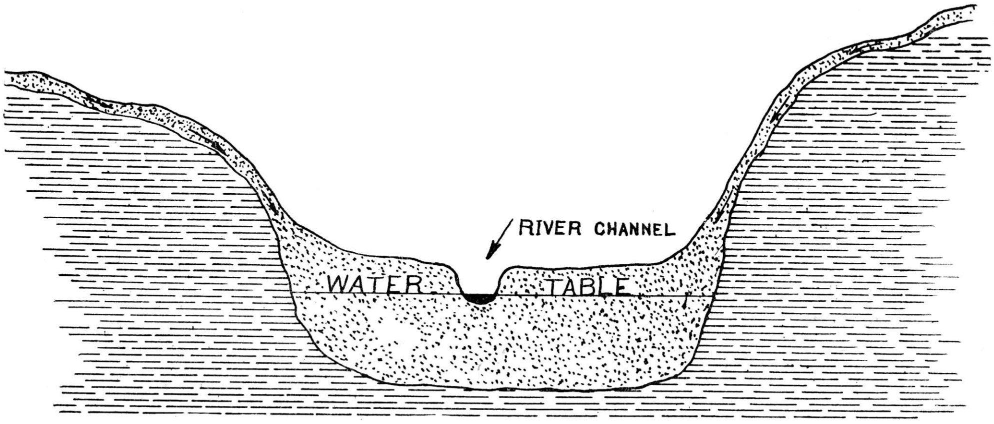

FIGURE 4, representing a modern river valley produced by erosion cutting a channel down into the solid rock. Later, sediment of various kinds has partially refilled the valley, as shown, leaving the actual present river channel occupying a narrow ditch in the alluvium material. Rain water falling upon adjacent uplands and the river valley fill the valley with water up to the water in the present river channel, as shown.

A little calculation will show some interesting facts. Suppose we have a valley like the Kansas River valley, that averages five miles wide, and suppose the river channel on the whole lies in the middle of the valley. Rain water working its way down the hillsides and into the valley must travel an average of two and a half miles from the outer sides of the valley before it can enter the channel in the form of seeps. If water travels through such material eight feet per day, as was found to be true for the Arkansas valley at Garden City, then it would require 660 days for such water to travel one mile, or 1650 days, or about 4½ years, to travel 2½ miles, in order to reach the river channel. Should conditions be such that water will travel 17 feet per day, as was found to be the rate at St. Francis, it would still require more than two years for water to migrate from the bluff lines down to the river channel. Actually, water upon entering a river valley from the uplands soon begins flowing down stream, angling towards the channel. This makes the distance of travel greater than above assumed, and the time correspondingly increased for water to reach the channel after it has entered the river valley. By and by, however, a large proportion of such water reaches the river channel in the form of seeps and sustains the flow of water in the channel during periods between rains. If one will consider how small a fraction of the time water actually flows over the surface of the land into streams one can readily see that all streams would become dry within a few days after a rain were it not for the seepage of ground water from the river flood plain into the river channels. It is this continuous seepage which maintains the flow of rivers.

During protracted drouths the seepage is sufficient to lower the water table throughout the entire flood plain, which in turn checks the seepage, and hence decreases the flow in the stream. Should a drouth be sufficiently severe, seepage would ultimately lower the water table throughout the flood plain to a level with the bottom of the channel, and to even greater depth through evaporation. The amount of water still left in the river valley, therefore, would depend upon the depth of the valley proper below the river channel, that is, the distance from the bottom of the river channel down to the floor of the river valley. As already explained, this may be a few feet, or it may be even hundreds of feet, and therefore the amount of water available for wells in periods of extreme drouth will vary with the general character of the river valley.

A limited exception should be made to the general explanations above given. If from some cause there should be a rapid rise in a river without a corresponding local rainfall, the water level in the river channel will be lifted above the water table throughout the river valley. In such cases water to a varying amount works its way from the river channel outward and spreads partially across the river flood plain and lifts the water table accordingly.

Many careful observations have been made at different places and different times which substantiate the above explanations. Perhaps the most detailed investigation made in Kansas was that on the Arkansas River valley in 1904 made by Dr. Charles S. Slichter, of the U. S. Geological Survey, and published in Water Supply and Irrigation Paper No. 153. He and his assistants determined that for the Arkansas River valley at and near Garden City the water table sloped down stream an average of 7.5 feet per mile and from bluff lands in toward the river from 2 to 3 feet per mile during ordinary stages of the river. If, however, the river became flooded by heavy rains to the west, without corresponding rains in the vicinity of Garden City, then the water table near the channel was raised and water actually flowed from the river channel out through the sands into the river valley for a short distance. They further ascertained that a heavy rain at Garden City would materially raise the water table in the valley, and that with surprising quickness, and they decided that an average of 60 per cent of local rainfall worked its way downward and joined the general ground water. Their general summaries may be here quoted:

"1. The underflow of Arkansas River moves at an average rate of 8 feet per twenty-four hours, in the general direction of the valley.

"2. The water plane slopes to the east at the rate of 7.5 feet per mile, and toward the river at the rate of 2 to 3 feet per mile.

"3. The moving ground water extends several miles north from the river valley. No north or south limit was found.

"4. The rate of movement is very uniform.

"5. The underflow has its origin in the rainfall on the sand hills south of the river and on the bottom lands and plains north of the river.

"6. The sand hills constitute an essential part of the catchment area.

"7. The influence of the floods in the river upon the ground-water level does not extend one-half mile north or south of the channel.

"8. A heavy rain contributes more water to the underflow than a flood.

"9. On the sandy bottom lands 60 per cent of an ordinary rain reaches the water plane as a permanent contribution.

"10. The amount of dissolved solids in the underflow grows less with the depth and with the distance from the river channel.

"11. There is no appreciable run-off in the vicinity of Garden City, Kan. Practically all of the drainage is underground through the thick deposits of gravels.

"12. Carefully constructed wells in Arkansas valley are capable of yielding very large amounts of water. Each square foot of percolating surface of the well strainers can be relied upon to yield more than 0.25 gallon of water per minute under one-foot head.

"13. There is no indication of a decrease in the underflow at Garden City in the last five years. The city well showed the same specific capacity in 1904 that it had in 1899."

The application of above principles is of great importance in Kansas. Few river valleys can be found in the state which will not supply all the water desired by residents in the valleys, even through our most protracted drouths. As the floor of these valleys is quite irregular, as already mentioned, it may be at times that the water table will fall below the ridges of the floor so that wells which chance to be put down directly over such ridges will fail to reach water, although an abundance of it exists in other places in the valley.

River valley ground water is available for municipal supplies at practically every city and town along the larger rivers of the state. Along the Arkansas River this is very common and I think every town without exception has a municipal supply of this character. Along the Kansas River a few exceptions may be found. Kansas City uses river water direct. Lawrence and Topeka use water principally from wells, although occasionally river water is substituted in part. Manhattan uses water from wells close to the Blue River, but yet within the Kansas River valley where the ground waters of the two valleys coalesce. Abilene uses water from wells or springs, water which has not yet entered the Kansas River. Here a large and permanent amount of water is flowing from the sandy uplands down into the river valley. Abilene intercepts this water while on its journey to the river.

Many of our Kansas towns along similar streams have not resorted to ground water, but impound surface water in artificial lakes and depend upon them for their supply. Naturally, during a protracted drouth such impounded water becomes scarce and more or less undesirable for use, and hence the water supply is deficient and of bad quality. In some localities a prejudice seems to exist against ground water. Many people think it does not exist in sufficient quantities to be worth going after, even in face of the facts easily obtainable that it exists in large quantities. A remarkable case of this kind came to my attention this summer.

Late in August I was called to a thriving Kansas town, a county seat, located in the edge of a beautiful valley in southeast Kansas. Their water supply was from Fall River, a stream rising in northwest Greenwood County. Months had passed since a rainfall had put surface water into the river, and seepage had lowered the water table in the valley until but little water seeped out into the river channel. As a result water was very low in the river, and stagnant and undesirable in quality. The river valley proper, however, held much water, as was shown by wells on every farm for miles above and below. Although reduced to extreme necessity the citizens of this town were debating the question whether or not they should resort to wells for a supply, and this in face of the facts that a test well could be put down at a cost of $5, water found within 12 or 15 feet of the surface, and there was about 18 feet of water-bearing sand.

The valleys in Kansas most important as ground-water producers are the valleys of the following rivers:

Arkansas
Blue
Caney
Cimarron
Delaware
Kansas
Marais des Cygnes
Neosho
Ninnescah
Rattlesnake
Republican
Sappa Rivers
Solomon Rivers
Verdigris
Walnut

Some of the rivers given in above list are in the western part of the state and do not have typical river valleys, that is, their river valleys are not cut down into impervious rock masses, but rather spread laterally and connect with the general underflow of western Kansas. All of the rivers in the eastern part of the state, and occasionally a portion of those in the western, have their valleys cut down troughlike into the water-tight stratified rocks so that little if any of the water once in the valley trough escapes laterally. Under ordinary conditions large quantities of rain water falling upon the water sheds of such streams will ultimately join the ground water of the river valley. It should be remembered the floors of these river valleys, or troughs, are not uniform. Usually, especially with the larger river valleys, a well put down at random within the flood plain area is sure to yield water in copious quantities.

If, however, the floor of the valley should be sufficiently irregular to permit certain concealed ridges in the floor to rise above the water table, then a well put down over such a ridge would yield no water from the underflow.

The amount of water in such a river valley may vary greatly with circumstances. With a copious rainfall the tendency is to raise the water table, thus increasing the thickness of the water-bearing sand. This in turn tends to increase the slope or fall of the surface of the water, the water table, and thereby accelerate the flow of water down stream through the sand. These two tendencies in a way balance each other so that the depth to water in most of the river valleys does not vary many feet from year to year. At Lawrence, the Kansas River valley is about 5 miles wide, and where sounded in bridge building it is about 60 feet from the surface of the flood plain to the bottom of the river valley, or to the impervious floor. The average pumping distance throughout the valley is from 25 to 30 feet, leaving about 30 feet of water in the sand. Upon an average it may be assumed that about one-fifth the space occupied by the water-bearing sand is available water, so that we have here a total amount of water equal to a width of 5 miles and a depth of 6 feet. This mass of water, of course, is slowly moving down stream, but at what rate has not been determined. At Garden City, with a fall of 7.5 feet per mile, the rate of flow is 8 feet per day. Here we have a fall of less than 18 inches per mile so that probably the downstream flow does not exceed 3 or 4 feet per day. It will be seen, from this, that a drouth of a few months, or even a year, would hardly have any effect upon the volume of water held within the sand of the Kansas River valley unless it should be pumped many scores of times as rapidly as has yet been done. Stock water and water for municipalities will always be present in greatest of abundance.

ARKANSAS RIVER.

The Arkansas River rises in Colorado, crosses the state boundary into Kansas near Coolidge on the western end of the state, flows in general east and south, and passes out of the state into Oklahoma at Arkansas City, about 130 miles west from the east end of the state. From Coolidge to near Lakin the river valley is cut down into Cretaceous shale and limestone, which are exposed to view in the bluffs on the north side of the river. To the south, however, bluffs are not observable and a mass of "sand hills" from 5 to 10 miles wide borders the river. Eastward from Lakin almost to Wichita the river bluffs are composed of loose, porous, Tertiary material, with the Dakota sandstone formations visible for a short distance in the vicinity of Larned. From Wichita south to Arkansas City the bluffs on the east side of the river are composed of stratified rocks, and a portion of the rocks on the west side as well. Here is a stream, then, with varied conditions as to river bluffs, width of river valley, and also as to character of the floor underneath the flood plain material.

The thickness of flood plain material, that is, the distance down to the floor, is exceedingly variable. At Arkansas City some wells have reached it within 30 feet; at Great Bend it is about 90 feet; while according to Slichter[4] it is about 311 feet at Garden City and only 39 feet at the so-called "Narrows" near Hartland. I have no data for depth of floor westward to Colorado, but from general information it is evident the thickness varies in different places in Colorado as well as in Kansas. The valley proper extends upstream substantially to Canyon City where the water flows over rock masses without having much river alluvium deposited.

This irregularity of depth of floor of the Arkansas River valley, of course, would make a great variation in available ground water were it not for the fact that the water table throughout the valley is so near the surface an inexhaustible amount of water is available, and therefore there is no practical need of being concerned as to the actual amount of water-bearing sand, for the water will never become exhausted by pumping. Few determinations have been made of the speed of flow of this ground water. Slichter and his assistants made elaborate determinations in the vicinity of Garden City, as already stated, in the summer of 1904. They carried their investigations westward as far as Hartland. While they found quite a variation in rate of flow, due principally to the sudden change in inclination of water table through heavy rains, yet they found an average of about 8 feet per day down stream. The direction of flow varied slightly from place to place, but in general, practically straight down stream with the river valley and entirely independent of the immediate crooks and

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[4] Slichter, Dr. Charles S., The Underflow in Arkansas Valley in Western Kansas. U. S. G. S. Water Supply and Irrigation, papers 153, page 51.

turns in the present river channel. With no evidence to the contrary, and with appearances strongly in its favor, we may assume that throughout the entire Arkansas River valley in Kansas the rate of flow varies from about ten feet per day at the west end of the state, where the inclination of surface is greatest, to about 5 or 6 feet per day at Arkansas City, where the inclination of surface is least.

The width of the river valley varies exceedingly, from less than a mile at the Narrows near Hartland to 10 or 20 miles in places from Great Bend downward. In fact, this bold bend to the north in the vicinity of Great Bend has already been explained[5] by assuming that the river has gradually slipped down the gently inclined bedding planes of the soft shales within the Dakota formation. Whether or not this assumption is correct, it is practically certain that the ground water of the river valley coalesces with the ground water from this great area south of Great Bend and the area following down the river to below Wichita. We may conclude, therefore, that in order to exhaust the supply in the river valley proper, virtually one would have to exhaust the supply from this wide area just outlined, and no one need have any fears of such a Herculean task ever being accomplished. Here is an area including all of the Arkansas River valley in Kansas, portions of Harvey and Sedgwick counties, all of Reno and Stafford counties, parts of Barton, Pawnee and Edwards counties, nearly all of Ford County, and substantially half of Gray, Finney, Kearny and Hamilton counties which have ground water in and connected with the Arkansas River valley in such quantities that no one need have any fear of the supply ever being exhausted. To prevent the reader from drawing a wrong conclusion by anticipation it should be added here that other parts of the counties named and adjoining counties may be equally well supplied with water, but discussion here is confined to the Arkansas River valley.

BLUE RIVER.

The Blue River enters Kansas from Nebraska, crossing the line near the middle of Marshall County about a hundred miles west from the east end of Kansas, and enters the Kansas River at Manhattan. Throughout its course it flows almost straight south, its mouth being only 4 miles farther east

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[5] Haworth, Erasmus, Geological Survey of Kansas, vol. II, p. 31, Lawrence, Kan., 1897.

than where it enters the state. It has cut is channel deep into the Permian rocks, which form a solid wall of stratified rocks on each side throughout its entire course. Its valley is about one mile wide, being a little wider near the mouth than at the northern part of the state. The flood plain alluvial material is not very thick, that is, the valley channel proper has not been cut very deep below the top of the flood plain material. About five miles above its mouth a dam built across the stream rests upon the solid rock, so that here the flood plain material probably is less than 20 feet thick. At Blue Rapids the stream has not yet succeeded in fully wearing away the limestone which crosses the valley and by its existence produces mild rapids and falls. In the aggregate, however, the valley has filled in enough to have the present river channel flowing over flood plain material throughout the greater part of its course, and therefore conditions are favorable for ground water within the valley held in place by the gravel, sand and soil of the river alluvium. This makes it possible to find water in wells located at random throughout the valley, which water is abundantly sufficient for all ordinary purposes during ordinary seasons. In extremely dry weather, however, when the water table has been greatly reduced by seepage into the river channel and otherwise, it should be expected that here and there ridges in the floor will be higher than the water table, and hence wells which chance to be drilled over such ridges will become dry.

During the present summer water flowed continuously in the Blue River, although the amount of flow was reduced to a minimum. The river is so young physiographically that it has a number of riffles similar to those at Blue Rapids, only less prominent, and deep pools above such riffles, as is common with rivers of this character. Water was abundant in these pools all summer long, being supplied by seeps from the ground water of the valley. No accurate measurements have been made in this valley, but it is substantially certain that the water table on each side of the channel gradually rises away from the channel, as already described for the water table at Garden City.

From the above explanation 'it is safe to conclude that the Blue River valley has an abundance of water easily available by wells to supply all the needs likely to be placed upon it. An occasional well going dry in extremely dry weather should be explained as above mentioned and should not in any sense of the term condemn the entire valley.

CANEY RIVER.

One branch of the Caney River rises in the southwestern part of Elk County and the other in the northwest part of Chautauqua County. The western fork is the larger of the two, but passes out of the state before it assumes sufficient size to warrant discussion here. The eastern fork flows southeast by way of Peru and Caney. Throughout the upper portion of the stream its valley is so narrow and shallow that it need not here be considered. Along the lower portions and farther south in Oklahoma the valley has sufficient width and depth to make it an important producer of water. Here we have the same conditions already explained for other streams. The flood plain material absorbs rainfall and water coming into it from the uplands. The ground water thus produced flows gradually down stream as in other river channels. No measurements have been made on the rate of flow in this valley. Its inclination of surface, however, is not very great and probably the flow does not exceed from 4 to 6 feet per day. The amount of water available has not been ascertained, but it is reasonably sure that the lower part of the valley would furnish all the water it is ever called upon to yield.

CIMARRON RIVER.

The Cimarron River rises in southeastern Colorado, crosses the line into Kansas in the southwestern part of the state, flows in an easterly direction near the south line of the state, occasionally crossing and recrossing the boundary, and finally leaves the state, crossing southward into Oklahoma, about a hundred and thirty miles east of the southwest corner of the state. Throughout almost all of its course it is flowing across Tertiary formations which are water-bearing and which will be discussed later in this report. Neither its bluffs nor its valley here touches the regular stratified rocks, but are confined entirely to the loose porous Tertiary material. From southern Meade County to where it crosses the state line into Oklahoma it flows over the Red Beds into which, in places, it has cut a moderately deep channel and has built up a flood plain of considerable thickness.

Water conditions along the Cimarron in its upper course throughout the Tertiary area are substantially the same as the Tertiary provides elsewhere and will be discussed in a general way under the Tertiary. Portions of the valley have the Red Beds for floors, and wells here supply but little water, and this frequently is too highly mineralized for domestic use. It will not do, therefore, to make purely general statements about this valley from Meade County eastward similar to those made for the broad Arkansas River valley. Here and there the flood plain material furnishes an abundance of good water.

DELAWARE RIVER.

The upper tributaries of the Delaware River rise in the eastern and southeastern portions of Nemaha County, with lesser tributaries rising in Brown and Jackson counties. These several streams flow southeastward across southwestern Atchison County, forming the Delaware River which flows by way of Valley Falls, Ozawkie and Perry and enters the Kansas River opposite Lecompton. Throughout the upper portion of its course it flows over glacial debris which covers the northeastern part of the state. Here the narrow valleys of the several tributaries are well supplied with water and usually furnish an abundance of well water, even in dry times. Southward it comes in contact with the hard, carboniferous limestones and shales, into which it has cut its channel, forming a valley. Here and there it has not yet worn away the limestone beds which it crosses so that falls exists, such as at Valley Falls. The alluvial material in the valleys holds considerable ground water, in a way similar to that already described for other river valleys. These cataracts or falls, however, practically divide the ground water into pools so that but little, if any, water flows from one pool to another. Such conditions of course render the sum total of ground water, and hence its reliability as source of supply, much less favorable than is found in other streams. Nevertheless, large quantities of enduring water are found here and there in the valley, readily available as well water.

Throughout the last few miles of its course the valley of the Delaware coalesces with the valley of the Kansas River and has the same general water conditions furnished by Kansas River.

KANSAS RIVER.

The Kansas River rises close to the west end of the state and flows east and empties into the Missouri at Kansas City. Some of its tributaries bear a little to the north and pass up into Nebraska, where they are gathered into the Republican River which recrosses the state line back into Kansas a little east of the middle of the state. Throughout their upper portions the tributaries frequently cut down through the Tertiary covering of the West and form channels in the stratified rocks. This is quite irregular, so that frequently we find such channels for a distance, and farther down stream the channel has not reached the stratified rocks. From Ellsworth down along the Smoky Hill River, and from Scandia along the Republican, and Beloit along the Solomon, the valleys are quite well marked, and are trenches from 50 to 250 feet deep cut down into the stratified rocks. From here to the mouth of the stream we have typical river valleys with their flood plains and ground water and underflow reaching substantially from bluff to bluff.

Few soundings have been made along the Kansas River to find the exact depth of the river valley. At Lawrence, as above stated, it is about 60 feet at the north end of the wagon bridge across the river, and also at wells near by which furnish water for the city. It may reasonably be expected that in other places the depth varies considerably. At Lecompton, for example, water in the river flows immediately over stratified rock, so that here the impervious rock layers rise to the bottom of the present river channel. It may reasonably be expected that in some places the depth of the flood plain material is much greater than in others, possibly reaching from one hundred to two hundred feet.

Throughout the river valley, as above outlined, water seems to be available everywhere. The rich farm lands have attracted buyers so that the average farm is less than 160 acres. Under all ordinary circumstances the farmer simply puts a well down wherever he happens to want it and water is found at a uniform depth for each particular area. The water-bearing sand in the lower part of the Kansas River valley will average about 30 feet in thickness, about 20 per cent of which is water, making the equivalent of a solid body of water 6 feet thick and as wide as the river valley. Should this water flow down stream an average of 7 feet per day, which surely is much more rapid than it flows from Manhattan down, but which may be a fair average for the entire course, a raindrop falling on the surface and ultimately joining the underflow at the beginning of the year would find itself only half a mile down stream at the end of the same year.

The greatest loss of ground water is seepage into the stream itself. As is well known, the Kansas River does not cease flowing during our most protracted drouths. This means that the water table in the valley has not become depressed lower than the bottom of the river channel and therefore seeps are constantly passing from the underflow to the river channel. Here is the greatest loss, and in calculating under what circumstances the river valley would become entirely dry we must determine the depth of the river channel itself with reference to the valley, or the floor. Assuming an average of 15 feet throughout the entire river course for the distance from the bottom of the river channel to the bottom of the river valley, the water table might be lowered until no seep whatever would enter the channel so that the river would become entirely dry and we would still have an equivalent of 3 feet of solid water reaching from bluff to bluff and moving down stream at the rate of half a mile per year.

One other factor of water dissipation must be stated, however, and that is the evaporation from the surface of water brought upwards by capillary action. So far as I know we have no data whatever on this subject sufficiently accurate to be worth applying. It is evident that a very appreciable amount of water does work its way upward during dry weather and is evaporated from the surface. But whatever this factor may be it will be seen from the above calculations that should we have a drouth sufficiently protracted to force the upper level of the ground water in the Kansas River valley down below the river channel so that the river would become entirely dry, we would still have a great abundance of ground water within the river valley to supply all our needs for a number of years.

MARAIS DES CYGNES RIVER.

The upper tributaries of the Marais des Cygnes River rise in northeastern Lyon County and southern Wabaunsee County. One branch of considerable importance rises in western Osage County. From the union of these several branches in western

Franklin County to where the stream crosses the east line of the state into Missouri in Linn County, almost opposite Pleasanton, the stream is known as Marais des Cygnes, although throughout its course in Missouri it is called the Osage River. It has cut its valley into the limestone and shales of upper Coal Measures. To the west, where streams are small and the valleys narrow, the supply of ground water within the flood plain materials is quite variable. In some places it seems to be abundant and permanent, while elsewhere it is not so reliable. Eastward, however, after the stream has reached considerable proportions in Franklin County, it has a wide, substantial valley with satisfactory depth of flood plain material and consequently a good and reliable supply of ground water. Here, also, the floor upon which the river alluvium rests is quite irregular, making the alluvial material uneven in thickness. At Ottawa where the river flows over a limestone mass an approach to rapids exists, but the limestone is worn down so much it would be an error to give it this designation. In times of low water the stratified rocks are easily visible in the stream channel. Eastward the valley becomes wider and deeper and no approach to rapids is noticeable, so that we have a persistent flood plain which gathers water and seepage from the uplands, giving us a supply of ground water easily available by wells and sufficient in quantity to meet all the demands which may be made upon it.

From the above description we must conclude that the Marais des Cygnes River valley is substantially the same as other river valleys, and that the valley proper underneath the flood plain material is crossed occasionally by limestone beds which in a degree divide the ground water into pools more or less disconnected from each other. Under such circumstances we may find a relatively weak supply of water, such as at Ottawa where the stratified rock lies so near the surface, and both above and below find an abundance of water. Unfortunately, elaborate tests for quantity have not been made anywhere throughout the course of the stream. From the general conditions we should place great faith in the abundance of water in this river valley, and I strongly recommend that attention be given to ground water as a source of supply for cities situated along the river.

NEOSHO RIVER.

The Neosho River proper rises in central Morris County. The larger upper tributary is the Cottonwood River, which stream rises in the western part of Harvey County and the extreme western part of McPherson County. These upper tributaries have cut their channels into stratified rocks of Permian age, and throughout the lower part of its course it has cut its channel into the shales and limestones and sandstone of the Carboniferous. The river, therefore, throughout its entire course, with all its tributaries, flows over stratified rocks. Here also we have a stream which in places has not yet worn the rocks away as much as in other places, so that the channel of the valley proper is exceedingly variable, both in width and depth. The Cottonwood valley from Cottonwood Falls down is continuous, without interruptions of rock beds. The Neosho river from Council Grove down to below Emporia is similar. At Burlington the Oread limestone comes to the surface in the river channel, so that we have miniature falls where the water of the river plunges over the limestone. The same is true at Neosho Falls and to a lesser extent at other places. The basins for ground water, therefore, are partially or wholly separated from each other, producing what may be called ground water pools quite analogous to the pools along such river channels. The Cottonwood River valley and the Neosho River valley contain vast quantities of water which may be had for the asking. In general the river alluvium does not contain much sand, and therefore recovery of water is more or less difficult when large quantities are desired. This has led some people to conclude that ground water in the valley was so limited it was not worth seeking, a conclusion entirely erroneous and contrary to all known facts. These valleys have within them a great abundance of water to supply every demand likely to be made upon them. In general, the farther down stream one goes the larger the amount of water available. The Neosho river, therefore, from Neosho Rapids down is capable, not only of supplying water to the farmer and stock raiser, but also to every town and city throughout its course should proper methods be employed for recovering it from the ground.

NINNESCAH RIVER.

The Ninnescah River rises in southwestern Reno County and southwestern Stafford County, flows southeast and enters the Arkansas River two or three miles above Oxford, in Sumner County. Throughout the larger part of its course it flows over what has already been described as the old channel of Arkansas River. Its channel is cut down to the general water table level in many places throughout the upper part of its course, and therefore is well supplied by seeps and springs which make it a never-failing stream. It is capable of furnishing a large amount of water immediately from its channel. Should this be insufficient in quantity wells may be put down in the valley and tap the general underflow of the area, which can not be exhausted by ordinary pumping.

In the lower part of its course it flows over Permian shales which are relatively rich in gypsum. This contaminates the water to such an extent that farmers and stock raisers from its mouth up to a little above the Rock Island railroad crossing at Hayesville do not use the water to any considerable extent. Above this, water obtained in the river valley is substantially the same as that farther west, which is very satisfactory.

RATTLESNAKE RIVER.

The Rattlesnake rises near Bucklin in Ford County, flows northeast and enters the Arkansas river a little below Raymond in Rice County. Throughout its entire course it flows over a water table covered with silt and sand and soil which is water-bearing and which is a part of the general underflow of ground water of western Kansas. Wherever its channel is cut deep enough to reach the water table it is supplied with an abundance of water by seeps and springs which are as never-failing as the ground water itself. Well water may be had everywhere along the course of the stream, which, added to the water of the stream itself, makes an abundant supply for all demands made upon it.

REPUBLICAN AND SAPPA RIVERS.

The Republican River is one of the principal tributaries of the Kansas River and as such has already been mentioned. Quite a number of streams rise in northwestern Kansas and across the line in Colorado. The larger one of these is called the Republican River, while the others are known as Beaver

Creek, Sappa Creek and Prairie Dog Creek. All of them flow northward across the line into southwestern Nebraska and unite, forming the Republican river, which reënters Kansas at the northeast corner of Jewell County, approximately midway of the state in an east-and-west line. All of these streams have their rise and the main part of their courses within the great Tertiary area of the Great Plains and have cut their channels downward into the Tertiary material to the water-table level, and hence are supplied with seeps and springs and therefore have "living" water throughout the main part of their courses. In general, their flood plain valleys are well filled with water, in many instances the water being near enough the surface so that alfalfa and other crops grow luxuriantly, even though it be unusually dry. Few detailed investigations have been made of the ground water along any of these valleys. In 1898 Doctor Wolff[6] of the U. S. Geological Survey conducted some interesting investigations in the vicinity of St. Francis on the waters of the upper Republican River. He found that in the Republican valley the water-bearing materials are from 10 to 20 feet in thickness and that they are coarse enough to permit the satisfactory operation of pumps. The water table dips or slants down stream about 10.7 feet per mile and the ground water flows in that direction an average of 17 feet per day, with a maximum of 56 feet along the middle of the valley and minimum of about 4 feet along the borders where sand and gravel are mixed with fine silt. The floor of this valley is the Pierre shales. The water-bearing sand on top of the shales is from 10 to 20 feet, and the depth of water from the surface from 2 feet to 10 feet, making a total thickness of alluvium from 20 to 30 feet. Wolff[7] sums up the result of his investigations in the region around St. Francis as follows:

"1. The source of the underflow is the precipitation in the drainage basin of the river.

"2. The water-bearing gravel in the valley averages about 15 feet in thickness.

"3. The water plane at St. Francis, Kan., slopes down the valley at the rate of 10.7 feet per mile.

"4. The underflow of South Fork of Republican river moves at an average rate of 17 feet a day.

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[6] Wolff, Henry C., Utilization of the Underflow near St. Francis. U. S. G. S. Water Supply, paper No. 258, pp. 98-119.

[7] Loc. cit., page 119.

"5. The rate of movement is, in general, much faster near the center of the valley than near its edges.

"6. Better wells for irrigation can, in general, be sunk near the center of the valley than near its edges.

"7. There is no danger that the underground water in the valley will be exhausted by pumping.

"8. The water-bearing gravel contains enough large material to permit the use of a well strainer having openings as large as 1 inch long by three-sixteenths inch wide.

"9. Except perhaps in a few localities along the northwestern side of the valley the quantity of dissolved salts in the ground water is not large enough to be injurious to plant life."

Could Mr. Wolff have followed the Republican river throughout its entire course, doubtless he would have found many variations from the conditions observed at St. Francis, variations in quantity rather than quality. The floor of the valley throughout its entire course is stratified rock consisting almost entirely of shale, so that it is everywhere impervious to water. The thickness of the alluvial material and distance of the water table below surface likewise varies, and in places ridges in the floor might have been found extending above the water table. Throughout the entire course, general conditions would be the same, which guarantees an unlimited amount of water.

Conditions along the Beaver, Sappas and the Prairie Dog are practically the same as those already described for the Republican. No detailed investigations have been made like those Wolff made on the Republican, but conditions have been observed enough to show the strong similarity. Each stream has its valley resting upon an impervious shale floor. Each stream also has its valley well filled with alluvial material, the lower portions of which are water-bearing. In extreme cases the water table lies below the surface of local hills or ridges within the floor.

For example, some years ago the town of Norton on the Prairie Dog found its supply of water from wells to be insufficient during a protracted drouth. The writer visited the place, learned what he could from surface indications, and advised a series of small test wells cross-cutting the channel at different places in order to locate whatever ridges and depressions might exist in the floor. In a short time it was found that the wells then in use were immediately over a ridge, and that by going up stream a short distance there was a depression in the floor, not at all indicated on the surface, where the water-bearing sand was thick enough to supply them with all the water they desired. Recently the Rock Island Railroad Company has built large wells here in the valley and has all the water it can use, and much more is available.

From the north side of Kansas near Superior, Neb., to the mouth of the river at Junction City the valley is more distinct and the bluff lines are more marked than farther up stream. This is particularly true from Clifton down, throughout which course the valley is cut into Permian rocks. The supply of water is good and there need be no fear but that the river valley area will supply all the water that may be desired to be pumped from it.

SOLOMON RIVER.

A discussion of the Solomon River would be in a great measure a repetition of that already given for the Republican River. Each branch of the Solomon rises away to the west in Sheridan and Thomas counties, substantially alongside the upper waters of the Prairie Dog. They flow over the same kinds of materials, the Tertiary to the west, then the Cretaceous, and finally, for a short distance near its mouth, Permian rocks are passed. Along the upper portions of the stream frequently the river valley is cut down to a level with the water table in the Tertiary sands and gravel so that seeps and springs from the general underflow produce "living" waters in the streams. The water table here is inclined to the east substantially with the surface. The thickness of alluvial material varies greatly from place to place, and also that of water-bearing sands. The Cretaceous shale floor is somewhat irregular, occasionally rising above the water table.

This is well illustrated in a part of the city of Stockton. Private wells are common here and in most portions of the town can be had for the digging. A certain place was pointed out to the writer where a well might be sunk down to the shale, or the Niobrara chalk beds as it happened to be in this case, without finding water. Quite evidently a subsurface ridge of the chalk extended from the north bluffs out into the river valley a short distance. Also, at Solomon Rapids, the stratified Cretaceous rocks come close to the surface, producing miniature rapids at this place.

We have here, then, the same conditions found along so many other streams, a river valley cut down into imprevious rocks and refilled with alluvium which holds water in large quantities, but which has a little irregularity in amount of water due to the irregularity of the impervious floor of the valley proper. In most cases throughout the entire river valley an abundance of water may be had, sufficient to supply all the needs of the farmer and stock raiser and also to furnish a good municipal supply to every town along the valley.

VERDIGRIS RIVER.

The Verdigris River rises principally in the southern part of Lyon County, with a few of its tributaries rising across in Chase County. Fall River, one of the principal tributaries, rises in northwestern Greenwood County, with its uppermost tributaries in the northeastern part of Butler County. Throughout its uppermost portion the Verdigris flows over Permian rocks, and over Carboniferous rocks throughout all its lower part. It has cut its valley deep into these rocks and has built a flood plain throughout its lower portions. Wherever the flood plain is of any considerable thickness a reliable supply of ground water is available. This is true on the Verdigris proper from Toronto to Coffeyville, and also Fall River from some distance above New Albany to its mouth at Neodesha where it joins the Verdigris. Each of these streams has an unusual amount of flint gravel in its valley, washed downwards in earlier times from the Flint Hills. In some places the gravel is very coarse and is an excellent material from which to pump water. At Fredonia on Fall River the floor is about 30 feet below the valley surface and the water table from 10 to 14 feet below, producing from 16 to 20 feet of good water-bearing sand and gravel. The valley here is 2 to 3 miles wide, and is thickly populated with farmers who are great stock raisers. Frequently from one hundred to six hundred cattle have been watered from one well with no indication of lack of water in the well. At Altoona in the Verdigris valley one large well was constructed to furnish a municipal water supply. It proved to be insufficient, and therefore some argued that the valley did not contain water enough to supply a town as large as Altoona. It is certain, however, that water exists in the valley in great abundance, that the stream has its channel cut below the water table and that throughout all dry weather the water found in the river channel itself is supplied by seeps and springs from the general underflow of the valley. There is no reason for doubting that the Verdigris River and Fall River valleys have an abundance of water for all demands likely to be made upon them.

WALNUT RIVER.

Walnut River is somewhat unique in its location. It lies on a westward dip plane of the Permian limestones producing the Flint Hills, and flows west and southwest from this dip plane and finally enters the Arkansas River at Arkansas City. As the limestone carries so much flint the Walnut River valley probably contains more flint gravel than any other stream in the state. At Arkansas City vast quantities of gravel have been recovered and used for street paving and road making in and around the city. From El Dorado to its mouth the Walnut has a very respectable river valley and flood plain cut into the Permian limestone. Due to the peculiar westward slope of this limestone with a thin soil covering over it the Walnut is supplied with many seeps and springs throughout its entire course, so that it has pools of water in dry times to a very considerable degree. The valley, therefore, is unusually well watered and is capable of supplying all demands that may be made upon it.

CHAPTER III.

AREAS COVERED WITH GLACIAL DEBRIS.

GEOGRAPHICAL EXTENT.

The northeastern corner of Kansas is covered with a mass of debris brought southward by glacial processes. In general the area is that portion of the state lying north of the Kansas River and east of the Blue River, although here and there glacial material has extended beyond these boundaries. Also, in portions of the area outlined, particularly along the southern and western boundaries, the debris is so thin that it has little, if any, effect upon ground-water conditions. Along the scarps and faces of steep bluffs it may be entirely wanting, and throughout practically all of Pottawatomie and Marshall counties it is so limited that it may be neglected in this discussion.

CHARACTER OF MATERIAL.

Materals composing the glacial debris are quite variable in character, but are principally sand and fine silt and loam producing the rich soil of the area. Here and there boulders of crystalline rocks abound, of various sizes. One lying about eight miles north of Topeka is 40 by 25 feet on the surface. Many of them may be found from 4 to 6 feet in diameter. From these large sizes they grade down to pebbles and gravel, with the smaller sizes being by far the most abundant.

Immediately preceding the glacial period the surface of this part of Kansas was covered with soil and local debris, as the surface is now outside the glacial area. Ice masses brought similar soil and debris southward from the north and to a very great extent scraped up the local soil and debris and mingled them with like materials from the north. It is hard to conceive of a more irregularly mixed mass of material than was thus produced.

These several materials in places are mixed together in a general way, producing the "till" of the geologist. Elsewhere they are more or less separated, with sand layers here, and clay layers there, etc. Sometimes the layers are approximately horizontal in position, having accumulated on the floors of temporary lakes produced by the melting of ice. Elsewhere they are inclined at various angles or curved in position as irregularly as one could well imagine. Frequently sand masses exist at the surface with clay beds underneath; or sand beds lie within different layers of clay. In general these conditions are the same throughout the entire glaciated area, but in detail they are so varied that it is hard to find any two quarter sections throughout which they are closely alike.

The glacial debris rests upon a floor of the stratified carboniferous rocks composed principally of shales and limestones. Finally, when the ice melted and an excess of surface water was produced many temporary lakes and river channels formed which long ago have gone out of existence. The finer grained and lighter materials were carried here and there to a varied extent and were deposited wherever they happened to be, the bedding planes of such materials conforming more or less with the surface of the ground.

Many of the old river channels were entirely filled with this glacial debris, and all the smaller ones were. Subsequent erosion has produced a new drainage system. The lesser streams are located entirely independently of preglacial streams. The larger ones, the Missouri River and Kansas River, in most places are in their old channels, but have not yet succeeded in carrying away quite all the glacial material which filled them, so that along the bluff lines glacial deposits, variable in extent, are yet to be found.

The floor of stratified rock which underlies the glacial material, therefore, is exceedingly uneven, and consequently a set of conditions is established irregular in character, differing in detail within very narrow limits, thereby making a complete exposition of such conditions very difficult.

WATER CONDITIONS.

The general principles of water accumulation already explained are here applicable just the same as with river alluvial material. The rainfall is copious and the run-off no larger, perhaps, than elsewhere. A portion of every rainfall sinks down into the ground and is drawn by gravity farther and farther until some obstacle to its downflow is encountered. The floor of stratified rock constitutes such an obstacle, because in most places it is limestone or shales. A few sandstone beds reaching the ancient surface and now covered by glacial debris, of course, will absorb all the water they can, and hold it or pass it on, depending upon whether or not a sufficient outlet exists. Naturally the upper surface of this floor will be as irregular as the surface of the country was at the beginning of glacial times. As already stated, numerous small streams have had their channels filled and not yet reopened. Valleys varying in width and depth were more than filled with glacial material and recent erosion has not rediscovered them. One can not predict where such old channels are excepting as they are discovered by soundings. To make a complete survey of the area so that all the irregularities of the shale floor could be pictured would require such an outlay of time and money that no one would ever recommend it. However, citizens of this part of the state should have correct ideas of actual conditions, so that in their search for water each one might for himself explore his own domains in an intelligent and economical way.

The amount of water accumulated in any one place depends upon the amount of rainfall, thickness of surface materials, and the rate of migration or underflow. With so irregular an upper surface of the floor as we have in the glacial area the rate of travel or underflow of ground water will be exceedingly variable. In some places this floor is substantially level and but little water will be able to flow away and escape. Elsewhere, the floor may have a steep inclination and the flow of ground water may be relatively rapid, so that the accumulation of large quantities of ground water would be impossible. Again, glacial debris is so exceedingly heterogeneous we should not expect to find a broad continuous mass of water, sheet water, similar to that found beneath river flood plains. Here, a mass of impervious clay may rest immediately upon the floor, and there, a mass of similar clay may be immediately at the surface so as to greatly interfere with absorption of rain water. On the whole, however, glacial debris material is as thoroughly saturated with water as is river alluvium, so that here and there all over the uplands of the glaciated area water in great abundance can be found.

It is desirable again to emphasize the great irregularity in the character of the glacial debris. It is entirely possible that at one place a well might be put down to the shale floor and find no water, while within a hundred yards, or even a hundred feet, a well might strike a bed of sand lying below the general water table and therefore produce all the water desired. This utter irregularity of material makes a corresponding irregularity of ground-water conditions. It is strongly recommended that those in search of water be not discouraged by the first, second or third failure, should such failures come, but, with proper instruments, continue prospecting with a firm belief that sooner or later they will be rewarded. It is my best estimate that scarcely a quarter section of land can be found in the glaciated area of Kansas where the glacial debris is sufficiently heavy which does not have at least one place on it where water in abundance may be obtained.

A good illustration of this condition exists here at Lawrence. The glacial material reaches across the river southward into the Wakarusa valley and beyond. Just south of Lawrence the Southern Kansas Railway line, the Santa Fé, years ago had large wells to furnish a supply of water for the road. I was not here at the time the wells were dug and have not been able to learn details of the materials passed through. Water was found in abundance, which usually stood within a few feet of the surface. Bordering the right of way, Mr. L. Bullene owns a piece of pasture land. A well in the pasture close to the right of way now has water in it standing within a few feet of the surface. A windmill and pump supply water in abundance to a water tank for the live stock in the pasture. This well is only about 12 feet deep. It was dug so long ago that inquiry has failed to reveal the kind of material passed through, but quite probably the water is found in a bed of sand which rises to the east through a considerable catchment area. A number of other wells within a fourth of a mile of the Bullene well are only moderately satisfactory, and during the present dry summer have either failed entirely or almost so. Could we determine all subsurface conditions in this immediate vicinity, without doubt apparent anomalies could be explained quite readily.

It is not at all unusual in glaciated areas to find sand beds inclined to such an extent that good artesian flows are obtained, which are permanent or intermittent, depending on extent of catchment areas. Such wells are abundant in eastern Dakotas, Minnesota, and Iowa. Perhaps the most famous of these is an artesian well obtained at Belle Plaine, Iowa, in

1884. This particular well was a little farther down the hillside than others which had been drilled before it. In some way the water began flowing outside the well casing and in a short time had rifled a hole in the ground 3 or 4 feet in diameter from which a solid stream of water was flowing with sufficient force to lift the water column 3 feet above the surface. It brought out great quantities of sand, which threatened to cover up valuable town property in that vicinity. After a few months rampage it was brought into subjection by throwing into the opening hundred of carloads of rock. Prof. T. C. Chamberlain[8] of Chicago University visited it and reported upon it. According to his estimation the entire source of water was rainfall upon a catchment area lying to the west and north not exceeding a mile square.

We have no specially famous or notorious wells in the glaciated areas of Kansas, but in general the area is well watered for domestic supply, and all natural conditions indicate that with proper and intelligent prospecting, based upon the general conditions above outlined, water in sufficient abundance may be had to supply all the needs of farmers and stock raisers and municipalities, no matter how protracted the drouth may be.

ADDITIONAL AREAS.

Here and there all over the eastern half of Kansas may be found lesser areas throughout which general geologic conditions are substantially the same as those already described, either for river flood plains or for the glaciated areas. The fundamental principles controlling water conditions are the same in each of these two cases. If, now, we have a lesser stream than those mentioned in chapter II, such as the Wakarusa, or Grouse Creek, or many others, an examination will reveal conditions the same in quality as those described for the larger streams. With an encyclopedic article being written on the subject every one of these lesser streams, even to the ravines not more than half a mile in length, would be listed. Of course this would be unnecessary work and expense. The intelligent citizens of Kansas having once understood the fundamental principles of the geology of ground water can apply them for themselves in whatever parts of the state they chance to live.

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[8] Chamberlain, Prof. T. C., The Belle Plaine Artesian Well. Science (I), vol. VIII, pp. 276-277.

During the present summer farmers along the Wakarusa, a stream only about 40 miles long, did not suffer at all for want of water. Many wells have been examined and diligent inquiry made, with the same results; water in abundance. The Wakarusa did not go entirely dry, although there was a period of about 3 months throughout which not a drop of water entered it from surface flows. Pools of abundant stock water were found here and there throughout its course which were maintained by seeps from the ground water. This shows conclusively that the water table throughout the flood plain material of the valley was not reduced to a level below the surface of the water in the pools. Therefore, whenever the bottom of the pool was not below the water table, water in abundance could be had from such pools.

It should be remembered that it is impossible for all of the ground water of a valley two or more miles in width to seep into the river channel within three months' time, no matter how dry the weather may be. If we take the maximum average speed for any place yet mentioned in Kansas, the 17 feet per day of the Republican River valley at St. Francis, a simple computation will show that more than 300 days would be required for water a mile back from the river to seep into the river channel. Instead of the 17 feet per day probably the maximum speed would be only 3 or 4 feet per day, since the inclination of the water table throughout the valley towards the stream channel rarely is more than 2 feet per mile, and frequently not more than one foot per mile. With a water table so nearly level the seepage would be correspondingly slow. With a river valley flood plain 2 miles wide thoroughly saturated with water it is doubtful if all this water would seep into the stream within a period of 2 years continuous drouth. Due to those conditions usually obtaining in the valleys of eastern Kansas, the bottom of the present channel being away above the bottom of the flood plain material, it will be seen that it is impossible for all the water ever to seep into the present river channel. Therefore, as has already been pointed out in discussing river conditions, a stream might go entirely dry during a protracted drouth and yet water might be obtained from wells in many places in the river valleys.

Along the smallest of tributaries it often happens that a large amount of debris or "slip" accumulates in a mass from

10 to 40 or 50 feet thick having slipped down from the escarpment or bluffs on either side. Such places as these are excellent for producing water. A good illustration of this kind may be found at Lawrence in the little ravine leading north from the University campus through Marvin Grove and McCook Athletic Field. A narrow ridge of shale bounds this little valley upon the east, the ridge extending north beyond "North College" a distance of about five-eighths of a mile. On the west likewise is a hill of Coal Measure shale forming an impervious floor. The water shed of this valley is about three-eighths of a mile wide by five-eighths of a mile long, or a total of a little less than 160 acres. This catchment area holds rainfall so that wells situated along the northern end of the valley have an abundance of water, no matter how dry the weather, and in wet weather stand almost full of water.

All eastern Kansas is cut into ridges and valleys, the lesser upper tributaries being like unto the sands of the sea in number. It will not do to say that every one of them will furnish water in dry weather, but doubtless more than half of them would, were proper search made in the right places. I am acquainted with different parts of the state from which live stock was rushed to market late in August this year on account of a scarcity of stock water, and I have many reasons for believing diligent search would have found a great abundance of water in the very pasture from which stock was shipped. He who would prospect for water should get clearly into his mind that this loose material permits rain water to soak down into it, and if in the years that have passed rains have been sufficiently copious, it has filled underground valleys, large or small, with water, where it now awaits an intelligent search by man.

Assuming that all the foregoing is correct, we are now ready to examine the hillsides and the sides of escarpments to determine whether or not conditions are favorable for supplying ground water. Secular disintegration of rock masses is all the time furnishing debris, or waste material. The more soluble of these pass into solution and ultimately find their way to the ocean through seeps and springs. The less soluble accumulate on the hillside and gradually work their way down hill to the valleys below, although this movement of debris is so slow it is rarely observed by the ordinary citizen. This debris resting on the hillside absorbs rain water the same as loose material will anywhere else. The undecomposed rock beneath constitutes a more or less impervious floor, so that here we have the same conditions already described for all kinds of river valleys and for general surface throughout the glaciated area where water is so abundant. Therefore, according to the principles so proclaimed, we should find water along such hillsides in greater or lesser abundance, depending upon the detailed conditions obtaining. Many hundreds of wells in Kansas obtain their water from just such areas and quite frequently springs of great value burst from the foot of debris-covered hillsides.

In eastern Kansas the hill tops are usually covered with hard rock, most generally limestone. The bluffs, therefore, are steep near the summits, frequently being precipitous. Down below, however, the steeply inclined surface merges into one of milder incline, the lower portion gradually joining the level floor below. Abundance of water along such places must depend upon the rainfall, the thickness of the water-bearing debris and the shape of the shale floor beneath. When all these conditions are favorable large and permanent supplies of water may be found.

In 1896 the writer made an investigation of certain portions of the state for the U. S. Geological Survey, report upon which was published and constitutes Bulletin No. 6 of Water Supply and Irrigation Papers. In that report, after giving a general discussion of conditions favorable for ground water, an illustration was taken from Lawrence, from the account of which a short quotation is here made:

> "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 debris 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. Figure 5, drawn to scale (figure 5 of this report), 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 debris was found to be 40 feet deep. A well dug here *B*, during the driest part of a dry year, showed 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*, 1000 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 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 debris gradually decreases, so that a mile away it is only an ordinary soil above the undecomposed shale. Were the debris 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 debris from a mass of shale is principally 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 debris. Yet in the vicinity of the well a water supply is found sufficient to produce 5000 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.

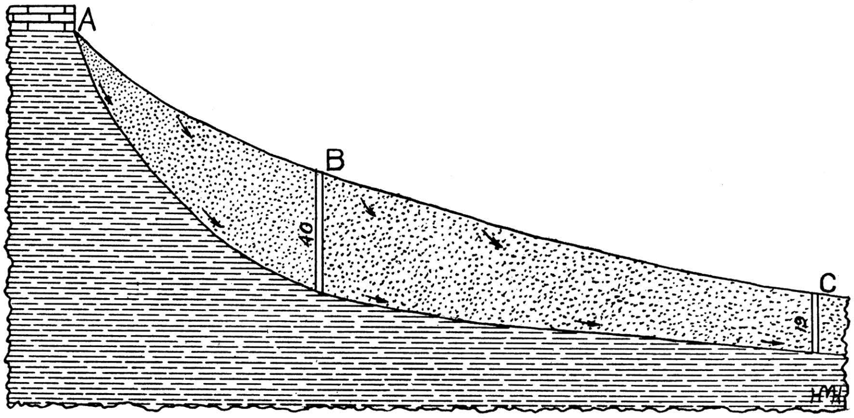

FIGURE 5, showing general geologic and ground-water conditions on the hillsides at the University campus, Lawrence, Kan. The hilltop is covered with a limestone, below which the entire hill is composed of shale. Debris gathers on the hillside to variable thicknesses and absorbs rain water, which gradually creeps down the inclined shale floor. Wells at B and C supply water in dry weather.

"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."

It might be added that on this particular occasion the narrow valley on the north, in which the ball park of McCook Field is located, was looked upon as a favorable location for a large supply of water because it was hemmed in on all sides, so to speak, and hence the water was concentrated along the shale floor. But fear was expressed by health officers lest the quality of water to the north was not what it should be, while to the south no sources of polution existed. It might be added that the autumn of 1893, when this volume of 5000 gallons of water per day was obtained, was generally considered a moderately dry time.

Only a few years ago almost every resident along the eastern slope of the ridge to the west of Lawrence, that is, between Massachusetts street and Oread avenue, had a well in his back yard. Water was found in sufficient quantities to supply all demands for domestic use, and dry weather conditions lasting for a few months or half a year had but little effect on such wells. Farther east, away from the slope of the hill, well water was not so easily found. Of course the mere fact that this hillside is now situated within the limits of a corporate city has nothing to do with its abundance of ground water. Therefore, we may use this illustration as a type of water conditions which we have a reasonable right to expect along every similar hillside where climatic conditions are the same. It is the combination of rainfall, absorbing power of the debris, and the shale floor beneath which provides the water.

I have traveled all over Kansas, and in general, particularly throughout the eastern half of the state, I know from personal observation that a large proportional part of the land lying outside the river valleys and south of the glaciated areas has many similar conditions to those described in and around Lawrence. Therefore I have great confidence in my belief that few areas as large as a mile square can be found which would not produce water in dry weather were wells properly located and dug to a proper depth.

CHAPTER IV.

THE TERTIARY AREA OF WESTERN KANSAS.

Before beginning a discussion of water conditions over the western part of Kansas it should be stated clearly and with emphasis that the mere geologic age of rock masses, or of areas, has nothing whatever to do with water conditions. It is true, however, and here is the main point, that rock masses of the same geologic age within a given area usually have substantially the same physical properties. From our present standpoint we care nothing for geologic age, as such. But since it has been found that the Tertiary and Pleistocene material of the West, hereafter for brevity referred to as Tertiary, is uniformly of a light, porous character, composed of sand and silt and gravel, these physical properties are always implied in the term Tertiary. Elsewhere, in many parts of the world Tertiary formations have entirely different physical properties, and hence could not play the role of water gatherers as they do in Kansas. Likewise, the Cretaceous shales of the West, which form an impervious floor underlying the Tertiary, are known to have certain particular physical properties here in Kansas, although elsewhere they may have very different properties and may serve poorly as a floor for water-bearing horizons. It is the physical properties of these formations of different ages that we must bear in mind. Their geologic names are used because we must have them designated in some way and these names will do as well as any others.

Many investigations of the water-bearing qualities of western Kansas Tertiary have been made by different people throughout the last 25 years. The first of special note was made under the direction of the U. S. Agricultural Department, with Col. E. S. Nettleton at the head of the investigations and W. W. Follet his chief engineer. These investigations covered a large area of the Great Plains throughout which water conditions are substantially the same. Their report is published in volume 4, part 2, Senate Executive Documents 41, 52d Congress, 1st session. These investigations resulted in much good, largely because they were the beginning of a correct understanding of the ground water of the West.

The term "underflow," now so widely used, as far as I can learn, was introduced by Judge J. W. Gregory, in 1889, then editor of the Garden City *Sentinel,* in which paper and in different eastern newspapers and magazines he published much regarding the general underflow of the Arkansas river valley and adjacent plains. The late Prof. Robert Hay was a member of the Nettleton commission and wrote a considerable part of their report. Also, in different places he published short articles upon the ground-water of the plains, all of which were beneficial. In the spring of 1895 the newly created Board of Irrigation Survey and Experiment began a series of investigations in the western part of the state, which resulted in the publication early in 1897 of a report consisting of 238 printed pages, with many maps and illustrations. In this report is an article contributed by the writer, the summing up of observations made during two field seasons with himself and from 9 to 12 assistants studying the Tertiary and Dakota groundwaters of the state. This was followed in 1897 by a 65-page pamphlet, known as Bulletin No. 6 of the Water Supply and Irrigation papers, U. S. Geological Survey, written by the present writer, describing a quadrangular area in western Kansas, one degree of latitude and one of longitude in extent, lying immediately north of the south line of the state and west of the 100th meridian. In 1903 a folio report, Professional Paper No. 32, was published by the U. S. Geological Survey, prepared by Mr. N. H. Darton, giving the geology and groundwater conditions of a large portion of the Great Plains, including the western two-thirds of Kansas. This valuable report has many maps and charts and an extended verbal description of water conditions in western Kansas, including the Tertiary underflow and the Dakota artesian water. In 1904 Dr. Charles Slichter and assistants made a series of interesting and instructive observations on the underflow water in the Arkansas River valley and adjacent areas in the vicinity of Garden City. The results of their work were published in Water Supply and Irrigation Paper No. 153, already referred to a number of times in this paper. Again, in 1908, Mr. Henry C. Wolff and assistants made similar investigations on the underflow of the South Fork of the Republican River near St, Francis, Cheyenne County, Kansas, the report of which constitutes a part of Water Supply Paper No. 258, U. S. Geological Survey.

It would seem, therefore, that there has been a great abundance of investigation and publication upon the water conditions of the West. The present paper will summarize what has already been published, and tell it in a plain way so that it may be understood easily. Only a few new matters will be introduced in it.

The subject is plain and simple. We have a Cretaceous floor of substantially water-tight material, the upper surface of which is irregular, corrugated as it were, generally with ridges and valleys trending substantially east and west, but not always so. This floor in general is as regular as the surface of the ground now is. Doubtless in Pre-Tertiary time it had a more or less well-defined drainage system flowing over it before the Tertiary material was deposited, for the Tertiary material has been carried eastward by the streams from the Rocky Mountains. At present there is a mantle of Tertiary soils and gravels overlying this Cretaceous floor. I am tempted to say it has fallen like a snow, lighest to the east. This idea expresses its conditions better than anything to which I can compare it. As a matter of fact, however, since the close of Cretaceous time, the date when the Rocky Mountain area was lifted so as to force the drainage eastward, waters from the mountains and from local rainfalls have been flowing eastward and carrying with them debris from the Rocky Mountains.

All mountain masses decay under natures processes of rock disintegration. Part of the materials of decay are soluble and are carried away in solution. Other parts vary in texture, some being the finest of silt and soil, others sand, and others pebbles and gravel. The debris along the foothills of every mountain range is working its way down hill across adjacent plains. This is true the world over. Wherever one goes in mountainous countries one will find a mass of debris along the foothills. Water processess of transportation are such that the finest material will be carried the farthest. One can find fine sand and silt along the easternmost limits of the Kansas Tertiary, a little coarser material to the west, from which it is gradually graded until along the foot hills proper boulders weighing tons are common. This may be noticed at the present time along any of the streams. At Arkansas City the sand in the Arkansas river is moderately fine. Follow up stream to Coolidge and one finds sand and many pebbles and occasionally boulders 4 inches in diameter, and likewise all over the face of the country. I was much interested some years ago in Goodland by looking at a sand pile used in making concrete for ordinary construction. The sand was largely feldspar, and nearly half its volume was over one-eighth to one-fourth an inch in diameter. It had been gathered from one of the little streams near by, not the valley of any particular river. A hundred miles east such coarse sand would be difficult to find, excepting in the bottom part of a river flood plain.

We have, then, this Tertiary material carried eastward by rivers and scattered here and there all over the entire plains area. Probably many of these streams have entirely disappeared and others have changed their channels, so that the earliest Tertiary drainage does not now exist. But the general conditions were as they now are. Temporary lakes doubtless were formed here and there, beneath the quiet waters of which the finest of sediment was deposited. There is good reason for believing that the relative elevations of the Rocky Mountains have changed from time to time, so that at one time streams would have a greater velocity than at another, and thereby carry the coarser gravel farther east. Scarcely a well has been put down upon the great plains that did not find an occasional gravel bed of coarser material, and in turn it is overlaid by a more recent bed of fine material. This alternation between coarse and fine materials is important practically, because water is most abundant in the coarse material, and perhaps equally important because it gives us an insight into the actual history of Tertiary times when the velocity of flow in the several streams was lessened or heightened by mild periodic uplifts and depressions of the Rocky Mountain area.

The immediate surface of the Great Plains area at the present time owes its characteristic features quite largely to wind action, generally a north wind or a south wind, which has scattered the finer materials here and there crosswise of the drainage channels, filling and obliterating some of them and giving others an extra load of fine material to carry farther to the east. This wind action has leveled and smoothed and softened the sky line section of the entire area, so that as one looks across it now it presents a beautiful, although somewhat monotonous, scene of broad, level plains, so level that perspective gives them the appearance of rising toward the horizon in every direction. Hills and valleys are scarcely noticeable over a large part of the plains area. It is only the larger streams which have been able to carry away enough of this loose material to produce much of a valley, the lesser ones usually having their channels cut but 50 to 100 feet below the upland level.

The distance east to which Tertiary material has been carried varies greatly. Where the early Tertiary rivers were the largest probably the material has been carried the farthest, and the old Tertiary divides perhaps extend eastward the shortest distance. The most of the present streams in the plains rise east of the mountains and hence are very young. Such is the Kansas River with all its tributaries, the White Woman, Bear River and the Cimarron River, none of which have their rise in the mountains proper, and all of which in their present form are doubtless of recent geologic age. Some of these streams have cut their channels down through the Tertiary material so that their floors are now in the Cretaceous material. In places much Tertiary material has slipped down the hillsides into the valleys faster than the streams were able to carry it away so that an uncertain amount of Tertiary material is scattered over the valleys. Other streams have not yet cut their channels to the bottom of the Tertiary and therefore no Cretaceous rocks may be seen along them.

WATER-BEARING CONDITIONS.

Water conditions here are in every respect similar to those already explained for the glaciated area in northeast Kansas, excepting that the great, broad Cretaceous floor underlying the Tertiary of the plains is more even and more regular and has a greater stretch of distance than the Carboniferous floor under the glacial debris of northeast Kansas. The underflow is rainfall which came east of the Rocky Mountain summit. A portion of this rainfall is carried away by surface streams, another part is carried away by evaporation, and a third part sinks into the ground and goes downward until it comes in contact with the impervious Cretaceous floor. Here its downward movement is checked, and it begins moving east with the slow, sluggish motion of water traveling through sands and clays. The general motion has been eastward, but it has been diverted to the northeast and southeast and in extreme cases to the north and south by local irregularities in the Cretaceous floor. The speed at which it travels varies with local conditions and is always dependent principally upon two factors—the inclination of the floor and the porosity of the material through which it flows. As already pointed out, Wolff found in the Republican River valley at St. Francis a maximum rate of movement of 56 feet per day and a minimum of 4 feet or less, the difference being due principally to the character of matter through which the water was flowing.

Many apparently anomalous conditions result from general conditions as above outlined. In earlier times more than at present, water conditions on the Great Plains seemed very hard to understand by the uninstructed. Here is a river valley with an abundance of ground water in its flood plain material; yonder is another river valley near by with a valley composed of shale or chalk beds and no water can be found in it. Probably in this latter case by climbing the divide a hundred, two hundred, or three hundred feet higher, well water in abundance is at hand. The old idea held by many that well water was more abundant in river valleys than upon uplands seemed abrogated and conditions seemed topsy turvy. To make matters worse, if possible, and less readily understood, it not infrequently happens that one of these lesser streams will have great pools of cool, fresh water almost entirely unaffected by rains or drouths. Many of them exist in the plains area and were a boon to cattle men in early days. All this is perplexing, but one is more confounded by traveling down stream to find that for many miles the bed of the stream is entirely dry. Quite frequently an abundance of spring water gushes forth where one would least expect to find it, such as the springs near Meade which feed Crooked Creek, or those along Rose Creek in Wallace County, and many others that might be mentioned.

Could the observer have seen all there is at hand, he would have seen that there is nothing mysterious about it. These variable conditions, puzzling as they appear at first, are readily understood, are in fact just what one would expect from the conditions above explained. If the channel of a modern stream has not been cut into the Tertiary deep enough to reach water level in the sand or gravel, as shown in figure 6, water could pass outwards into the cut from the general ground water. But if the stream has cut its channel to a depth below the water level, as shown in figure 7, no matter whether it has reached the Cretaceous floor or not, there will be a seepage

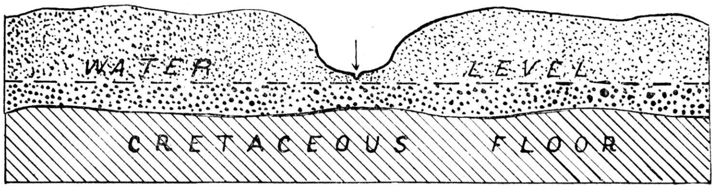

FIGURE 6.

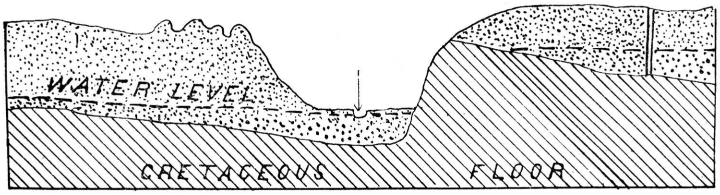

FIGURE 7.

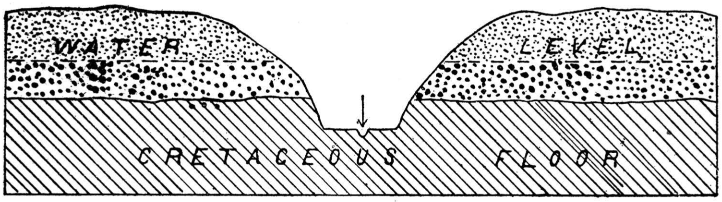

FIGURE 8.

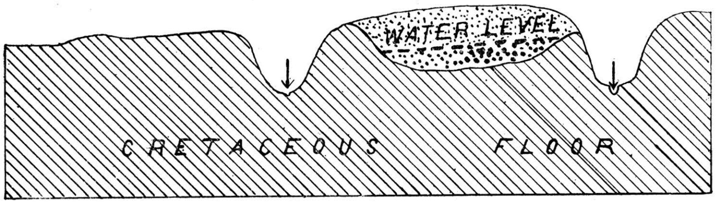

FIGURE 9.

along the banks from the ground water. If the porosity of the material should be uniform the seepage will be uniform and the springs scarcely noticeable. But such conditions are hard to find. A bed of clay, a mass of coarser or finer sand, or some other irregularity intensifies the seepage at one place at the expense of another, and a spring is the result. Farther down the stream where the channel has been cut far down into the Cretaceous floor, as shown in figure 9, leaving the base of the water level 100 feet or more up the hillside, the springs will be found at a corresponding altitude. A stream fulfilling the conditions of figure 6 will have no water in it except from the surface-water drainage, while the one corresponding to the conditions shown in figure 7 has an abundance of water along its course throughout the entire year. Still farther below, as shown in figure 8, with the source of the water supply far up on the hillside, it often happens that the stream has accumulated a mass of sand and gravel along its newly formed channel which absorbs and conceals from view the water flowing into it from the springs above. It is a most common observation along many of the Kansas streams to find that at certain places springs and pools of water abound equaling in quantity and quality those commonly found in more humid regions, while both up stream and down during the long summer months the whole valley seems to be as dry and destitute of water as a desert.

It sometimes happens that a shallow trough in the Cretaceous floor trends east and west. In such instances springs rarely occur along the side of the trough, but at the lower end they are very abundant. Of course it will not matter how high the Tertiary material is piled above the floor of the trough, as this has no bearing on the water question. A good example of this is the long Tertiary ridge between White Rock Creek on the south and the Republican River on the north in Jewell County. Here is a high Tertiary ridge extending nearly all the way along the north side of the county, under which Tertiary water is found in great quantity. At the eastern extremity of the ridge, where it passes down into the Republican River, springs of good, cold, pure water are abundant and strong. The cross-section, figure 9, and the Tertiary as shown on the geologic map, plate I, in connection with the hydrographic map, plate VI, tell the whole story.

In one other case, that shown in figure 9, no spring water can be found. Here a stream cuts into the Cretaceous floor at a place where the floor slants away from the stream, and of course the water drainage would be away from the stream.

AMOUNT OF WATER IN THE TERTIARY.

The amount of water available for use throughout the Tertiary area varies greatly with the location. Broadly speaking, it is safe to say that it is unlimited, meaning thereby that there is no danger of the supply becoming exhausted through its use by man. This is quiet a different matter, however, from stating how much may be obtained from one individual well, or a group of wells. The wells supplying water for Newton are really the same as wells within the Tertiary, although lying beyond the extreme eastern border. Here it seems that the limit of water supply can not be found. If the wells now in use should prove to be insufficient for the demands, all that is necessary is to add other wells to the group. The same is true along the Arkansas River at various places where extensive pumping has been carried on.

It is generally believed that more water exists in the Arkansas River valley than can be found upon the uplands either north or south, yet it is probable that this belief is erroneous, at least in part. Going back to our fundamental conception of conditions governing ground-water, it will be remembered that the Cretaceous floor is more or less corrugated, the channels in general draining east and west, but locally in detail quite often varying from this. It will also be remembered that the source of the ground water is the rainfall on the eastern side of the Rocky Mountains and throughout the Great Plains area. Add to this the further fact, well established, that the ground-water moves eastward upon an average only a few feet per day, and we are forced to conclude that local rainfall is one of the main factors in replenishing the supply of water where large pumps are in operation. Local rainfall plus the eastward movement maintains the supply. Slichter[9] found for Garden City that the water table sloped toward the river on the north from 10 to 14 miles, and that beyond this distance the water table slopes to the north and northeast, and the direction of flow is substantially the same. In the Republican River in Cheyenne County, Wolff[10] found that the direction of flow is substantially parallel with the general direction of the Republican River valley, which is to the northeast. He also found that the underlying gravel is much coarser

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[9] Slichter, Dr. Charles, Water Supply and Irrigation, paper No. 153, page 7.

[10] Wolff, Henry C., Water Supply, paper No. 528, page 100.

and cleaner along the middle of the valley than it is along the borders, which gives a maximum velocity of 56 feet per day through the coarser gravel and only about 4 feet per day along the borders of the valley where the sand is much finer and carries so much more fine silt.

With so many wells here and there more or less all over the uplands we are now able to report upon conditions in some places outside river valleys. At Scott City, where Mr. Lough has installed his large pumping plants, the coarse gravel is by no means universal. While sounding the water-bearing sand and gravel, in order to determine the best locations for his big wells, he found a number of places where the sand was so fine grained a well would scarcely be able to produce enough water to justify the installation of a large plant. Elsewhere within the water-bearing horizon he found beds of coarse gravel through which water could percolate rapidly and thus supply a well from which water was being pumped at a rapid rate.

These several illustrations I trust will be sufficient to convey a correct general idea. All over the plains area this Tertiary material rests directly upon an impervious Cretaceous floor. The floor is irregular in shape, with mild valleys and ridges. The material itself is quite variable in character, ranging from the finest silt and sand to coarse sand and gravel. Water in general is abundant, and so far as is known is liable to be just about as abundant in one part of the plains area as in another. In order to obtain the largest amount of water by pumping from wells proper soundings should be made in advance and wells should be located where the water table is farthest from the Cretaceous floor, that is, where the water-bearing material is thickest and coarsest. If one wishes a well for general farm use the character of material is of less importance because water will flow through fine sand into a well fast enough to supply an ordinary windmill pump and hundreds of head of live stock.

These are the broad general conditions, easily understood and easily tested. They are applicable over the entire plains area wherever the Tertiary material exists. Water is found practically everywhere, excepting in the few small areas where wrinkles lift the Cretaceous floor above the general level of the water table.

A great deal has been said and much concern manifested about the total amount of water this western area is capable of producing. From the foregoing we may draw the conclusion that for all practical purposes the amount is unlimited. This bulletin is written principally to help citizens all over the state to find water for domestic demands and for the live-stock industry. It is not intended to be a treatise on irrigation.

It may be proper, however, to give a few figures on the amount of water which has been pumped from a few of the largest wells. It is reported that the Beet Sugar Company at Garden City have wells in the Arkansas river valley, and also on the uplands, which have maintained a flow of 2000 gallons per minute. The writer assisted in measuring the flow of two of the large wells belonging to Mr. Lough, near Scott City. These tests lasted for a period of 50 hours at each well and were very severe. The two results were practically identical, each well produced an average of 1090 gallons per minute for the entire 50 hours. In each case the sum total time the pumps were idle was carefully recorded. The stops made were short and not very frequent. In one case they totaled a little under 2 hours and in the other a few minutes over 2 hours. These are large quantities of water, so large in fact that one must figure a little to appreciate how large they are. If a well produces continuously 2000 gallons per minute, it will produce 2,880,000 gallons per day, an amount sufficient to supply the wants of an average city of 50,000 population, on the basis of 50 gallons of water per day for every man, woman and child. A well producing 1090 gallons per minute will produce 1,589,600 gallons per day, or enough to supply a city of between 31,000 and 32,000 population. If we assume that the average animal on the farm—cattle, horses, sheep, and hogs—will drink 20 gallons of water per day, then a well producing 2000 gallons per minute will supply water sufficient for 143,750 head of live stock, and one of Mr. Lough's wells would supply water enough to support 79,475 head of live stock. Of course these amounts are so great that they seem absurd, and yet they are results of actual tests. Still further, the writer knows that the Lough wells would have produced a much larger quantity of water had the machinery been sufficient to pump it. In each case the water in the well was lowered only ten feet, a condition assumed within about a half hour after the pump was started. The machinery was unable to force the water in the well any lower, although the water-bearing gravel was very much thicker. It has been shown in pumping tests that the rapidity with which water comes into a well from the surrounding sand and gravel is greatly increased by lowering the water in the well. The surface of the water becomes depressed, cone shaped, called the cone of depression. The more rapid the rate of pumping the sharper this depression becomes, and therefore the more nearly vertical the walls of the cone, all of which helps the water to flow into the well with ever-increasing velocity. It is quite probable, it seems to me, that the capacity of Mr. Lough's wells actually is double the capacity obtained when the tests were made.

In order to comprehend a little better what such a well means to the stock raiser we may look at it in another way. Under present conditions in the western part of the state a farmer rarely would keep more than 100 head of live stock on a square mile, with perhaps 200 head being the very maximum. This would give 20,000 head of live stock for an area 10 miles square. In order to consume all the water produced by such a well with 200 head of live stock per square mile we should have to use an area almost 25 miles square, while if we assume that one square mile of land will support 100 head of live stock, the area required to support enough live stock to drink all the water coming from one such well will be almost 34 miles square.

CHAPTER V.

ON PROSPECTING FOR SHALLOW WATER.

In order to prospect in a satisfactory manner for shallow water, that is, water which lies on top of rock masses such as river flood plains, glaciated areas, hillsides, valleys, and the Tertiary area of the West, one need not make a very expensive or difficult job of it provided the water does not lie at a depth greater than 40 or 50 feet. The most satisfactory method is to use an ordinary auger and simply bore down into the ground and find out whether water exists where it is wanted. For this purpose one can usually obtain a suitable augur from his plumber, who uses it for boring horizontal holes through short distances of earth in order to save digging.

If one can not obtain a suitable augur in this way one should go to a hardware store and buy an ordinary carpenter's two-inch auger. He should take this to a blacksmith shop and have a proper piece of iron welded on the shank of the auger, large enough so that when the new end is threaded it will fit into the coupling for a half-inch gas pipe. He then should go to his plumber and obtain a number of half-inch gas pipes threaded at each end with one coupler for each joint. These joints may be any length, varying from 5 to 10 feet. Some prospectors prefer to have the first joint 12 or 15 feet long in order to save time in making connections. He should then obtain a good pipe wrench suitable for handling the half-inch pipe. He is now prepared to begin work. Go to the place where it is hoped to find water and simply begin boring down into the ground by using the pipe wrench for a rachet wrench. In starting the augur one should place it vertically and push it down into the soft soil as far as his weight will push it, and while holding the gas pipe in a vertical position with his left hand, he should use the tongs as a rachet wrench with his right hand. When the auger has buried itself in the ground it should be pulled out, which can be done by using the wrench for a handhold. It will be strong enough for him to pull upon it all he can. Persons with experience in this mode of boring need no instructions, and it will surprise the beginner to learn how rapidly he can bore into the ground.

When the auger meets with plastic clay it will be hard to lift out of the hole, because it forms a more or less air-tight fitting for the hole and, consequently, the person is lifting against the pressure of the atmosphere as much as the pipe itself. At sea level the pressure of the atmosphere is practically 15 pounds per square inch. The area of a hole is approximately 3 square inches, so that one would have to lift about 50 pounds plus the weight of the augur and load, plus the friction. I have known special augers being made with an air chamber reaching down to the point so as to avoid such atmospheric pressure. Such an auger would be hard to obtain, however, and the prospector will have to content himself without it. If the lifting becomes too hard, two men, each with a gas pipe wrench, may work on the same auger. For this purpose they should stand opposite each other and each may hold the gas pipe while turning the pipe with the tongs as rachet wrenches. With a little practice they can work in perfect unison and under ordinary circumstances the progress will be quite rapid. I have known two ordinary unskilled men to bore holes in this way at the rate of 20 feet per hour, although an average of 10 feet per hour should be satisfactory in ground that is principally clay. Of course, as the depth increases a larger proportion of time is occupied in withdrawing the auger and again in replacing it. For this reason some men prefer the joints of pipe to be much longer than other men prefer them. In general I would recommend about 10 feet per joint.

Suppose now you live along a river valley which you wish to prospect, or on a hillside where the debris or "slip" has accumulated to quite a depth, or in the glaciated area of northeast Kansas, or in the plains area of western Kansas. Unless you know something of the conditions, the best thing for you to do is to buy an auger and prospect your land. There is no excuse worth giving for any landowner not being thoroughly posted on the water conditions of his own land. This boring is so cheaply and easily done that one might prospect 160 acres thoroughly, making 20 or 30 prospect holes if necessary, and scarcely miss the time required. Should one be searching for a relatively large supply of water in this way he can make an estimate of the amount available by measuring the thickness of the water-bearing horizon.

Should the water exist in sand or gravel the augur will scarcely lift out the material after the water table has been reached. The prospector should then provide himself with a "sand bucket," which can be made at the tin shop by making a long slender tube small enough to pass up and down in the auger hole, with a ball valve fixed at the bottom and a short rod of wood or metal fastened on the under side of it and sticking below 2 or 3 inches. When the bucket is let down into the well this rod will open the valve and let the water and sand rush in and fill the bucket. Upon lifting the bucket out with an attached rope the weight of the water closes the valve so that it will carry to the top the mud and sand which entered it. At this stage also one should provide himself with some form of a drill. It may be a two-inch chisel bought from the hardware store, or an ordinary iron rod hammered out chisel shaped. This can be screwed into the same gas pipe used with the augur and can be worked by hand without the gas pipe tongs. After the sand bucket has brought out all the sand and mud available this improvised drill should be let down in the well and churned up and down until a mass of loose material is produced which may be lifted out with the sand bucket. In this way the entire thickness of the water-bearing horizon may be passed through and measured, and also the character of the water-bearing material may be determined in a satisfactory manner.

Should the area to be prospected be where it is practically certain the depth of water is more than 40 or 50 feet it becomes more serious. Hand drilling is not so easy. A little ingenuity, however, in many cases will help greatly. For example, the mere labor of twisting the auger in the ground is no greater with depth than at the surface. An improvised derrick may be arranged by fastening together two or three scantling of sufficient length. In the apex of this derrick a sheave wheel may be placed, from which a rope is passed with one end fastened to the gas pipe drill shaft and the other end attached to a windlass so that windlass power may be used in lifting out and letting in the drill shaft. Also, the two-inch auger bit may be changed for a larger one if so desired and the hole made may be used for a permanent well. Many other variations may be brought in should the prospector desire, all of which are more or less dependent upon one's opportunity for obtaining supplies and one's anticipation of depth of water and one's desire or otherwise for retaining the hole for a permanent well. In the latter case, of course, the well must be cased properly after the water is found and cared for in a proper way to preserve it and render it useful. Should the depth of water be known to be more than 50 feet or 75 feet at the outside, quite likely it would be best to employ a man with a regular drilling outfit and let him drill the well by contract. A large part of the state may be prospected for water as above explained by the landowner and a hired man for a mere trifle of cost. It is recommended, even, that before purchasing a farm the prospective purchaser may just as well insist upon proper water conditions as upon richness of soil or choice of location.

CHAPTER VI.

GROUND-WATER WITHIN STRATIFIED ROCKS.

This chapter treats of ground-water within stratified rocks more or less deeply buried and usually with impervious rocks above and below the water-bearing ones. The subject will be followed geographically, beginning with the southeastern part of the state and moving westward. The reader should study carefully the general plan of the stratified rocks of Kansas, as exhibited in the maps, and sections, and figures herewith included.

Briefly stated, the oldest rocks of the state, those belonging to the Mississippian time period, are in the extreme southeast corner. Here they dip to the west an average rate of about 25 feet to the mile. If one travels westward one soon comes upon rocks a little younger than the Mississippian. These belong to the Carboniferous period, recently called the Pennsylvanian by some, and they overly the Mississippian strata. The Carboniferous rocks are about 3500 feet thick in Kansas. Their eastern extremity has been worn down by erosion so that the western part of their outcropping area is nearly a fourth of the way across the state, as shown on the map, being approximately along the line of Chautauqua, Greenwood, Lyon and Pottawatomie counties. Above this lie the Permian rocks, which occupy a narrow zone entirely across the state, extending to the west along the southern boundary, reaching as far west as Meade County. Above these are rocks belonging to the Cretaceous period, on top of which rests the Tertiary, already described. All these rocks are in rock layers, one on top of the other. They are limestones and sandstones and shales, alternating with each other all the way from the Mississippian at the bottom to the top of the Cretaceous. In the eastern part of the state all of them dip to the west and northwest, doubtless having been elevated at the time the Ozark area received its uplift. In the western part of the state the formations dip to the east, quite evidently due to the uplifting of the Rocky Mountain area. Throughout the middle part of the state the rocks have but little dip in any direction. Erosion has modified the surface features of the state by wearing away the rocks regardless of geologic age. River valleys or trenches have been cut in the upper surface in whatever direction the surface was inclined, which has given practically all of our streams an east-west direction.

Where we have alternating beds of hard and soft rock erosion always wears away the soft rock faster than the hard ones. This results in leaving the hard rock exposed on top of the highest hills, with the main volume of the same hills composed of the softer shales and sandstones. In eastern Kansas, where the strata all dip to the west, these same limestones on the hill tops gradually grow deeper and deeper underneath the surface as one follows them to the west, so that in most cases in from 5 to 20 miles they entirely disappear beneath the surface, which condition is represented in figure 3.

Let us suppose now that in eastern Kansas any one of these rock masses absorbs water from local rainfall. A part of this rainfall will flow eastward with the surface of the ground, but a part of it will be absorbed by the rocks. As soon as the water gets within the rocks it will have to follow the fissures and bedding planes of its host, and therefore it will travel westward, even though the surface at that immediate place is inclined to the east. In this way over the entire eastern part of Kansas a portion of every heavy rainfall flows eastward on the immediate surface of the ground, while the portion which works its way down into the ground and becomes lodged within the stratified rocks works its way westward.

An important question now is: What becomes of the water migrating westward within the stratified rocks of eastern Kansas? So far as has yet been observed there is no general outlet to this water, and therefore it can not escape, at least not very rapidly. Where streams have cut their channels down into the stratified rock a portion of the water may escape as spring water. But our streams have not cut very deep, and therefore it is probable that the water within the deeper lying rocks has never yet found an outlet to the west. This is a very important point, because it accounts for the widely known fact that water obtained from deep wells within the stratified rocks all over the eastern half of Kansas universally is so highly mineralized that it is entirely unsuitable for domestic use. Other conditions obtain here, however, which in the aggregate are worth millions of dollars to Kansas.

Water within a mass of rock dipping westward in a way corresponds to water in an ordinary vessel having a considerable vertical depth. It is well known that if a solution of mineral water be put into such a vessel and be allowed to stand without any agitation, in the course of time the mineral materials to a considerable degree will settle to the bottom, so that the water at the bottom of the vessel is more strongly mineralized than that at the top. A familiar example of this is in the ordinary gravity electric battery so widely used by our telegraph companies. Here we find in a glass jar a mass of water with copper sulphate dissolved in it. The series of vessels constituting the battery are allowed to rest quietly on the shelf. Gradually the copper sulphate which has passed into solution accumulates at the bottom, forming a strong solution, while water near the top of the vessel is correspondingly impoverished and left more nearly pure water. Our stratified rocks dipping to the west from 10 to 25 feet per mile correspond in a way to these gravity batteries. They catch rain water along their outcropping borders, which water dissolves the old-time ocean salts held by them. Here everything remains in apparent quietness. The water can not escape back westward because the strata becomes deeply buried and no escape is possible. This condition has obtained for many thousands of years, giving the best possible opportunity for all the mineral materials dissolved in the water to migrate gradually down hill to the west, leaving the water to the east, and consequently nearer the surface, relatively fresh. Facts of observation correspond with this explanation, and where one can find water within the stratified rocks at a depth little, if any, over 200 feet it is reasonably free from mineral salts excepting the limestone which may be dissolved in it. If one follows the same strata farther west to where they are buried from 500 to thousands of feet in depth, invariably the water is very salty and contains much other mineral held in solution.

We may establish, therefore, a general principle, which is correct in theory and correct in practice, as abundantly proven by wells already drilled. We will assume that here and there all over the eastern part of the state rain water gets down into the stratified rocks and tends to migrate westward as above explained. We will put wells down into these stratified rocks near their eastern outcropping lines and we will be able to find water suitable for farm use. We are now ready to take the matter up one area at a time and cover the entire state with our investigations.

THE GALENA-PITTSBURG AREA.

The Mississippian occupies the surface of a very small area in the southeast corner of the state. The strata dip to the west about 25 feet to the mile, and therefore soon become buried beneath overlying formations. Also, they rise to the east and cover the surface throughout the entire Joplin mining area, and even farther. Underneath them, with substantially no shale beds between, we find beds of dolomitic limestone and sandstone lying conformable (parallel) with the Mississippian formation. The whole of these rock masses, therefore, have an outcropping over thousands of square miles in an area where the average rainfall is about 40 inches per annum, which gives great opportunities for water to work its way down into the crevices, or voids, and along the bedding planes of the Mississippian and underlying formations.

If one drills down into these rock masses one is sure to find water. Sometimes it will have a decided artesian effect and will rise in the well partly or wholly to the surface. If we travel westward to where the Coal Measure shales and limestones overly the Mississippian formations we still would have the same probability of finding water on drilling down into or through the Mississippian. This has been done in many places. At Joplin and Galena where the Mississippian covers the surface, deep wells produce an abundance of water. At Columbus, and Cherokee, and Girard, and Pittsburg similar wells furnish a satisfactory municipal supply of water. Some of these deep wells obtain their water principally from the Mississippian while others go entirely through the Mississippian into dolomites and sandstones below and obtain even a greater supply.

The amount of water these formations contain is in every way unlimited, measured by the possibility of our demands. The more we pump out through a multitude of wells the more the rock masses will absorb throughout the catchment area to the east. The amount of water which any one individual well will produce will depend upon outlet and local conditions of porosity within the water-bearing rock. These conditions vary from place to place, sometimes within very narrow limits. For example, at Pittsburg two wells less than a hundred feet apart vary greatly in the amount of water they produce. It so happens that one of them struck water-bearing formations where openings were most abundant and water could flow into the well with most rapidity. There can be no danger but that a well put down anywhere in Cherokee, Labette, Crawford, Neosho, or Bourbon counties would find a great abundance of water in these formations. One may feel perfectly safe to drill in his back dooryard or barnyard or anywhere he chooses, so far as quantity of water is concerned. It should be remembered that, as above explained, one well may produce more than another, as mentioned for Pittsburg.

Quality of Water. The quality of water obtained from Mississippian and underlying formations is reasonably good until we get far away from the catchment area. At Joplin and Galena, for example, the water will do very well for municipal supply. Farther west, at Columbus, Girard, etc., it is not quite so good. It has a considerable amount of mineral matter dissolved in it and an objectionable amount of sulphuretted hydrogen, a gas which gives it a peculiar odor. This is partly overcome by having a settling basin exposed to the atmosphere so that the water gives up the main part of the gas. As we travel farther west and northwest the quality of the water changes quite irregularly, but in general it becomes more highly mineralized. A somewhat famous well was drilled in Fort Scott years ago. This is situated on the west bank of the Marmaton River in the western part of the city. Here the artesian effect is sufficiently strong to throw water a few feet above the mouth of the well and a perpetual stream has been flowing ever since the well was drilled, over 20 years ago. Unfortunately, the water is so highly mineralized it is not at all suitable for general domestic use. A few wells farther west in the oil and gas region have gone down into and through the Mississippian limestones, all of which obtain a copious supply of water, but in every instance it is so highly mineralized it is entirely nonusable.

From the practical standpoint we have two questions in connection with water supply from Mississippian and underlying formations. One is the amount of water. As above stated, it may be assumed that the amount of water obtainable is inexhaustible, no matter where in southeastern Kansas the drill may be located. Drive a stake in the ground at the place where you want your well and have the driller go ahead and he will find all the water you want. But the question of quality of the water in this case is the important one and is the one about which we should be most concerned. A somewhat careful examination of the wells already drilled shows that there is a greater difference in quality than one might expect from geographic location. The Fort Scott well is much more highly mineralized than the Girard, while mere geographic location would hardly explain it. It must be remembered that the farther west one goes the greater the probability of the water being unfit for use. This means that the area of suitable water supply is quite limited and can not be defined with exactness until a much larger number of wells have been drilled. In general, one may expect the water to be reasonably good throughout Cherokee and Crawford counties, although in the northwestern portion of each county it is a little doubtful.

THE CHEROKEE SHALES.

The name Cherokee shales is given to the mass of shales and sandstones immediately overlying the Mississippian limestone. They are about 400 to 450 feet in thickness. While called shales, in reality much of this rock mass is sandstone. This is particularly true over a wide area to the east and southeast of Columbus. The hilltops just west of Crestline on the St. Louis and San Francisco railroad is composed largely of coarse, porous sandstone. The so-called Timbered Hills are likewise entirely covered with sandstone. The rock formations along the upper part of Brush Creek, between the Timbered Hills area and Columbus, is practically all sandstone. Doubtless much of other areas is composed of sandstone. All of these sand rocks outcrop to the east and become buried westward. Many good wells here and there in Cherokee County obtain a supply of soft water from these sandstone beds. Here it is quite evident the supply is entirely dependent upon near-by rainfall. We are so close to the catchment area that the water is free from salt and other minerals and the purity is about all that could be desired.

These sand rocks occupy the same position stratigraphically that the best paying oil and gas sands do farther fest in our oil fields. Throughout the oil and gas fields of Kansas and Oklahoma when such sand rocks are reached they usually contain water, or oil, or gas. If the latter, water comes in as the gas is allowed to flow out. But here the water is very salty, while farther east it is fresh. This is the question already explained in detail in two different places in this report, where it has been shown that to the west the water is more salty than farther to the east. Just how far to the west from the outcropping lines of the sandstones the water is sufficiently free from salt to be serviceable has not been determined. To the eastward it is good, potable water and is obtained in many wells; to the west it is salt water. Citizens throughout this area are advised when in need of water to drill down into these sand rocks and test the water to see whether or not they are so far west it is salty.

In writing the above section I do not mean to convey the idea that the same individual beds of sand rock outcropping in the vicinity of Crestline and Brush Creek are continuous westward to the gas fields. Such a condition does not obtain. Generally an individual sand rock does not have an east-and-west extension more than from 10 to 20 miles. Other sand rocks appear, however, at substantially the same horizon, so that throughout a wide area we are likely to find sand rock at practically the same stratigraphic position occupied by those at Crestline and along Brush Creek. In this way wells drilled promiscuously are likely to find sand rocks in the places named.

ROCKS OF THE MARMATON STAGE.

The Marmaton formation is a combination of limestones, sandstones and shales alternating with each other and immediately overlying the Cherokee shales, and extending in a northeast-southwest direction across the state, occupying the east state line from the south side of Miami southward to a little beyond opposite Fort Scott. On the south line of the state they occupy the space from the hilltops west of Chetopa to a little beyond Coffeyville.

Within the shales many sandstone beds occur in a manner similar to the sandstone beds already described within the Cherokee shales. Each individual formation in turn outcrops to the east and gradually dips to the west and becomes covered with the overlying formation. In this way a series of conditions are set up similar to that already described farther to the east.

These sandstones absorb water readily and permit it to work its way westward within them. The limestone layers are more or less filled with vertical fissures and spaces between the individual layers, all of which facilitates the westward movement of water. Here we have exactly the conditions described elsewhere. Water obtained toward the east, near where the particular horizon outcrops, is good, fresh water, while water obtained from the same horizon farther west is more or less salty. Prospecting, therefore, should be confined to shallow depths, from 100 to 200 feet as a maximum, within the stratified rocks. Otherwise it is certain salt water will be obtained.

Here is a suitable place to describe conditions when ordinary open wells are dug through a mass of shale. It is quite common for farmers to dig wells from 3 to 5 feet in diameter down through, or partly through, a mass of shale and to obtain water, sometimes from the shale itself, but frequently from sand rocks lying just below the shale. In such cases the water at first may be reasonably good. In the course of time it becomes so contaminated with iron and sulphuric acid that it is scarcely usable. I am well acquainted with a good many such wells. The difficulty arises by having an open well which permits air to come in contact with the shale. All of these shale beds are more or less filled with the double sulphide of iron, the mineral pyrite, which in coal mining countries is usually spoken of as sulphur rock, but which throughout the Joplin area is usually called mundic. This compound of sulphur and iron is very easily affected by the atmosphere when moist. The sulphur is oxidized and a soluble iron sulphate is produced which dissolves and enters the water. From such wells water may be drawn perfectly clear when fresh, but upon standing sooner or later an iron-rusty tinge appears within it, and if allowed to stand a thin layer of iron rust is apt to form on the walls of the vessel. If the old-fashioned well bucket is used it soon assumes a rusty appearance and the iron hoops rust away in a short time, and no moss grows on the bucket and rarely in the watering troughs connected therewith. Instead of growing moss we generally find a coating of iron rust wherever such water is used.

The oxidation of pyrite found in the shales is carried on slowly, as the air is able to work its way back into the shale mass. This will occupy years, and perhaps may never cease entirely. The result is that the water, which may have been reasonably good when the well was first dug, within a year or so becomes affected, and within a period of from 5 to 15 years reaches its maximum state of contamination. Some wells with which I am acquainted later began to improve, and one particularly that I have in mind in Cherokee County, which was dug during the summer of 1866, for quite a number of years past has yielded water that is fairly satisfactory, after having passed through a bad-water period as above explained. These iron laden wells abound throughout Cherokee, Labette and Crawford counties, and in fact many other counties in the state. Many of them have become so bad that they are abandoned and people have quit searching for water in such shale beds.

It is evident from the above explanation that could a well be made by drilling down through the shale beds and then treated in such a way that the atmosphere would be entirely shut out the bad results from oxidation would not prevail. This may be done by a number of different methods. First, a drilled well may be made and iron casing put in so that the atmosphere will not come in contact with the shale walls. In such a case the water would not become contaminated from the oxidized walls and would retain the properties it had when the well was first made. Should the landowner prefer to dig his well with pick and shovel, then it is desirable to put some kind of covering over the well so that the shale walls will be protected from the atmosphere. A very good way to accomplish this would be to lay the well wall in concrete mortar, leaving out the mortar for only a few feet at the bottom to permit the water to flow into the well. A wall of either brick or stone may then be made substantially air tight. When the wall has reached within 3 or 4 feet of the top a slab of stone or concrete should be laid on top of the wall with a hole cut through it large enough to permit a pump barrel to pass. After the pump has been installed the remaining top part of the wall should be entirely filled with earth so that no air whatever could get down into the well.

At first thought some will object to covering a well so as to shut out all the air, because there is a widespread notion that the air in a well tends to rectify and keep pure well water which otherwise might be unhealthy. This idea may be correct in part, but certainly it is very incorrect in part. The method mentioned guarantees that the well will be free from crickets and toads and snakes and dead animals which otherwise may fall into it. It also guarantees that no surface contamination containing disease germs may get into the well, so that if the water itself is pure originally, or free from disease germs, it will remain so. Much more than half of the unhealthy water becomes unhealthy from surface contamination. This method of fixing and preserving a well, therefore, not only will prevent the air from oxidizing pyrite within the shale and thereby rendering the water heavily iron laden, but also is a splendid method for the prevention of surface contamination of every kind.

The area occupied by rocks belonging to the Marmaton stage has its most common base of supply of well water from rain water absorbed by the surface deposits, debris which lies on top of the regularly stratified rock.

ROCKS OF THE POTTAWATOMIE STAGE.

Rocks belonging to the Pottawatomie stage outcrop and occupy the surface of the ground in and along a slender zone just west of the Marmaton area and east of an irregular line from Kansas City to the southwest corner of Montgomery County. The rocks have substantially the same general outcropping conditions as those of the Marmaton stage and the same general conditions govern their water supply. Many places may be found where good supplies of good water are available from the stratified rock near their outcropping areas. Sometimes water is found within a mile or two miles of the intake area. A row of hills marks the eastern limit of this Pottawatomie area. They are the hills just to the west of Mound Valley, northwest of Erie and west of Uniontown and Pleasanton and around Mound City and La Cygne and Osawatomie.

Some years ago, during an unusually dry autumn, the farmers of Allen County who lived up on top of the escarpment just described began drilling wells for stock water within a mile or two or three to the west of the escarpment. They found a reasonably good supply of relatively pure water. Neighbors farther west were likewise hard pressed for water, and began drilling also. The wells would pass down through the first limestone and usually would find water in the underlying sandstones, although sometimes it came from the limestones themselves in part and in part from the shales. I watched this with great interest and followed the well drillers as far west as Iola, at which place this particular water-bearing horizon was 300 to 400 feet beneath the surface. Here, however, the water was so salty and highly mineralized it was entirely unsuitable for domestic use, or for use in steam boilers. One well driller with whom I talked had drilled a line of wells all the way from the top of the hills west of Uniontown into Iola. He said on the east the water was bountiful and satisfactory in quality. As he migrated westward with his well-drilling operations the water became more and more salty, gradually changing from a desirable water into an undesirable one. At Iola it was so bad it was not fit for use. Farmers living from one to two miles back from the escarpment line are encouraged to drill wells for water supply, while those living a little farther west are advised to hope for nothing usable from identically the same rock horizon.

The reader should become thoroughly familiar with the term dip plane and its significance. The term is so convenient it should be used by every one, and, further, we have no other good term by which to express the same thought. By referring to figure 3 the reader can understand what is meant. It is the surface of the ground on top of a mass of limestone or other hard rock which dips in any particular direction. Figure 3 shows how throughout all eastern Kansas the rocks dip to the west, and how the traveler migrating from the east to the west or northwest travels over a dip plane some distance and then mounts an escarpment and travels down its dip plane to the foot of the next escarpment. Thus, all dip planes in Kansas are generally narrow, sometimes only a few miles wide, and rarely are as much as twenty. They trend across the state in the same direction as the outcropping of the rock masses. The geological map, plate I of this report, shows the surface areas occupied by these several stages, the Cherokee, Marmaton, Pottawatomie, etc. The eastern line of each invariably is a line of escarpment, or outcropping of the hard rock. It is always rapidly down hill to the east from such a scarp summit, and very generally down hill to the west along the dip plane.

Throughout the area above discussed we have the dip plane on top of the Iola limestone reaching from near Uniontown on the east to beyond Iola on the west. In a few places the overlying rocks have not been entirely worn away, so that the Iola limestone is covered and the dip plane as such is concealed. But throughout the greater part of the area the dip plane characteristics are easily recognized, with the eastern portion always higher than the western portion. A remarkably good illustration of a dip plane lies a little farther to the west with Fredonia substantially in the center of it. The high escarpment just west of Neodesha and Chanute, and across the river west from Iola, marks the eastern outcropping of the Allen and Stanton limestones which have a westwardly dip. First above the Stanton limestone is a heavy bed of shales about 300 feet thick, including the thin Kickapoo limestone, which produces but little effect on the landscape. These shales are worn away back to the west for a number of miles, leaving the Stanton limestone exposed near the surface along a zone reaching from Leavenworth to the southwest, crossing the state line into Oklahoma near Sedan. The mass of shale on top is worn away quite irregularly, so that the dip plane is more easily recognized at some places than at others, but even a casual observation as one passes over this part of the state will discover it.

With the above definitions and explanations water conditions may be described in a few words. By drilling down into the stratified rocks along these dip planes one is almost certain to find water. Throughout the eastern portion of the dip plane areas the water is likely to be usable, while only a few miles to the west it is almost certain to become so contaminated it is substantially worthless.

ROCKS OF THE DOUGLAS STAGE.

The area covered by rocks of the Douglas stage may readily be determined from the accompanying geological map. It is one of those northeast-southwest zones similar to those already described. The bottom of it rests upon the Stanton limestone and the top is capped by the Oread limestone.

Water conditions here are the same as those already described. At Fredonia, in the middle of the Douglas stage area, or putting it another way, in the middle of the dip plane of the Stanton limestone, we find that fresh water may be had by drilling down through the Stanton limestone into whatever sandstones happen to be embedded within the underlying shales. I am told by well drillers that every oil and gas well lying to the north of Fredonia passed through this zone of fresh water, which would have supplied a large amount of good water had any one desired to use it. Within the city of Lawrence we have a number of good examples. In the eastern part of town water is not as abundant as might be desired. Quite a number of wells have been drilled down into the stratified rock which rises to the east to their outcropping areas, where an abundant catchment area exists. The wells are close enough to this catchment area so that the water is good and fresh and wholesome, and the annual rainfall is sufficient to supply the water in great abundance. Now, when a dry spell comes, the great volume of water held within the rock reservoirs is so large that there is no danger whatever of exhausting it. When the succeeding rains again come the reservoir is again filled and awaits the call of man.

This dip plane area reaches entirely across the state, as just named, and during the present dry spell thousands of head of live stock have been rushed into market from it on account of lack of stock water. And yet it is highly probable that in every township throughout this entire area a good supply of good water could have been had for the asking.

SUCCEEDING CARBONIFEROUS STAGES.

There is danger of wearying the reader with these detailed descriptions. The Douglas stage is succeeded westward by the Shawnee stage, and that in turn by the Wabaunsee stage, which carries us to the top of the Carboniferous, and to the foot of the Permian, all of which is well represented on the geological map, plate I. Nature's conditions here are substantially the same as elsewhere. The northern part of the area is largely covered with glacial debris already described at length. South of the Kansas River the glacial material does not exist in any considerable quantity, and therefore the stratified rocks are exposed immediately to the surface, excepting where they are slightly covered with soil and silt. It is certain here, as elsewhere, that large quantities of good and usable water may be obtained by drilling down into the stratified rock. It is strongly recommended that those who prospect for water in this way confine their investigations to the eastern portions of the dip-plane areas, or to a narrow zone lying just to the west of the outcropping lines. How wide this zone may be before it carries one far enough west to get salt water nothing but experience will show. In some instances salt water is found within five or six miles of the outcropping escarpment, while elsewhere it seems safe to go twelve to fifteen miles to the west.

Jackson County is better supplied with water than Pottawatomie County, largely due to its having a heavier mantle of glacial debris. Pottawatomie has suffered as much this summer from lack of water as any county in the state. The citizens in general here have not prospected for ground water nearly as much as they should. It is quite probable that should extensive prospecting be done a good many failures would result. It is confidently believed, however, that in many places, particularly in the eastern part of the county, serviceable water may be found within the stratified rocks the same as it is throughout the area covered by rocks of the Pottawatomie and Marmaton stages. It might be added, further, that prospecting has by no means exhausted the possibility of ground water resting upon the top of the stratified rocks and underneath debris on the hillsides formed by decomposition of the hillside rocks.

THE FLINT HILLS AREA AND THE FLINT HILLS DIP PLANE.

The term Flint Hills has been given to a prominent escarpment stretching entirely across the state from south to north, more particularly prominent in the south part of the state along the eastern side of Butler and Cowley counties. This great escarpment exists on account of the presence of massive beds of limestones carrying large quantities of flint resting on top of thick beds of shale. The shale wears away rapidly and the limestone slowly. In this way the hill or scarp faces the east and is most pronounced where the underlying shale beds are the thickest. This line reaches from the middle of Sumner County on the south to the middle of Marshall County on the north. It is quite sinuous, as all those boundary lines are, but in the main is almost north and south. When once on top of these heavy flint-bearing limestones, which have been named, from bottom upward, the Wreford, the Florence flint, Ft. Riley limestone and flint, and the Winfield limestone, one can look westward down the gently sloping dip plane for quite a number of miles. The present drainage likewise follows this dip plane. Hence, we have the little streams flowing west from the flint hills escarpment forming Grouse Creek and Walnut Creek which drain a very considerable area.

It so happens that along this escarpment we have a splendid catchment area reaching across the state. The water sinking into the ground soon becomes caught by the stratified rock masses and is carried westward down their dip planes. In a few places farmers have found that by drilling through the upper stratified formations a good supply of water can be had. One such area is in Cowley County where many farmers have wells which from their standpoint are inexhaustible. With windmills and water tanks attached they can laugh at the drouths so far as stock water is concerned, even though the drouth should be severe enough to destroy all their forage crops.

Another area investigated lies to the west of Council Grove, in the vicinity of Wilsey. Here for quite a number of miles every farmhouse has its well and windmill and water tank, so that the citizens live in comfort and live stock have all the water they can drink, even in driest seasons.

A third area especially examined lies on the high divide between the Blue River and the Republican River from Garrison to Clay Center. The hilltops west of the Blue River form a great catchment area and windmills dot the prairies both east and west of Leonardville, implying that water is abundant everywhere. Investigations showed that these wells pass down through the first stratified rock, and at depths varying from 100 to 200 feet, depending principally on surface levels, they come into the water-bearing horizon, which is a limestone sufficiently filled with vertical seams and open spaces along the bedding planes to permit water to work its way westward an indefinite distance. Early in September, 1913, I traveled from the Blue River to eight miles west of Leonardville. Everywhere beyond the immediate river bluffs windmills abounded and water was abundant. I made inquiry of many citizens and always obtained the same answer in substance, which was to the effect that throughout their part of the country although the drouth had seriously affected crops it had produced no effect on the water supply. Here was no hauling of water or driving of stock to water; here was no change of location to where water could be found. It was everywhere found. It seems that a well could be put down anywhere with substantially the same results. The quality of the water throughout this area is very satisfactory to those using it. It has no salt so far as one could tell by the taste. It is perfectly clear and therefore free from iron. Water tanks frequently were full of moss, showing that the water contained no mineral contents poisonous to the lower forms of vegetation. It was pleasant to the taste and satisfying to thirst. It had sufficient amount of limestone dissolved in it to make it desirable to "break" it for laundry purposes. This would make it objectionable for boiler use, but by no means prohibitive.

A most important question is somewhat as follows: If wells with an abundance of good water can be had around Leonardville and Wilsey, and to the east and northeast of Winfield, why can not similar wells be obtained throughout the entire zone stretching across the state from north to south where general geologic conditions are the same? I believe they can, and that here is a zone from 10 to 20 miles wide and 200 miles long throughout which good, usable water may be had in great abundance on substantially every quarter section of land. If this idea is correct, what a great misfortune it is that one should make a financial sacrifice on account of not having water enough, at least before he has fully prospected his property.

It is very well understood by the writer that there may be places here and there where the conditions are not favorable for the existence of water, and which, therefore, would prove barren when prospected. It is confidently believed, however, that such areas are small and far between, and that the entire zone mentioned, with but few exceptions, is water-bearing.

How far west this ground water extends before its quality becomes undesirable has not yet been determined. Some observations indicate that the east-west extent of good water is much greater here than any of the fresh-water zones farther east already described. For example, springs are abundant in some places the water of which apparently comes from the stratified rock. In the vicinity of Herington and to the north a number of noted springs which produce large quantities of water apparently find their water supply from this same water-bearing horizon within the stratified rock. Opportunity has not yet offered for a sufficiently detailed examination of these to warrant a positive statement. If this assumption is correct, it seems probable that the spring water to the north of Herington comes from the catchment area in the vicinity to the west of Council Grove. Long ago the saline material was leached out and carried away, so that the water at the present time is substantially void of salt.

THE MC PHERSON-NEWTON WATER AREA.

A most interesting and valuable area well supplied with water lies in the vicinity of McPherson and Newton. A stretch of country reaching from the Smoky Hill River on the north near Lindsborg southward by way of McPherson connects with the water-bearing areas of the Arkansas River in the vicinity of Halstead. The underlying rocks here are the Permian shales, which have almost no water in them, and what is found is so highly mineralized it is unfit for domestic use. It seems that a groove, or channel, has been made by nature on the upper side of these shales and then filled with debris, similar to river alluvial material, or Tertiary material of the West. One is led to believe that the Smoky Hill River at one time passed this way from a little below Marquette and entered the Arkansas near Halstead, and that it had a valley to the north of Halstead from 20 to 25 miles wide. It seems this valley has become entirely filled with debris, as above mentioned, and therefore becomes a most important catchment area for water, which works its way down through the porous material to the Permian floor. As this floor is almost level, and as the water in the Smoky Hill River near Marquette is substantially on a level with the Arkansas River near Halstead, there is little tendency for the water to move in either direction.

This area was examined hastily by Dr. J. W. Beede and the writer in 1896 and 1897. Wells at McPherson had been made six or eight years before, which showed the wonderful possibilities of the area. In the autumn of 1897 the city of Newton became greatly interested in the water question, and by the advice of the writer went westward until this area was reached, where an abundance of water was available. The wells were put down and water pipes laid to Newton, since which time the town has been well supplied with good water. Doctor Beede prepared a map and sections of the area, which were published in the Report of the Board of Irrigation Survey and Experiment early in 1897, constituting plates 19 and 20, and also in volume II, Kansas Geological Survey, pages 287-296, with the same plates reappearing as plates 45, 46. The following extract was taken, in substance, from volume II and printed in the Report of the Board of Irrigation Survey and Experiment, pages 103, 104, and the two plates are also herewith reproduced as plates III and IV.

"THE MCPHERSON AREA. In the vicinity of McPherson exists an area remarkable in its geologic properties and very important in connection with the underground water which it conveys. In past time it seems an old channel similar to a river channel was worn, connecting the Arkansas with the Smoky Hill river, and covering a width in some places of about twenty-five miles. This area is represented on the map (plate XIX) by obliquely ruled lines and light stipples.

"By an examination of this map it will be seen that it covers all of the surface from the Smoky Hill south to the general lowlands of the Arkansas river, including the area around McPherson, Groveland, Elyria, Mound Ridge, Halstead, Burrton, and other places. On the east it passes within about two or three miles of Newton, and a like distance of Lehigh. From this point it bears rapidly to the northwest until the Smoky Hill river is reached. Aiken is near the western boundary, from which point it bears south until the general lowlands of the Arkansas river are reached, to the northeast of Hutchinson. Plate XX shows four sections across the area, the location of which is marked on the map. By an examination of these sections it will be seen that the covering of sandy material is relatively thin throughout the main part of the eastern area, but that near the western side the sand increases in depth to nearly 200 feet. How much deeper the old river channel was is not known, as the original floor of the channel has not yet been reached by any of the wells in the locality.

"The important feature of this area in connection with the present discovery is the unusually large supply of good, fresh water which it provides. The whole area is supplied with an abundance of water, which is in almost every respect similar to the Tertiary ground water of the west. The city well at McPherson is a good illustration of the amount of water which can be had. This well reached a depth of about 140 feet, and obtained a supply of water so great that the constant running of the large pump in the ten-inch well could have no apparent effect upon it. It is described by Dr. S. Z. Sharp as follows:[12] 'Here the water is obtained in abundance at 100 feet. The well of the city waterworks is 140 feet deep, and the water is pumped through a ten-inch pipe by steam into a standpipe. When the waterworks were constructed eight years ago and put to

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[12] Sharp, S. Z., unpublished paper read at 1895 meeting of Kansas Academy of Science.

a test, previous to their acceptance by a stock company, the pump was kept running continuously for ten days, lifting 10,080 gallons per hour.

"The economic importance of this water supply can not be overestimated. It is easily seen by an examination of the surface of the country during the summer season that the general farm crops throughout this whole area are more flourishing than on either side. The artificial groves of different kinds of trees, and orchards, show a marked difference in health and rapidity of growth. This is so strongly marked that one standing on a prominent ridge on either side of the area in midsummer can trace with the eye the boundary lines of the area by the different appearance of vegetation here and elsewhere. It is not overestimating the conditions to say that year after year the average yield of crops in this locality is decidedly superior to the yield on either side. In addition to this, the farmers and citizens throughout the whole of the area have within easy reach an abundant supply of water, which is suitable for all kinds of domestic purposes, and which is sufficient in quantity to meet any demand that may be put upon it. The city of Newton at present is arranging to obtain its water supply from wells bored six or eight miles to the west of the city, located in this same Pleistocene sandy area, or old river valley.

"At present it seems that there is here an underground water connection between the Arkansas and Smoky Hill rivers."

Little more need be added here. Regardless of the source of the water, we have here a broad area of agricultural land unusually well supplied with water. A study of the cross sections made by Doctor Beede, which, of course, were from data furnished by wells, leads one to think that the immediate river channel was much deeper than other portions of the area, producing a sort of "first bottom" and "second bottom" conditions. A well at McPherson carried to a depth of 140 feet withstood a severe test, as given on the authority of Doctor Sharpe, at that time president of McPherson College. A ten-inch well in sand, which will endure a ten-day pumping test, and will average 10,080 gallons per hour, or 241,920 gallons per day, with no indication of exhaustion, is of untold value. It is firmly believed that similar wells may be obtained here and there all along the principal channel, and that good wells for farm use may be had practically at random all over the area outlined.

WATER FROM THE DAKOTA SANDSTONE.

Probably the rocks of no other geological age in America furnish as much ground water as the Dakota sandstones. The St. Peter's sandstone of the Great Lakes region, which supplies artesian water to Wisconsin, northeast Iowa, Illinois, etc., is its closest rival. Rocks of the Dakota age are spoken of generally as sandstone. As a matter of fact they are sandstone interbedded more or less irregularly with shale. It may be doubted whether or not any one sandstone mass extends entirely from the west side to the east of the Dakota area. The proportion of sandstone in the Dakota is much greater than in the Carboniferous, or the Permian, to the east, and therefore it is not very much of an error to speak of the Dakota sandstone.

The Dakota sandstone outcrops along the foothills of the Rocky Mountains from our southern national boundary entirely across to the northern, and probably beyond in each direction. This is represented in part on the map, plate V. On it is shown the outcropping of the Dakota formations in a long, narrow band throughout Colorado and parts of Wyoming, with an odd-shaped area where it comes to the surface in the central part of Wyoming, and also western Montana from Great Falls southeastward. Other irregularly shaped areas are shown on the map, also, where the Dakota comes to the surface in or close to the mountains.

In the vicinity of Trinidad and throughout a part of Colorado its outcropping has an elevation of 8000 feet above sea level. West of Cheyenne it is about 6500, from which elevation it drops to about 5000 feet farther north, and rises again to above 8000 in central Wyoming. Farther north its elevation is not quite so great. Beyond the national boundary in Canada it follows the mountain border very much as in the United States, but of course its elevation grows less because the mountains to the north are not so high.

Throughout the greater portion of the areas where it exists it is overlaid by younger formations, the Benton, Niobrara, Pierre, Fox Hill, and Laramie in regular order. Above this is a mantle of Tertiary through the greater part of the Great Plains area, material which has been carried eastward from the Rocky Mountains and strewn over the surface, already described in these pages as Tertiary.

Far to the east from this western outcropping the same Dakota formations outcrop again, due to the eastern slope of the surface being greater than the dip of the rocks. This line of outcropping on the east is quite irregular. It is found in southeastern Colorado and almost entirely across the states of Kansas and Nebraska and a portion of Iowa. To the north, where it otherwise should be expected, we find a heavy mantle of glacial debris covering it, so that what otherwise would be a northern extension of the outcropping area is concealed from view. This eastern outcropping area also is shown on the map, plate V. It will be seen from this map how water may be taken in throughout its great catchment area to the west, migrate slowly through the entire Dakota, and escape as spring water on the eastern outcropping. The map also will give one an idea of how water may be held within the Dakota under a varying hydrostatic pressure, depending upon the ease of outlet along the eastern border.

It is unreasonable to suppose that water can migrate eastward with equal freedom throughout all the Dakota area. On the contrary, we should suppose that here and there are places through which it can flow with comparative freedom, and other places where the sandstone is so fine grained it can scarcely flow at all. Again, if water is migrating eastward through a sand rock which does not extend all the way to the eastern outcropping, but which may possibly deliver its water through narrow shale beds to succeeding sandstone beds farther east, we have an additional reason for irregularity of flow. To the north, where the eastern outcropping is covered by the glacial mantle, the water can not escape so rapidly as to the south where no such mantle exists, and hence we might expect a greater head or artesian pressure. In fact, one should carry in mind the probability of irregularities here and there, if one desires to understand the situation as it actually is. Of course, if there is an outlet to the east through which water can escape as rapidly as it approaches it is impossible to find much, if any, artesian pressure in the sand rock immediately to the west of such outlets. The pressure, or head, is created by water trying to travel eastward faster than it can, so that the sand rocks on those high elevations of the given area become full of water which is trying to escape down hill to the east, but which can not escape as rapidly as other water is ready to take its place.

Now let us see what we have and what conclusions should be drawn therefrom. We may compare this sand rock to a great flat bowl the walls of which are as thick as the thickness of the entire Dakota formation. The bowl must be very flat. Its western margin must be very irregular, full of notches, so to speak, to match the western margin of the outcropping Dakota, as shown on the map, plate V. The eastern margin of the bowl likewise can be very irregular to match the eastern outcropping of the same Dakota, as shown on the same map. Now, if this bowl is made from porous clay, such as our filter jars are, and if we fill the bowl with something which will not let the water into it from above, then set the bowl into a bed of mortar which likewise will not let water into it from below, our illustration is fairly good. Rain water falling upon the western edge of the upturned bowl will slowly percolate through the wall of the bowl. The material in the bowl being impervious will not let this water rise up into the bowl where water is usually kept in bowls, but will keep it down within the walls of the bowl itself. In the course of time, should the western edge of the bowl be kept wet, water will work its way through to the eastern edge.

What are the facts in the case? We have the western outcropping of the Dakota, as explained, which we know because many different men have examined the same and have made maps showing their exact location. Our map herewith included is a compilation from these various maps. We know that we have the eastern outcropping because such outcroppings have been studied by many different people and are likewise shown. Citizens of Kansas living along the eastern outcropping area, as shown on our map, will agree with me that such sandstone masses do exist, usually capping the tops of hills. These sandstone-capped hills, and ridges, and scarps exist all the way from the north side of the state to Larned, south of which other material has filled in the valleys, so to speak, so that the Dakota sandstone lies more nearly on a level with the surface.

We have springs in varying abundance more less all along this eastern outcropping area. Many fine springs are known coming out of the rocks away up near the tops of the hills. where springs seldom are found. Sandstone-capped hills are abundant in the eastern part of Ellsworth County, reaching into Saline County as far as Brookfield, with outlying Dakota hills away east of Salina, as shown upon the lithographic geological map, plate I.

It is interesting to note that throughout this hilly area to the west and northwest of Brookville spring water is abundant, and almost invariably is found away up near the top of the hill where the sandstone rests upon impervious shale beds. Of course, as the water comes out of the sand rock it trickles down the hillside and usually sinks into the soil covering, making more or less swampy, marshy areas, which sometimes become dangerous to live stock. It is not infrequently necessary to fence off such marshes to keep stock from wading into them for the first green in early spring and becoming mired to death. One landowner pointed out such a place, in which he said were the bones of more than a dozen animals he knew of—animals which had waded too far into the soft material, sunk down and drowned. Such places as these can be traced up the hillside to the outcropping sandstone unless, as is sometimes found, the entire surface of the sandstone is covered with loose sand produced by the weathering of the sandstone. Some good springs of this character exist in the state. The famous Abilene spring, just west of the town of Abilene, flows from Dakota sands. Immediately north of the spring the rocks have been disintegrated, forming loose sand on the surface. For a number of miles on the north and northwest this sand rests upon the top surface of the Permian shales, which are impervious to water. We have here, therefore, a commingling of the water of the Dakota sandstone proper and water which has but recently fallen as rain on the loose sand produced by the weathering of the Dakota sandstone.

Now let us see what we have farther to the west. As one travels west one finds the Dakota sandstone covered by younger formations, the Benton, Niobrara, etc., as already explained, all of which are much less pervious to water than the Dakota. In some places these overlying formations reach a great thickness. In northwest Kansas we know they are over 2000 feet thick because wells have gone that deep without finding them, and we are left to guess how much thicker. At Rocky Ford, Colo., wells reached the Dakota at about 750 feet, so that the depth to the walls of our bowl used in the last illustration is quite variable. If we consider the entire area of the Dakota in the United States, as we may by referring to the map, plate V, we find that everywhere throughout the central area the Dakota lies moderately deep, while everywhere as we approach the borders, or outcropping areas, it becomes more shallow, a proposition so easily understood that there is no need of illustrating it further in these pages.

EXPLORATIONS ALREADY MADE WITHIN THE DAKOTA.

Already many hundred wells have been drilled down through the overlying formations and into the Dakota sandstone. Such explorations have been carried on to the greatest extent, perhaps, in South Dakota.

The map, plate V, shows the area throughout which wells are very abundant. To the east of this particular area the Dakota can not come to the surface on account of the glacial mantle, and therefore we should expect to find a good artesian pressure. This is actually the case, as many of the Dakota wells have water pressure sufficient to throw a column of water much above the housetops. A good many artesian wells have been found around the borders of the Black Hills area, where the drill has passed through overlying formations and down into the Dakota.

In Kansas we have a number of such wells along the Arkansas River in the vicinity of Syracuse and Coolidge. Drilling also has been done to the west up the Arkansas River as far as Pueblo, and invariably has rewarded the drillers with water reaching to the surface or nearly to the surface. At Rocky Ford the first well which was drilled, according to a statement of the well driller to the writer, had artesian pressure sufficient to raise water to a height of eighty-five feet in a water pipe erected. An open flow would not force water quite that high, on account of the resistance of the atmosphere. Near the eastern outcropping of the Dakota a great many wells have been drilled throughout Nebraska and Kansas, with quite varying results, which, as already explained, should be expected. Some of these have a decided artesian flow, but in others the water is lifted only a part of the way to the surface. This report is to be confined within narrow limits, and therefore it is not thought desirable to give a detailed report on all of the wells, but rather to mention a few of them, in order to establish a principle, so that we may predict what may be expected elsewhere.

Years ago a line of nice artesian wells were obtained in the vicinity of Coolidge. Here the Dakota sandstone lies approximately 200 feet beneath the surface. Local drillers with small drills sunk a number of wells into it and cased them with galvanized-iron casings, and obtained flows of from 25 to 75 gallons per minute. I believe that all such wells were located in the Arkansas River valley, and therefore passed through the water-bearing sands in the river valley. Naturally, within a few years the galvanized-iron casings would rust out, and the artesian water then would spread itself in the water-bearing river valley sands and commingle with the general underflow. I understand that at the present time all such wells in the vicinity of Coolidge have gone to the bad, and I am sure it is because the casing has rusted, permitting the water to spread out in the river valley.

Should one put down a well so that the bore within the sandstone would be from 12 to 24 inches in diameter, no one knows how productive it might be. I think it reasonable to suppose that, right here in the valley around Coolidge, flowing wells of this description might be obtained with a capacity of from 200 to 500 gallons per minute. Artesian wells also should be obtainable both north and south of the river valley, especially to the south. The entire portion of southwestern Kansas lying to the west of the Dakota outcropping lines should be supplied with artesian water from the Dakota. It must be borne in mind, however, that here and there we may find places where the sandstone is fine grained and mixed with silt, so that the flow would be greatly decreased, or possibly in extreme cases entirely prevented. No one can foretell these conditions, because no one can determine in advance the degree of coarseness of the sandstone.

Plate VI is a diagrammatical vertical section across the west end of Kansas, first published in 1897 as plate 26 in volume II of our State Geological Survey reports. It shows how all the stratified rocks here dip gently to the north, carrying the Dakota farther beneath the surface towards the north. We can only tell the exact depth at which they lie by drilling down and finding them. Near Oberlin, in Decatur County, I understand a well has been drilled to a depth of about 2000 feet in search for oil, although I have been unable to get an exact record of the same. Some years ago a company was formed to prospect for oil in this part of the state. They issued a prospectus, in which they stated one well was already drilled to a depth of almost 2000 feet, and another at that time to a depth of 1200 or 1300 feet. I tried by correspondence to get exact details, but failed. Darton[13] gives an account of a well at Jennings which reached a sand rock at 960 feet, that produced soft water, which rock he interprets as being Dakota. On the

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[13] Darton, N. H., U. S. Geological Survey, Professional Paper No. 32, pp. 293-294, Washington, 1905.

next page he gives the top of the Dakota at 1450 feet at a well at Kanona, only about eight miles away, from which data he calculates that the Dakota would be reached in Oberlin at 1200 to 1300 feet.

From what I know of the general conditions in that part of the country, I am sure the top of the Dakota can not be reached at 960 feet at Jennings, provided it is 1450 feet at Kanona. Some years ago a well was put down by the Union Pacific Railroad Company at Winona, in Logan County, about twenty-five miles west of Oakley. This well went to a depth of about 1300 feet and failed to reach the Dakota sandstone.

Recently a well was drilled at Goodland to a depth of 2160 feet, which failed to reach the Dakota. According to information just received in private correspondence from Hon. C. L. Calvert, of Goodland, the well put down by the county authorities two years ago reached a depth of 2160 feet. As I interpret the record of the well, it did not reach the Dakota sandstone. The record is as follows:

GOODLAND WELL.

Feet.	
0– 140	Soil.
140– 160	Sand, water-bearing.
160– 207	Clay and silt.
207– 267	Sand, strong water.
267– 285	Clay and silt.
285–1,650	Dark shale; a little gas at 1,150.
1,650–1,700	Limestone, with a little gas; probably Niobrara.
1,700–2,100	Dark shale.
2,100–2,160	Limestone; probably Benton.

Numerous wells of lesser depth have reached the Dakota at different points along the Arkansas River, and north in the vicinity of Ness City. South of the river a few wells have been drilled in Morton County and elsewhere, all of which have obtained water from the Dakota, provided they were not too far east. It is quite probable that throughout the southwest corner of the state other Cretaceous sandstones older than the Dakota separate the Dakota from the underlying Permian, and therefore they may obtain water even from Triassic or other sandstones deeper down than the Dakota. Darton[14] reports that a well at Richfield to a depth of 701 feet obtained a flow of water from the Red Beds which was too salty for use.

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[14] Loc. cit., p. 308.

SUMMARY.

From all the foregoing it will be seen that a large portion of western Kansas is underlaid by the Dakota sandstone, a formation which is highly water-bearing, which obtains its water from a catchment area far to the west, high up on the foothills of the Rocky Mountains, so that it has a more or less artesian effect, giving an artesian flow in many places, and in others causing the water to rise toward the surface in wells. This sandstone horizon may be reached at reasonable depth throughout nearly all southwest Kansas, and doubtless can be reached at greater depths in the northwest part of the state. The little map, plate VI, was first published in 1897 in the Report of the Irrigation Survey and Experiment. On it is a heavy black line including an area throughout which it is known that Dakota water may be obtained within easy reach of the drill. At the time this was published it was considered unsafe to make predictions of the part of the state lying farther north. At present, however, I feel more confident that water can be found much farther north than indicated on this map.

Inasmuch as this Dakota lies under the same area as the Tertiary, where ground water is so abundant, the importance of water from the Dakota is greatly reduced. Otherwise, every one would consider it of great importance. Could we extend the Dakota sandstone eastward so that it would overlay the Permian, throughout which good ground water is so hard to obtain, it would assume a greater importance to Kansas.

THE RED BEDS.

If the reader will look on the geological map, plate I, he will notice that the Permian area extends away to the west along the south line of the state as far out as Englewood. The western part of this Permian area is the Red Beds. Immediately above the Red Beds is a thin zone of Comanche Cretaceous, a little streak of green on the map. The name Red Beds is given to a terrain all of which is red. It is a variety of red clay and shale, and occasionally sandstone mixed with it. One of the business blocks in Harper, for example, is built of red sandstone. We don't know how far to the north the Red Beds extend in under the Cretaceous, but at least as far as the salt mines at Kanopolis, and probably farther. Of course red beds are met with in many formations elsewhere, but these are a mass of unusual thickness and unusual geographic extent, and hence have attracted a great deal of attention.

To the west, most likely, they extend to the Rocky Mountains. It will be recalled that all the rock masses in the Garden of the Gods, between Colorado Springs and the mountains, are composed of red materials. It is probable that this red mass at the Garden of the Gods extends eastward into Kansas. We know it extends southward throughout portions of New Mexico. Upon the east they have been traced positively across Kansas into Oklahoma and into Texas. In Kansas they immediately underlie the Comanche area, a mass of dark, greenish-colored shales and limestones, and are separated from the Dakota by the Comanche. Conditions here are very different from what they are in the northern part of the state from Washington County to Ellsworth County. In this northern region the Dakota rests immediately upon the dark-colored Permian shales and light-colored limestones. Down here in Comanche and Clark counties the Dakota rests on the Comanche, which in turn rests on the Red Beds. Still farther to the southwest the lower Cretaceous formations are wedged in between Red Beds and the Comanche.

All of this is important in understanding water conditions in the extreme southwest part of Kansas. Years ago a well was put down at Richfield, county seat of Morton County. It has been stated in print that this well was over 700 feet deep. Within the last few days I have been told, upon seemingly good authority, that it was only 600 feet deep. The well produced artesian water, and a flow of water was constant throughout a long number of years. In March, 1911, Wilson and Dean brought in a new well at Richfield which flows, I am told, an average of 300 to 400 gallons per minute, through an 8-inch pipe, when allowed to run continuously day and night. If, however, it is shut in for a day or so the flow is greatly increased for a few hours after being opened up again. I have no definite information on the subject as to how great this flow is, neither do I know whether or not it has ever been measured. I have been told by different people that it may be made to reach a maximum approximating 2000 gallons per minute.

A few other wells have been drilled in this same vicinity. The J. B. Watkins Land Company has recently finished a well in section 11 in the northwest township of Morton County.

The well reached a total depth of 1160 feet, but they have filled it in to within about 730 feet of the top. They report that they can pump 500 gallons per minute from this well very easily. Dr. Charles L. Rea has put down a similar well about 30 feet deep up in Stanton County, in section 32, township 27, range 42, which is reported to be one of the best wells in that part of the state. Across the line in Colorado, in the vicinity of Artesia, is a well 390 feet deep which flows 120 gallons per minute through a 6¼-inch pipe, and another well 590 feet deep which flows 45 gallons per minute through a 3-inch pipe. To the east, in Stevens and Seward counties, a few wells have been put down, but they were not eminently satisfactory, possibly because they did not go deep enough.

All of the deep wells above mentioned seem to have gone through the Dakota formation and have obtained water from underlying beds. The Watkins well, in section 11, township 31, range 43, may be used as an illustration. By referring to the geological map, plate I, it will be seen that section 11 in this township lies very close to an outcropping of Dakota sandstone, and also that the Benton is found along the Arkansas River to the north, extending all the way west to the state line. We are left to conjecture, therefore, whether or not the Benton extends southward through Johnson County. The following is a rcord of the Watkins well:

Feet.	WATKINS WELL.
0– 5	Surface soil.
5– 25	Yellow clay.
25– 35	Sandy clay.
35– 55	Gravel, water-bearing.
55– 80	Limestone; probably Benton.
80– 95	Yellow clay.
95– 100	Sandstone, water-bearing.
100– 110	Yellow clay.
110– 116	Sandstone, water-bearing.
116– 135	Yellow clay.
135– 170	Blue sandstone, water-bearing.
170– 250	Blue shale.
250– 375	White sandstone, water-bearing.
375– 380	Red shale.
380– 510	Cream-colored sandstone.
510– 535	Red sandstone.
535– 720	Red shale.
720– 728	Red sandstone, water-bearing.
728– 765	Red shale.

Feet.	WATKINS WELL—Concluded.
765– 805	Limestone.
805– 910	Red shale.
910– 916	Red sandstone; water, strong flow.
916–1,000	Red shale.
1,000–1,050	Reddish brown shale, hard.
1,050–1,095	Dark brown shale, soft.
1,095–1,160	Sandy shale with water at 1,100, and much water at 1,150 in red quicksand.

From all the above facts regarding the occurrence of the Red Beds, the Comanche and overlying formations, I am reasonably sure the Watkins well struck the Benton limestone at 55 feet and that the Dakota here is a mixture of sandstones and shales with the bottom of same at 135 feet, making the Dakota surprisingly thin. Below this we have the Comanche down to the Red Beds at 510 feet, or possibly the white and cream-colored sandstone from 250 feet down belongs to some of the Cretaceous formations immediately under the Comanche, formations which do not come to the surface in Kansas but which may be found farther south in Oklahoma and Texas. My interpretation, therefore, is that any water found in these formations corresponding to 510 feet in the Watkins well would be from Cretaceous rocks. From here down we have the Red Beds, I should consider without doubt, to the bottom.

An interesting question now arises, which may be stated as follows: How does it happen that the Red Beds here produce usable water, while farther east and southeast they are so filled with salt and gypsum that water in them is entirely unusable? If my explanation is right it should be worth millions of dollars to southwest Kansas and southeast Colorado. I have a notion that these Red Beds here contain sufficient sandstone and conglomerates, similar to those exposed in the Garden of the Gods, to permit them to become water-bearing in exactly the same way the Dakota sandstone is water-bearing, and that therefore we have here a set of conditions so different from those in the northern part of the state that they deserve entirely different treatment. To the north, it must be remembered, we have the Dakota resting immediately upon the Permian. Here the Dakota seems to rest on the Comanche dark-green shales, and these in turn upon other Cretaceous sandstones down to a depth of 510 feet, where the Red Beds are found. The most important of all is that the Red Beds are so constructed that they are highly water-bearing and produce water of a reasonably good character.

This opens up two great questions: Can we obtain water throughout this region in sufficient quantity, not only for stock water, but for extensive irrigation, and is the water of sufficient quality to be suitable for this purpose? If an affirmative answer is given to each of these questions, then we have here one of the best water areas in the world. Again, if the Red Beds water should be too highly mineralized for irrigation purposes, we still have large quantities of water available from the Cretaceous sandstones, including the Dakota and those below the Comanche. Doctor Rea's well, in Stanton County, seems to draw its water from these Cretaceous sandstones. I have no account of this water, but am told it is reasonably satisfactory. Likewise one of the wells already mentioned, at Artesia, Colo., evidently gets its water from the same sandstones; all of which is good evidence that we have here a relatively newly discovered source of water which will play a most important role in the development of this interesting part of the state.

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