STATE OF SOUTH DAKOTA
George T. Mickelson, Governor

STATE GEOLOGICAL SURVEY
E. P. Rothrock, State Geologist

REPORT OF INVESTIGATIONS

No. 56

GROUND WATER RESOURCES

of the

SIOUX FALLS AREA, SOUTH DAKOTA

Part I - DESCRIPTION

GEOLOGY by E. P. Rothrock
HYDROLOGY by E. G. Otton

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INDEX MAP OF SOUTH DAKOTA

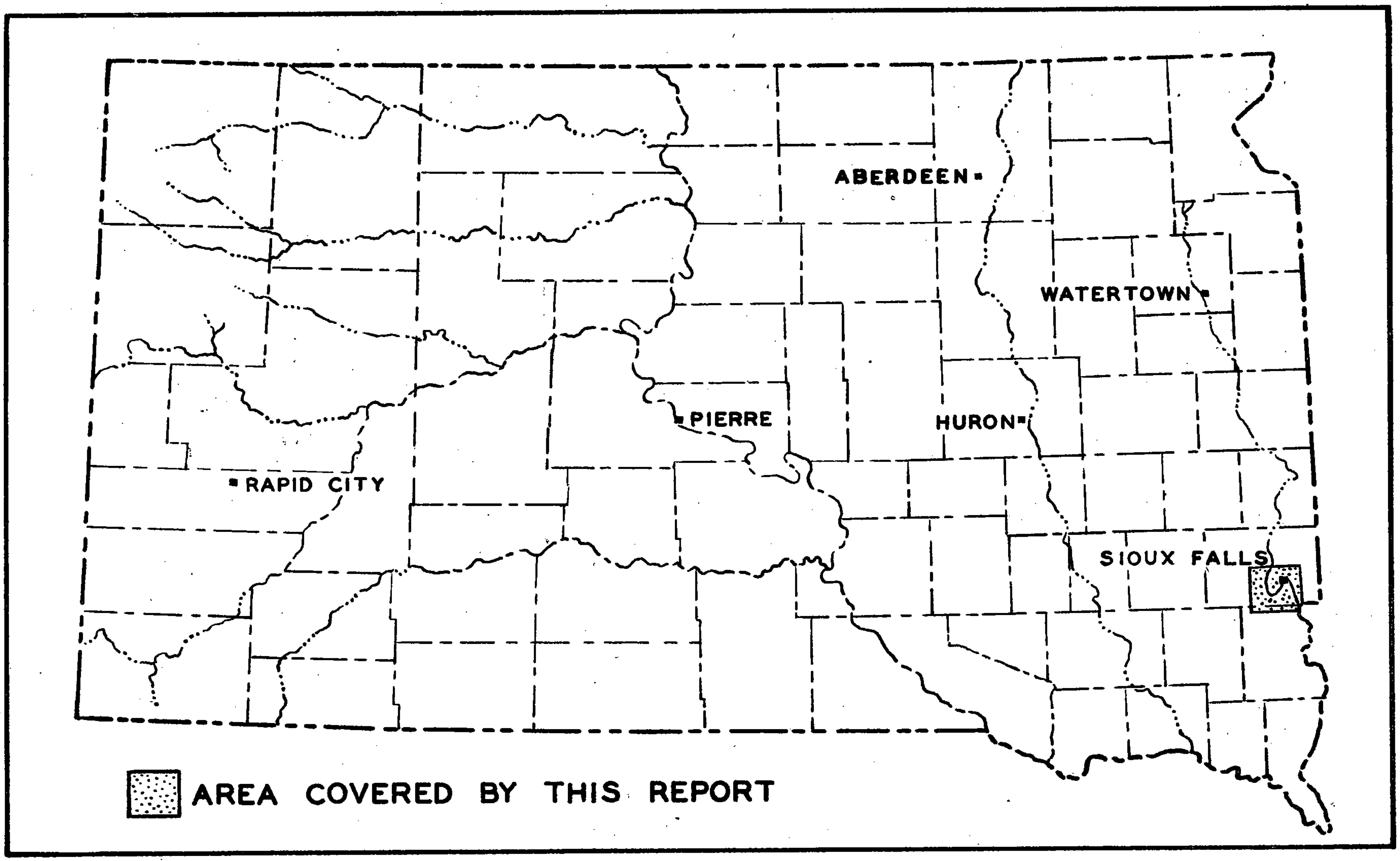

TABLE OF CONTENTS

PART I

PART II

LIST OF ILLUSTRATIONS

GROUND WATER RESOURCES

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PART I INTRODUCTION

PURPOSE OF REPORT

The following report is the result of investigations carried on by the South Dakota State Geological Survey and the U. S. Geological Survey, in cooperation with the city of Sioux Falls, to determine the amount of ground water available for the immediate and possible future needs of the Sioux Falls area. Experiences suffered during the recent drouth and from the war-time increase in population have brought out the fact that the water supply for this city is not unlimited and that there has been little reliable information on the amount of water on which the city can depend. It also became evident that the future growth of the city and its industrial development may depend to a large extent on the assurance of the existence of an adequate and secure supply of water.

At the request of the Chamber of Commerce and the city officials, therefore, the State Geologist undertook to direct investigations which would determine the volume of water available in normal times and times of drouth. Work done by the State Geologist some years previously (13)* showed that the present supply was confined to gravels in the bottom of the Big Sioux Valley. Plans were made for a test-drilling campaign to discover the depths, character and volume of the gravels which form the ground water reservoir. This was augmented by a study of the well samples in the laboratory of the Geological Survey and by some geophysical work on the shape of the valley bottom beneath the gravel; also by studies made by T.W. Robinson, of the U.S. Geological Survey, for war agencies.

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*Numbers in parentheses in the text refer to numbered items in the bibliography.

Further investigations of the hydrology of the valley became possible through a cooperative agreement between the city and the U.S. Geological Survey, under the direction of Dr. O.E. Meinzer, of the Water Resources Branch of the Federal Survey. These investigations included pumping tests to determine the rate of recharge of the ground water reservoir and the potential output of the wells, and the collection of the data on hydrology herein presented.

The purposes of all these investigations were:

First, to determine the total amount of water the ground water reservoir can hold.

Second, to determine the total volume of water which could be used from the ground water reservoir in times of drouth when no recharge is available; for example, how long the reservoir would supply water to a city having the present size of Sioux Falls under conditions similar to those of 1934.

Third, to determine the sources from which water for recharging the reservoir is derived and the amount of water which enters in under normal conditions and under dry conditions.

Fourth, to determine the maximum perennial supply that can be developed by inducing recharge and making full use of the storage capacity of the ground water reservoir.

In short, the object was to discover how large a city could depend on the water supply available in the Big Sioux Valley and how much water could be assured to prospective industries.

The answer to some of the above questions cannot be given as accurately as might be desired because of unpredictable factors in rainfall and stream flow in the Big Sioux Basin. It was possible, however, to determine the available water supplies with sufficient accuracy to insure efficient use of the present supply, to outline ways to increase the supply when needed, and to show how the city could survive a serious drouth without suffering the specter of a water famine.

ACKNOWLEDGMENTS

Before proceeding further with the discussion, the authors would like to recognize the assistance given them by others not directly connected with the investigations. As with most such studies, a large part of the success depends on the cooperation and aid given by residents of the region and others interested in the problem. For historical data investigators must depend on the reports of those who have been connected with the situation for a number of years. A great deal of the statistical data for this investigation came from the files of the City Engineer and the City Water Department of Sioux Falls.

The assistance of the city officials, especially Mayor C.M. Whitfield, City Commissioner Joseph Nelson, Water Plant Superintendent Rhea Rees, and City Engineer R.E. Bragstad, is gratefully acknowledged. Data on water analyses and temperature of the surface streams was furnished by Mr. L.L. Bradney, of the Sioux Falls sewage disposal plant. Periodic measurements of the water levels in the Sioux Falls well field were made by Mr. Carl Dahlund, of the Sioux Falls water works. Acknowledgment is given particularly to Mr. R.E. Bragstad and Mr. Rhea Rees for furnishing information of a detailed nature on the Sioux Falls well fields and for providing much of the equipment necessary to conduct the investigation. All city officials did their utmost to assure the success of the study.

Acknowledgment is made of the aid of Mr. A.L. Greenlee and Mr. P.D. Akin, of the U.S. Geological Survey, in planning the pumping tests and for their counsel and advice during the course of the investigation and of Mr. C.E. Jacob, also of the Federal Survey, who assisted materially in reviewing many of the quantitative aspects of the problem.

Appreciation is extended to officials of the Layne-Western Company, of Minneapolis, for their courtesy in providing logs of test wells drilled by their company, and to employees of the John J. Morrell and Company for similar courtesy.

Credit is also due to Mr. Bruno C. Petsch, staff geologist for the State Survey, for much of the compilation of data from well samples, the direction of laboratory tests on these samples, and the drafting of many of the charts and maps contained herein.

The authors also wish to acknowledge the many courtesies extended them by residents of Sioux Falls and the Big Sioux Valley.

Their assistance with information and the use of their wells added much valuable information which would otherwise have been unavailable.

METHODS OF WORK

The ground water reservoir formed by the gravels in the Big Sioux Valley had been mapped by the State Geological Survey in 1926, during a search for road gravel in Minnehaha County. (13) Its outlines were determined at the time by reconnaissance plotting of the base of the valley bluffs, locating their intersections with the section lines of the land survey and sketching their course between such intersections. This method guaranteed an accuracy within 200 feet for the horizontal control, which was sufficient for mapping so large a feature.

The volume and shape of the reservoir was determined largely from test wells drilled for this purpose. Nine lines of such wells were drilled; eight of them across the Big Sioux Valley, spaced approximately a mile apart at the lower end and two miles apart at the upper end, and one across the valley of Skunk Creek. The wells on these lines were drilled approximately one half mile apart. Each was drilled entirely through the gravel and into the underlying clay. From this data it was possible to plot eight cross sections in the Big Sioux Valley and one across Skunk Creek Valley.

Many wells have been drilled in and about the Sioux Falls well field at the lower end of the Big Sioux Valley. It was therefore possible to get a much more accurate picture of the shape of the channel here than farther up the valley.

A small area at the north end of the well field was mapped by electrical sounding. Resistivity measurements made on the valley fill showed the shape of the channel very nicely and gave other detailed information. Unfortunately neither time nor money was available to map the reservoir completely and most of the detail has to be interpolated between the points where information was given by the various wells.

Samples were taken regularly from the test wells and were tested for size and water bearing characteristics in the laboratories of the State Survey. These tests give a fairly accurate picture of the material of which the reservoir is composed.

Levels were run to the curbs of the wells used in this survey to determine their relative elevations. Using these well curb elevations it was possible to determine the shape of the ground water surface by the simple procedure of dropping a tape line into each well at stated times and measuring the depth of the water surface below the well curb. It was thus possible to determine the slope of the water table and the direction in which water was moving underground.

The rate of movement of water through the gravels was determined by pumping a well for a given time and determining the "cone of depression" thus formed. If water moves slowly through the gravels, water around the well is quickly pumped out and new water does not take its place rapidly. The water surface, therefore, makes a sharp cone or funnel around the well. If water flows readily through the gravels, however, the same pumping will make a much more shallow cone. The depth of the cone, therefore, compared to the rate of pumping gives a method for determining the permeability of the gravels, that is, the rate at which water can pass through them. The steepness of the cone is determined by measuring the depth to water in one or more test wells placed near the well that is being pumped.

Knowing the average permeability of the gravels in the reservoir and the rate at which the water table, or ground water surface, slopes down the valley, it is possible to determine approximately the rate at which water pumped out at the lower end can be replaced by water moving through the gravels from the upper end. Recharge must be estimated largely from the amount of rain and snow that fall on the surface of the reservoir, the flow of the tributary streams, and the amount of water that seeps out of the channel of the Big Sioux into the gravels. Figures obtained by any method must allow a margin of error since conditions vary in different parts of the reservoir and under different conditions of pumping, due to many factors, too numerous and complicated to be dealt with in this report. The results given in this report, however, show the average condition for the reservoir, and are of sufficient accuracy to make them usable in any practical scheme for utilizing available water.

PHYSIOGRAPHIC ENVIRONMENT

Sioux Falls is located in the extreme eastern part of South Dakota, near the southern boundary of Minnehaha County and about 15 miles west of the Minnesota line. It lies in a great bend of the Big Sioux Valley and its water supplies, therefore, are dependent on the geological features of the Big Sioux Basin. A brief survey of the physiographic environment, therefore, is in order.

Minnehaha County lies in the southern extension of an area known to the French fur traders as the "Coteau de Prairie" or the "Prairie Hill Country." The characteristic of this region is a hilly topography which varies all the way from a smoothly undulating plain of low relief to very rough areas of sharp, knobby hills.

The eastern two-thirds of the county is quite rough, the hills rising from thirty to fifty feet above their neighboring valleys. East of Skunk Creek the topography is entirely stream-made, short valleys fingering into one another to make a dendritic net which completely drains the area. No swamps or lakes occur between the hills of this part of the country. In the western third, the undulations are smoother and lower, giving much of the country a "plains" look. This surface is entirely the result of work done by glacial ice. Hills with long gentle slopes and sometimes with knobby prominences rise out of undrained depressions, many of which contain swamps and small lakes. The hilly character, however, is still dominant.

This hilly plain is drained by three major streams which, viewed from the south, form a crude trident or three tined pitch-fork with the city of Sioux Falls at its base. This pattern is of interest in any search for water supplies as these valleys will control most of the usable shallow supplies and offer the best sites for surface water installations. The master stream is the Big Sioux River, which flows directly southward across the middle of the county to Sioux Falls, where it makes a sharp loop around the city. After flowing northeastward for eight or ten miles it turns again southward into an ancient valley of Split Rock Creek, through which it leaves the county.

The two main tributaries forming the outside prongs of the trident are Skunk and Split Rock Creeks. Skunk Creek lies west of the Big Sioux, paralleling it half way across the county, then turning southeast enters the Big Sioux just above Sioux Falls. Split Rock Creek enters the county near its northeast corner, works its way south and west and enters the Big Sioux near Brandon, eight or ten miles below Sioux Falls. At this point the master stream, the Big Sioux, starts its southward journey out of the county.

The network of small streams which completely drains both sides of the Big Sioux Valley empties into this valley itself and into the two tributaries just described.

The valley of the Big Sioux is narrowed by bed rock, to a bottle neck at Dell Rapids. South of this rock ledge, however, it expands immediately into a flat bottomed valley a mile wide. Proceeding southward it gradually widens until it is two and a half miles across at Sioux Falls. The important features of this valley are its very flat bottom and its steep bluffs which meet the bottom at a sharp angle. These features indicate that the valley has been cut and then partially filled with river wash.

Most of Skunk Creek Valley is much narrower and gives the impression of being a deeper valley than the Big Sioux. In contrast to the Big Sioux its width is extremely variable. At Lyons it is a little more than a mile in width; six or seven miles downstream it narrows to half a mile; while the last five mile stretch, before it enters the Big Sioux, attains a width of a mile and a half. Its bluffs are steep and the narrower parts seem to be entirely the product of stream erosion. In the wider parts, however, there are flat bottoms, much like that of the Big Sioux, indicating fills of sand or gravel.

Split Rock Creek, as its name implies, flows in a gorge cut in bed rock through most of its course. Much of the upper part of its valley in Minnehaha County is only a few hundred yards wide. It contains some interesting examples of stream erosion as the stream is now flowing on bed rock. Between Corson and Brandon, where it enters the Big Sioux, it widens to a mile and contains some large terraces.

Waters from all three of the streams described leave the county in the gorge-like valley of the Big Sioux southward from Rowena.

POSSIBLE SOURCES OF WATER SUPPLY

Water supplies for Sioux Falls must come from one or more of the following sources:

1. Surface waters from lakes, streams, or artificial reservoirs made by damming stream valleys.

2. Ground waters which may occur in sandstone or similar bed rock formations, or in mantle rock reservoirs such as glacial outwash or sands and gravels accumulated in river valleys.

Surface Water

There are no fresh water lakes of sufficient size near Sioux Falls and no streams whose flow can be counted on to supply the volume of water the city needs at all times. Large surface supplies would have to be obtained by artificial impounding. It is not within the scope of the present investigation to determine the possibilities of such impounding. The following remarks, however, are given as suggestions to those who may contemplate such a project.

Favorable locations for dam sites occur in the valleys of the three major streams, the Big Sioux, Skunk Creek, and Split Rock Creek. These three valleys offer sites where good foundations could be obtained, and where water could be confined in a relatively small area and still have sufficient depth to prevent the lake from being an "evaporating pan" for the impounded water.

Some of the big tributaries, such as Slip Up Creek, which enters the Big Sioux two miles below Sioux Falls, have a fairly large drainage area. Their valleys, however, are not sufficiently sharp or sufficiently deep to impound large supplies of water. These minor creeks are fed only by flood waters from thunder showers in the immediate vicinity and by meltwater from snows. They are, therefore, not favorable for the development of large water supplies.

Dams might be constructed in the Big Sioux Valley just west of Sioux Falls, about four miles downstream from Sioux Falls, and at Rowena, four or five miles south of Brandon. The first location has the advantage of affording an excellent foundation for a dam. The width of the valley at this point and the necessary flooding of a very large area to obtain any depth of water, however, apparently rule out this site as a practical location.

Below the city, the valley is narrower and deeper, and a dam placed about four miles downstream from Sioux Falls would impound a large body of water in a relatively small area. The dam would have a clay foundation and large gravel terraces in the vicinity would allow leakage unless the dam were constructed to prevent it. These obstacles, however, are not insurmountable, and a considerable volume of water could be impounded in this part of the valley without flooding Sioux Falls. The question of sanitation would be a big factor in a lake down river from a city the size of Sioux Falls, as it is almost impossible to exclude sewage from such a location.

Near Rowena the valley of the Big Sioux offers an excellent site for a dam. The outcropping bed rock offers a splendid foundation, and the valley is narrow in the vicinity. Split Rock Creek and Spring Creek Valleys enter two miles upstream, however, and considerable swamp land might be developed there unless care were taken to avoid it.

From an engineering standpoint the valley immediately below Sioux Falls would offer the best reservoir site in the Big Sioux Valley, while the valley at Rowena offers the best available dam site.

The valley of Skunk Creek offers some good sites for impounding water, since it is narrower than the Big Sioux Valley. Gravel terraces are found along its bluffs in the lower part, but dam sites could be established above Ellis which could impound a large supply of water without flooding a great deal of land. Skunk Creek is not a permanent stream but drains a fairly large area.

The valley of Split Rock Creek, in the vicinity of Corson, offers some interesting possibilities and has been proposed as a reservoir site. It is narrow and deep and in much of its course has cut through quartzite bed rock which would offer an excellent foundation for a dam. Though Split Rock Creek is not a permanent stream, the valley is a long one and drains a very large area in Minnehaha and Moody Counties and adjacent parts of Minnesota.

The subject of surface water supplies should not be left without a word of warning. While installations could be made which would supply adequate water for the city in normal years, no surface supply in the state of South Dakota is dependable during times of drouth. Some expensive water works have been built for cities as well situated as Sioux Falls, but all of them have failed to supply the needed water during the worst of the dry years. Surface supplies should not be depended on exclusively for a city of the size of Sioux Falls. If surface waters are used, a reserve of ground water should also be available for use in emergencies or serious water shortages may ensue.

<u>Deep Wells</u>

In looking over water supply possibilities for a city in South Dakota, the deep-well situation always has to be considered. Deep wells can supply adequate volumes for small cities if properly spaced and managed and if an aquifer underlies the city which makes a sufficiently large reservoir to supply the amount of water needed. Sioux Falls, however, is unfortunate in this respect, since the rocks that underlie the vicinity are very hard and impervious and therefore will not supply large volumes of water.

Wells drilled anywhere within the vicinity of Sioux Falls must eventually encounter a pink quartzite which belongs to the Sioux formation. As near as can now be determined, this formation is approximately 1500 feet thick. Some of the neighboring towns have water supplies from this source and the water is of good quality for ordinary household uses. The formation also supplies farm wells in some localities. These wells obtain water by striking cracks or shattered zones in the formation or from poorly cemented areas which act as sand reservoirs. Such wells, though sufficient for a farm or small community, could not be depended on to furnish a large supply such as the public supply of Sioux Falls. The expense of drilling wells in a formation as hard as quartzite, the small yield of the wells, and the uncertainty as to the amount of water available all make the quartzite unfavorable for the development of a large supply. There is no hope of encountering more productive rock by deeper drilling; in fact, the reverse will be the case since the quartzite carries more water than the metamorphic rocks that lie beneath it.

Shallow Wells

Shallow wells which produce water from the boulder clay and sand covering the quartzite bed rock furnish good water for farm supplies in many places over the county. Water seeps through the boulder clay with sufficient rapidity to supply small farm wells. Pockets of gravel occur in many places which form little reservoirs from some of which fairly large volumes of water can be pumped. Such wells are very useful as farm wells, but will not furnish the needed volume rapidly enough to be used as a city supply. These wells are often very confusing since with limited use they seem able to deliver a large volume of water. If pumping is continued, however, they may run dry and pumping may have to be stopped periodically to allow replenishment of the well. Though the construction of such wells is inexpensive, they are not recommended as a source of large water supplies.

The only reliable sources of large volumes of water from shallow wells are the large gravel fills in the bottoms of the major stream valleys which were described in this report under "Physiography." Split Rock Creek has only a few such fills, but the Big Sioux and Skunk Creek Valleys contain large bodies of sand and gravel which act as excellent reservoirs. The present city supply is taken from the Big Sioux fill.

FIGURE 3. SIOUX QUARTZITE NEAR THE SURFACE OF THE BIG SIOUX SPILLWAY.
CONCRETE MATERIALS COMPANY QUARRY, SIOUX FALLS

PART II GEOLOGY

BIG SIOUX GROUND WATER RESERVOIR

The Big Sioux Valley was a spillway for glacial torrents that were responsible, not only for making the valley, but also for placing in it the sand and gravel which converted it into a ground water reservoir. The portion in Minnehaha County may be compared to a gold miner's sluice box, about 18 miles long, 2 miles wide, and 80 to 100 feet deep, which has been cut through a sheet of boulder clay spread over the county by ancient ice sheets. This boulder clay, then, makes the bottom and sides of the trough. Into this ditch gravels and sands were washed by subsequent glacial waters until the valley was about half full, and it is these gravels and sands which form the reservoir from which the city supplies are being drawn.

Two dams of quartzite bed rock cross the trough, one at Dell Rapids and one at Sioux Falls. The southern dam crosses the valley in the vicinity of Madison Avenue in the southern part of the city. Thus they limit the reservoir, the upper or Dell Rapids dam marking the northern limit of the gravel fill, and the lower or Sioux Falls dam marking its southern limit. No gravels are deposited on the bed rock in the Big Sioux Valley at Dell Rapids and only a thin sheet a few feet deep covers the quartzite where the valley crosses it at Sioux Falls. The general picture of the Big Sioux Ground Water Reservoir, therefore, presents a body of sand and gravel averaging 40 feet deep, 2 miles wide and 18 miles long, resting in a trough with clay bottom and sides and ending against bed rock dams at its upper and lower extremities. As the saturated deposits between Dell Rapids and Baltic are relatively thin, only the part of the reservoir below the vicinity of Baltic is considered in the hydrologic part of this report. The saturated deposits in this part are estimated to average 28 feet in thickness.

Sioux Quartzite

The bed rock underlying the Big Sioux Ground Water Reservoir is an indurated beach sand known as quartzite. It is exposed at the falls of the Big Sioux, in quarries in the western part of Sioux Falls, at Baltic and at Dell Rapids. It is also exposed in the valley of Split Rock Creek and at various other places in Minnehaha County indicated on the accompanying geologic map. (Figure 2) It underlies all of Minnehaha County, and, therefore, forms the foundation on which rest the boulder clays in which the Big Sioux spillway was cut. It belongs to the Sioux formation which also includes one or more zones of highly siliceous red and purple slates carrying, in places, the famous red pipestone. Some schists were also encountered in it in borings east of Sioux Falls.

The quartzite is a sandstone which has been so thoroughly solidified that the pore space has been almost entirely filled with cement. Physical analyses have shown the pore space to be as low as 2% of the volume of the rock. This is a high density and is not universally present, but it indicates that the rock is very impermeable. The color of the rock is pink; in fact, so pink that it has sometimes been called jasper. This coloration is due to a small amount (two or three per cent) of iron which is contained in the rock as a coating around the sand grains and is conspicuous since it is the only coloring matter of the rock. Analyses show that 97 to 99% is silica in the form of mineral quartz. Alumina, lime, magnesia and manganese have been identified in traces and very small amounts (12).

Some primary structures of the old beaches are still visible in the rock and sometimes play an important part in the breaking of the stone. Ripple marks are abundant along horizontal beds; cross bedding, usually of the torrential type, is abundantly displayed on all exposures but has little effect on the quarrying of the stone. Horizontal beds from one to four feet thick, however, are usually parted by planes which allow the quarrying of large pieces of the stone. The rock has been cracked by earth movements which have resulted in leaving parts of it badly shattered. The cracks, or joints as they are called, are far apart in some places, making blocks several feet in dimension. There are two major sets of vertical cracks that have about the same trend over the entire county. One set trends about north and south and the other, approximately east and west. A third set, which makes an angle of about 45 degrees to the main joints, occurs at many places.

The effect of the jointing is to break the rock into trapezoidal blocks varying in size from one or two inches across to two or three feet. This jointing is not only of prime importance in quarrying but also makes it possible to obtain water from the quartzite where large volumes are not needed. Such cracks can allow leakage where water is impounded behind dams set on the quartzite. In the case of the Big Sioux Valley, however, it should be noted that there has been little leakage through the lower dam so far as can be ascertained. This is in part due to the density of the rock in this particular locality and in part to grouting of the cracks by glacial clays and other material washed into them by the streams which deposited the valley fill.

FIGURE 4. QUARRY FACE OF SIOUX QUARTZITE SHOWING JOINTING OF THE FORMATION.
CONCRETE MATERIALS COMPANY QUARRY, SIOUX FALLS

The thickness of the quartzite is not known and estimates vary greatly. The greatest one published is 3000 to 4000 feet (4, p. 201). A more conservative estimate was made by James Todd, who placed it at 1500 feet (16, p. 35).

Where the formation is exposed over a fairly large area, as at Sioux Falls and in the valley of Split Rock Creek, a southward dip of the major beds appears. Measurements show that this dip amounts to as much as four or five degrees. Slipping has taken place along the east-west joints causing normal faults whose hanging walls are on the north sides of the fault planes. The position and distribution of these faults indicate that slipping of large blocks took place, tilting them southward in the manner ascribed to the formation of block-mountains. Although details of the faulting in the Big Sioux Valley are lacking, the position of the bed rock suggests that the ridges of quartzite that cross the valley at Dell Rapids and Sioux Falls are the peaks of such fault blocks, or possibly horsts which protruded some distance above the surrounding quartzite surfaces.

These ridges have been supposed by some to be the end of the ancient Killarney mountains and if so, they are a continuation of the iron ranges of Minnesota (10, p. 171). Whatever their origin and relationships, they have effectively limited the ground water reservoir to the section of the Big Sioux Valley which lies between them.

Old Glacial Drifts

As stated previously, the walls and bottom of the Big Sioux spillway are made of boulder clay. This is the typical, unsorted mixture of heavy clay, sand grains, pebbles, cobbles and boulders deposited by glacial ice where meltwater has been insufficient to sort out the materials of different sizes. Where exposed in deep road cuts and by well drilling operations this material is a heavy, stiff clay of a slatey blue color when dry and becomes a blue-black when wet. It makes a sticky, heavy mud, but on washing will yield a considerable percentage of sand. Pebbles and cobbles are visible and sprinkled through the mass. However, they appear to be more numerous than they actually are.

Where this boulder clay has been exposed to the weather it turns a buff-tan color, due to oxidation of the iron which it contains. Most of the road cuts and surface exposures show this weathered boulder clay. Though it is not entirely impervious and will even furnish enough water for small wells by slow seepage, it will retain water on its surface for a considerable time. It, therefore, acts as a very good liner for the reservoir, preventing leakage in any quantities that would seriously deplete the supplies in the gravel.

Two sheets of this boulder clay were spread over the reservoir site. During the Nebraskan stage of the geologically recent Great Ice Age or Pleistocene epoch, ice moved in from the northeast over the old quartzite surface. Upon retreating, it left the hollows partly filled with boulder clay whose surface now is below the top of the quartzite ridge where it is exposed in Sioux Falls. There is no way of knowing whether the ice covered the ridges or extended as tongues of ice into the quartzite valleys.

One of the few exposures of this old drift near the reservoir is above the flood water spillway at the State Penitentiary in north Sioux Falls where a deep cut was made in building the truck road from Highway 77. This has exposed 32 feet of Nebraskan drift, at the top of which is a well developed soil beneath a cover of Kansan till. To form this soil the surface had to be exposed to the action of the weather a long time in a climate sufficiently mild to cause growth of temperate zone plants in considerable abundance. Estimates on the length of time necessary vary considerably but are all in the neighborhood of 200,000 years.

It is not possible to separate this drift from the younger drift which lies upon it in a hand sample and therefore it has not been definitely identified from the well samples beneath the reservoir. Judging from the depths of the reservoir and the elevation of the old soil surface, it is probable that the bottom of the reservoir rests on Nebraskan drift to a large extent.

After a long lapse of time a second glacier descended on Minnehaha County bringing more boulder clay, which was spread on top of the Nebraskan drift as the ice melted. This sheet filled the quartzite valley to the brim and spread over the tops of the ridges. In short, it covered everything in and about the Big Sioux reservoir, including the quartzite ridges. In the portion of the Big Sioux Valley below Sioux Falls some gravels were deposited by meltwater from the retreating ice sheet (12, p. 19). Most of the material, however, and in fact, all that is connected with the ground water reservoir here under consideration was boulder clay. The thickness of this drift sheet varies considerably in different places. Where quartzite ridges are high it amounts to only 20 or 30 feet. At the spillway near the State Penitentiary in Sioux Falls, however, it is 88 feet. This latter figure probably is somewhere near the average thickness for this drift in and about the ground water reservoir.

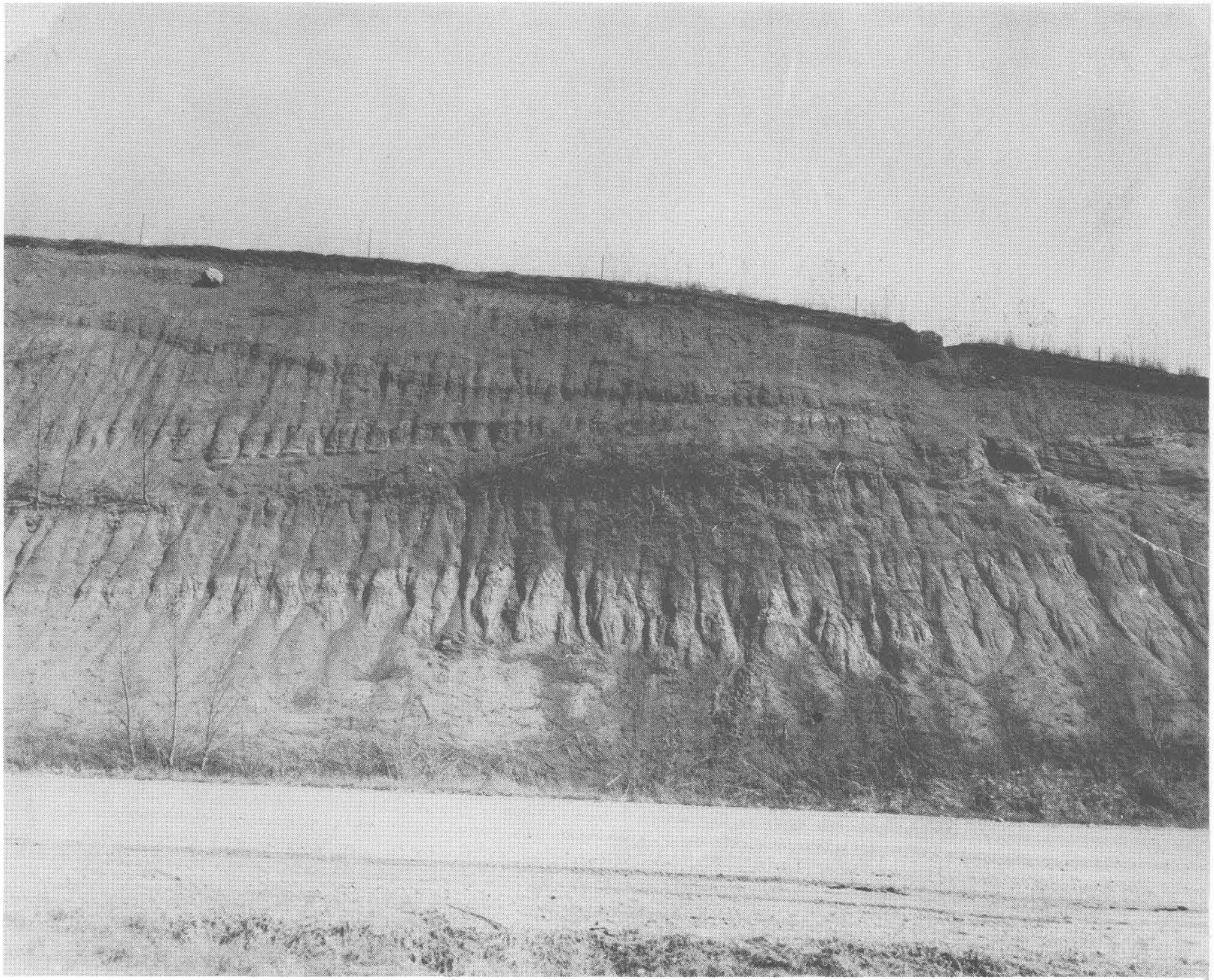

FIGURE 5. KANSAN DRIFT OVERLYING NEBRASKAN DRIFT. HIGHWAY CUT ONE HALF MILE EAST OF STATE PENITENTIARY.

This second ice invasion occurred during the Kansan stage of the Pleistocene epoch and is of interest here, since it deposited the drift which makes the sides and parts of the bottom of the spillway. It also forms the bluffs of the present Big Sioux Valley above the surface of the gravel fill.

<u>Gravels of the Wisconsin Stage</u>

The gravels of the reservoirs in both the Big Sioux and Skunk Creek valleys are the result of a third ice invasion of Minnehaha County. Kansan ice disappeared and there followed another period of temperate climate which leached the upper part of the Kansan drift to a bright tan for a depth of about 30 feet and formed a heavy clay soil on its surface. Estimates indicate about 500,000 years for the duration of this interval.

The county was then invaded by the Wisconsin ice sheet which nearly surrounded the entire length of the Big Sioux Basin. Ice from a tongue of the glacier in Minnesota moved westward toward the Minnehaha County line but was stopped before it reached the South Dakota border. A second tongue which worked its way down the James Valley spread eastward into Minnehaha County until it was halted along Skunk Creek.

The ice front thus formed a great wishbone forking from a junction at the head of the Big Sioux in Roberts County. Thus surrounded, the Big Sioux Valley had to carry all the meltwater and its debris from more than 400 miles of ice front. Enormous amounts of gravel were poured into the valley at the headwaters of the Big Sioux. Still more entered by way of outwash channels draining the ice on both sides of the Big Sioux. A large channel of this kind lies between Florence and Watertown, in Codington County, and another from Madison through Chester, in Lake County. The total number of these channels has not been determined, but there are a score or more.

The first effect of these torrents was to carve a spillway out of the channel of the Big Sioux, shaping it into the form it has today. This trough would have been narrow and deep in the vicinity of Sioux Falls, but for the quartzite ridge. This ridge was sufficiently resistant to prevent rapid downward cutting, and therefore, it forced the water to cut a wide, shallow channel. Scour in the soft boulder clays above the dam, however, deepened the channel to some 40 feet below the quartzite.

As floods began to subside, coarse materials, sorted from the drifts by meltwater from the ice, settled into the scour basin, eventually filling it to the level of the quartzite dam. All this material was furnished by meltwater from sections of the ice front north of Dell Rapids and was brought down the channel of the Big Sioux to its present resting place. The distance of travel necessary and the sorting action of the stream accounts for the fact that most of the fill in the reservoir is made of fine gravel and sand. Coarser materials were left farther up the stream or worn to fine grains by their long transit. Silt and clay, however, were carried farther downstream and no record of them is left in this part of the valley.

The last of the flood waters had neither the volume or speed of the earlier torrents and, therefore, were not able to carry as coarse material. They did carry fine sands, silts and clays, which they spread over the valley flats, covering the gravels with about ten feet of fine sand, loam and sandy silt. The surface is a black soil, much of which suggests the muck found in swamps. According to Mr. C.E. Bourne, of the Soil Conservation Service, U.S. Department of Agriculture, the upper part of the fill is of wind blown material which has weathered to soil and clay-like material. This forms a fairly impervious cover on top of the coarser materials which will hold puddles of water for quite some time after a rain in many level places in the valley.*

These gravels of the Wisconsin stage then formed the large porous mass which acts as a reservoir or storage basin for water introduced into it by rain and snow falling on its surface, water seeping out of the channel of the Big Sioux River and runoff from the surrounding hills. The permeability of the gravels allows movement of water throughout the reservoir which will slowly recharge any portion from which excessive amounts of water have been drained by pumping or other causes.

SKUNK CREEK GROUND WATER RESERVOIR

In the lower valley of Skunk Creek and around the bend in the Big Sioux Valley, south and east of Sioux Falls, is a considerable deposit of gravel and sand which could be used as an auxiliary to the main ground water reservoir of the Big Sioux Valley. These gravels are shown on the geologic map accompanying this report.

Like the gravels just described in the Big Sioux Valley, these deposits are the result of deposition by meltwater from the Wisconsin ice sheet. The size of the deposits is due to the fact

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*C.E. Bourne, Personal communication.

FIGURE 6. SKUNK CREEK GRAVELS, BURNS PIT, EAGLE. ON HIGHWAY 16, 2 1/2 MILES WEST OF DOWNTOWN SIOUX FALLS.

that Skunk Creek marks the eastern front of the Wisconsin ice sheet, and meltwater from it ran directly into Skunk Creek Valley, carrying the debris from the ice into the valley. The entire Minnehaha County section of this valley contains gravel fills and low terraces. Kame and esker deposits (gravel and sand hills and ridges formed in cracks in the ice) are found in many depressions entering it from the west.

This ice front was the edge of the James Valley lobe, which spread eastward from what is now the James River, crossed the pre-glacial Vermillion Valley just west of Minnehaha County, and was halted on the east bluff of the old Vermillion Valley, on the highland formed by the Kansan drift described above.

Since the surface of the Kansan drift rose toward the Big Sioux Valley east of the ice front, meltwaters could not flow from the ice front directly into the Big Sioux but worked their way southward along the ice front, cutting a channel for themselves in the old drift, which is now occupied by Skunk Creek. In this valley, the sands and gravels of the Skunk Creek Spillway were deposited.

Since most of the valley was narrow, the fills are composed of coarser materials over most of its length. Near the mouth, however, in the vicinity of Ellis, the valley widened, slackening the speed of the water and depositing sand and gravel over an area of approximately 6 square miles to a depth of approximately 50 feet.

Subsequent torrents have cut wide shallow channels in the gravel first deposited, leaving terraces at two levels above the lowest "bottom." The highest occurs in terraces along the side of the valley and can be seen a mile and a half south of Ellis where Highway 16 crosses it. The second terrace lies about 10 feet below the first and occupies most of the valley bottom. The village of Ellis is situated on its surface. The present channel of Skunk Creek has been cut into a third flat, some 10 feet lower than the second.

The overall picture of the lower Skunk Creek Spillway presents a large trough filled with 50 or 60 feet of gravel and sand whose surface descends from the bluffs in a series of broad steps. This body of sand and gravel forms the reservoir which will have to be used if the Skunk Creek deposits are needed for a supplementary ground water reservoir. It is to be noted that this reservoir is in no way connected with the Big Sioux reservoir, which is the source of city water. The two are separated by the quartzite dam which forms the southern end of the Big Sioux reservoir. It should also be noted that the boulder clay deposits of old drifts underlie the entire county between the Big Sioux and Skunk Valleys. This is sufficiently impervious to prevent any drainage of water from the Big Sioux ground water reservoir into the Skunk Creek ground water reservoir. There are no known buried sands or gravels which might cause leakage. Since both of these reservoirs are fed from independent drainage basins there is no intercontrol of recharge water. Each is supplied by runoff from its own basin and is independent of the other.

Because of its size and location, this reservoir can be of considerable importance as a supplementary water supply for the city water works or industrial establishments, and it should be given consideration in any long range planning.

An important factor in its location is the fact that it is above the city, which thus far has prevented its pollution. With careful management the water in this reservoir could be kept pure indefinitely. Drainage from sewage plants and stock yards or dwellings need not be allowed to enter these gravels.

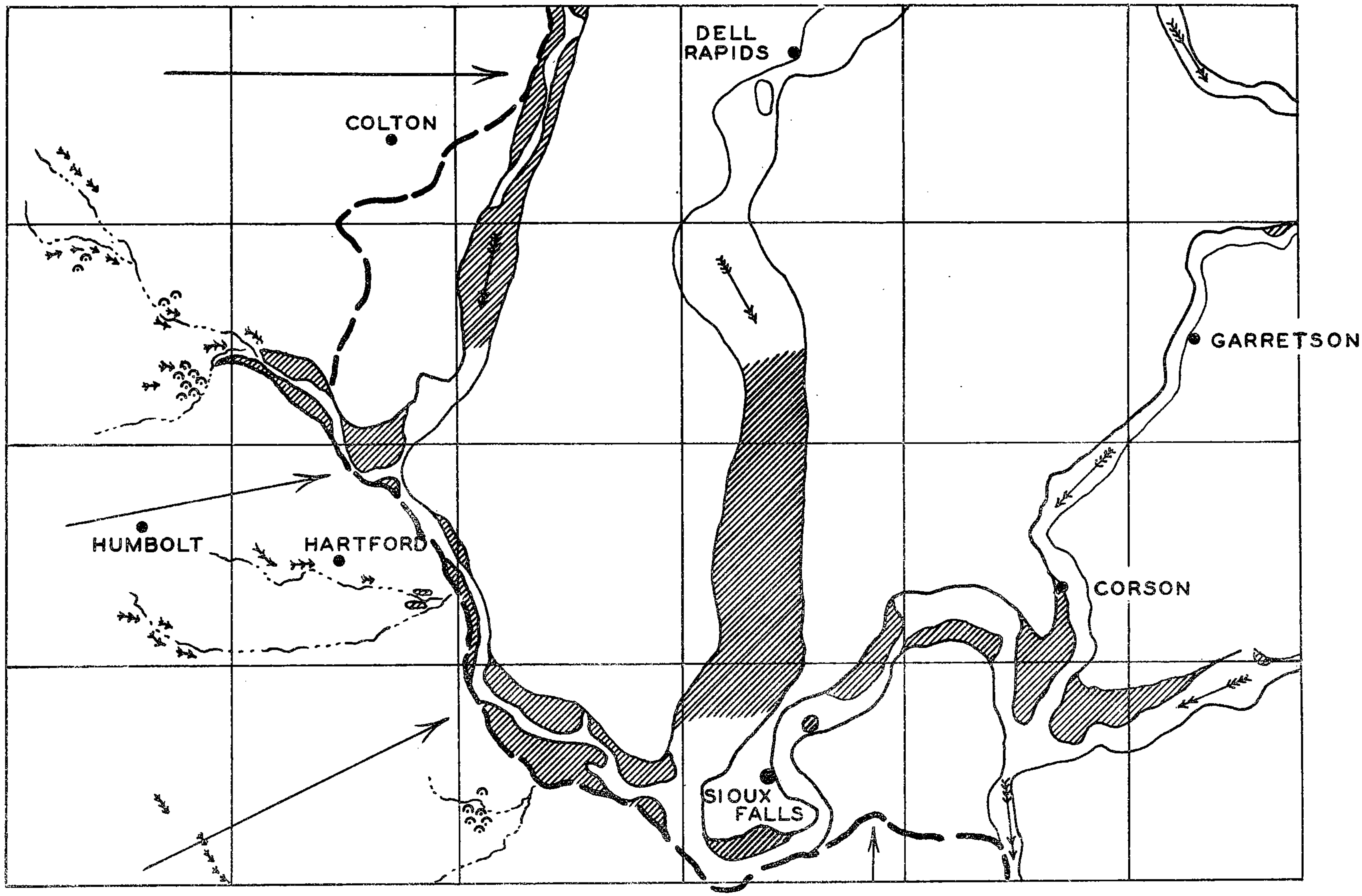
CHARACTER OF GRAVELS OF THE WISCONSIN STAGE

As in all glacial materials, the dominant character of the Big Sioux and Skunk Creek gravels is heterogeneity. Though most of the materials are fairly well sorted there are no bodies in which sizing is perfect. There is also heterogeneity in the placing of different beds in the deposits. Coarse gravel and boulder lenses are interbedded with sand, and clay partings are found in sand beds. The materials also are a heterogeneous mixture of local and imported rocks and minerals.

This is well illustrated in the following analyses of samples from Well No. 69, near Sioux Falls:

Screen Analysis of a Gravel Sample
Depth 19 to 24 Feet

Material	Screen Size	Percent	Percent Material
Gravel	retained on 10 mesh	37	52
	retained on 30 mesh	15	



FEATURES OF WISCONSIN GLACIATION IN MINNEHAHA COUNTY

WISCONSIN BOUNDARY

DIRECTION OF ICE MOVEMENT

CHANNELS SHOWING DIRECTION OF GLACIAL WATERS

TERRACES AND VALLEY TRAINS

KAMES

ESKERS

FIG. 7

Sand	retained on 60 mesh*	18	
	retained on 100 mesh	21.7	45.1
	retained on 150 mesh	5.4	
Silt	retained on 250 mesh	.04	.04
Clay	passing 250 mesh	.01	.01
		97.15	97.15

Screen Analysis of a Clean Sand
Depth 25 to 26 Feet

Material	Screen Size	Percent	Percent Material
Gravel	retained on 10 mesh	1.9	5.6
	retained on 30 mesh	3.7	
Sand	retained on 60 mesh	16.5	
	retained on 100 mesh	73.2	93.8
	retained on 150 mesh	4.1	
Silt	retained on 250 mesh	.3	.3
Clay	passing 250 mesh	0	0
		99.7	99.7

Screen Analysis of a Clean Gravel
Depth 26 to 31 Feet

Material	Screen Size	Percent	Percent Material
Gravel	retained on 10 mesh	86.7	
	retained on 30 mesh	6.8	93.5
Sand	retained on 60 mesh	4.1	
	retained on 100 mesh	1.8	6.1
	retained on 150 mesh	.2	
Silt	retained on 250 mesh	.02	.02
Clay	passing 250 mesh	0	0
		99.62	99.62

*The term "mesh" refers to the number of wires per inch in a wire screen. Thus a 10 mesh screen would have ten wires per inch in one direction and the same number per inch at right angles to them.

Opening size in:

10 mesh screen	.0787 inch	or 2.000 mm.
60 mesh screen	.0098 "	or 0.250 mm.
120 mesh screen	.0049 "	or 0.125 mm.

Of the one hundred and eighty samples which were analyzed only two showed no pebbles of gravel size (retained on 10 mesh). A great many were free from clay but only forty-five (one-quarter) were free from silt. Most of the samples showed coarse and fine sand and medium fine gravel mixed in varying proportions.

A perusal of the block diagram which accompanies this report (figure 9) will show better than words the lack of organization in the arrangement of the sand and gravel masses in the fill. No two test holes gave identical sections. Some beds could be traced into neighboring wells but not across the valley nor for any distance up or down its length. It is evident, then, that these bodies are lenses of sand and gravel deposited by torrents of water of varying velocity. Scour and filling of depressions are an important process in any stream action and are especially noticeable in streams the size of the meltwater streams which deposited this fill. The only thing the different lenses have in common is the scarsity of fine materials, silt and clay.

There is also no vertical order in the sizing of materials except that in the top ten feet fine material makes the cover of the underlying reservoir gravels. Coarse gravels lie on the bottom of the fill in some places and at the top of the fill in others. The same is true of sand. This complicated the problem of trying to find permeable beds from which to obtain large volumes of water rapidly. Each location must be explored to determine the depths to the most permeable gravels before attempting to sink an expensive well. While few sands are so tight that they will not yield water, the fine sands can make trouble by filling up wells and cutting out valves in pumping equipment. Furthermore, they do not yield water with sufficient rapidity to supply the volumes which may be called for in supplying a city of the size of Sioux Falls.

Being of glacial origin, the individual pebbles and grains of the fill show a great diversity. The glacier which furnished the material originated in the vicinity of Hudson's Bay. In moving southward it collected rocks from the entire surface over which it rode. It crossed the hardest and toughest volcanic and metamorphic rocks that exist. Most of these were encountered near the source of the glacier, north of the boundary of the United States. While they were ground to a fraction of their original size, their hardness and toughness prevented their entire disintegration before reaching the Big Sioux Valley. These hard materials constitute the major portion of the Big Sioux gravels. In southern Canada, northern Minnesota, North Dakota and South Dakota the ice rode over soft shales and chalk rock. Such materials were soon ground to rock flour, and very little of it is to be found in the valleys of the Big Sioux or Skunk Creek. However, pebbles of shale and chalk are present and make a conspicuous though not abundant assemblage in some of the gravels.

These soft substances are notably absent from most coarse materials of the fill and an inspection of the samples showed that both pebbles and sand grains were hard rocks of sedimentary volcanic and metamorphic origin. Pink and gray granite are very abundant. White dolomite gives most gravels a light gray color, while brown and black limestones are found abundantly in others. Metamorphic rocks are represented by gneisses, quartzites and some fine-grained dark colored rocks which appear to be pieces of slate. Flint and vein quartz are present in considerable abundance.

The sands are composed predominately of clear, angular pieces of broken quartz with here and there a grain of feldspar. This suggests that much of the sand was formed by grinding up granite as it was being carried in the ice. Mixed with the quartz grains are small grains of hard white dolomite and enough small pieces of slate and black ferro-magnesian minerals to give some samples a salt and pepper appearance.

In spite of the heterogeneity, the sands and gravels of the Big Sioux and Skunk Creek fills furnish a large body of porous material into which water can sink rapidly and from which it is not lost by evaporation. Seepage out of the fill is prevented by the stiff boulder clay which lines the sides and bottom of the Big Sioux Valley and little can be lost by percolation through the gravels down the valley because the subsurface dam of quartzite at Sioux Falls effectively seals that end of the reservoir. In other words, these sands and gravels act as a great reservoir in which water can be stored in volumes large enough to make an adequate supply for Sioux Falls not only in normal times but also in times of drouth, as will be shown in the section of this report which follows.

PART III : HYDROLOGY OF THE BIG SIOUX AND SKUNK CREEK VALLEYS

CONSUMPTION OF GROUND WATER

A primary consideration in the study of the ground water supplies of any area is a knowledge of the amount of water used. In 1944 the average consumption from the municipal water supply system of Sioux Falls was about 7 million gallons a day and the maximum was over 12 million gallons. The City of Sioux Falls is the only large consumer of ground water in the vicinity. There are, however, several hundred domestic and farm wells within a few miles of the city limits. No precise figures can be given concerning the total quantity of water pumped from these domestic and farm wells, but the pumpage is probably not greater than a few hundred thousand gallons per day.

It can be seen from a study of the following table that there has been a considerable increase in the consumption of water in Sioux Falls during the past ten years and that the maximum daily pumpage increased nearly threefold from 1923 to 1944. Part of the increase since 1940 is due to the greater consumption of water by the John J. Morrell and Company packing plant as a result of war food production. Water consumption was further increased in 1942 by the construction of the Sioux Falls Army Air Base. During 1944 the packing plant used about 18 per cent or the total water pumped by the city and the Army Air Base used a per cent of the total.

The future consumption of water in Sioux Falls will depend on the growth of the city, the expansion of existing industries, the construction of new industries whose manufacturing processes demand large quantities of water, the greater demand for air-conditioning during the summer, and the quantity of water that will be used at new institutions, such as the projected Veterans Hospital. In 1942 an estimate was made by Burns and McDonnell (1), consulting engineers, Kansas City, Missouri, that by 1970 the daily average pumpage would be 7.65 million gallons per day and that the pumpage on the maximum day of that year would be about 14.90 million gallons. At the present time this estimate seems too conservative, as that amount of pumpage has already been nearly reached. In any event provision should be made for large industries that may wish to locate in or near Sioux Falls, for the adequacy of available water supplies is often a determining factor in the choice of sites for industrial establishments.

Consumption of **Water by Years**
Public Supply of the City of Sioux Falls

Figures Indicate Millions of Gallons

Year	Yearly Total	Daily Average	Maximum Day*
1908	298	.81	--
1909	355	.97	--
1910	407	1.11	--
1911	359	.98	--
1912	401	1.09	--
1913	479	1.31	--
1914	541	1.48	--
1915	580	1.58	--
1916	648	1.76	--
1917	692	1.89	--
1918	686	1.88	--
1919	834	2.28	--
1920	853	2.33	--
1921	855	2.31	--
1922	922	2.52	--
1923(*)	942	2.61	4.10
1924	1,014	2.77	4.15
1925	1,154	3.16	4.81
1926	1,104	3.02	4.64
1927	1,086	2.97	4.90
1928	1,208	3.31	4.96
1929	1,353	3.70	5.61
1930	1,544	4.23	6.78
1931	1,641	4.50	--
1932	1,487	4.06	6.35
1933	1,197	3.28	6.14
1934	1,366	3.74	7.21
1935	1,327	3.64	6.49
1936	1,529	4.19	8.63
1937	1,674	4.58	7.36
1938	1,611	4.41	7.85
1939	1,685	4.63	9.09
1940	1,717	4.70	8.37
1941	1,965	5.23	9.11
1942	2,207	6.04	9.47
1943	2,805	7.68	11.05
1944	2,584	7.06	12.11

*Data for maximum day from 1923 to 1942 taken from reference 5 in bibliography.

The table below gives the consumption of water by the city of Sioux Falls by months for 1944 and part of 1945.

Consumption of Water by Months for 1944 and Part of 1945
Public Supply of the City of Sioux Falls

Figures Indicate Millions of Gallons

Year	Month	Total	Year	Month	Total
1944	January	213	1944	September	198
	February	209		October	188
	March	220		November	18[illegible]
	April	219		December	196
	May	232	1945	January	195
	June	243		February	174
	July	247		March	191
	August	238			

PRECIPITATION

The quantity of ground water perennially available for Sioux Falls is largely governed by the amount of precipitation in the vicinity of Sioux Falls and the drainage basins of the Big Sioux River and Skunk Creek. In the following tables are given the annual precipitation at Sioux Falls from 1891 through 1944, as taken from the records of the U.S. Weather Bureau (6), and the average monthly precipitation in this 54-year period. An analysis of these data shows that at Sioux Falls January is the driest month and December is the next to driest month, while June is the wettest month and May, the next to wettest month. The wettest year of record was 1909, when the precipitation was 36.02 inches and the driest year of record was 1894, when the precipitation was only 10.44 inches. Moreover, 1894 was the fourth in a five-year dry period, 1891 through 1895, during which the average yearly precipitation was only 19.13 inches. This period exceeded in severity even the dry years of the middle 1930 s, and it is probable that ground water levels were at extreme low stages by the close of the period. That a dry year may occur between two wet years is indicated by the record of 36.02 inches in 1909, 16.89 inches in 1910, and 34.57 inches in 1911. Precipitation during 1944 was 25 per cent above normal and ground water storage in the Big Sioux and Skunk Creek Valleys increased accordingly. The precipitation by months from 1940 through 1944 is shown in Figure 10.

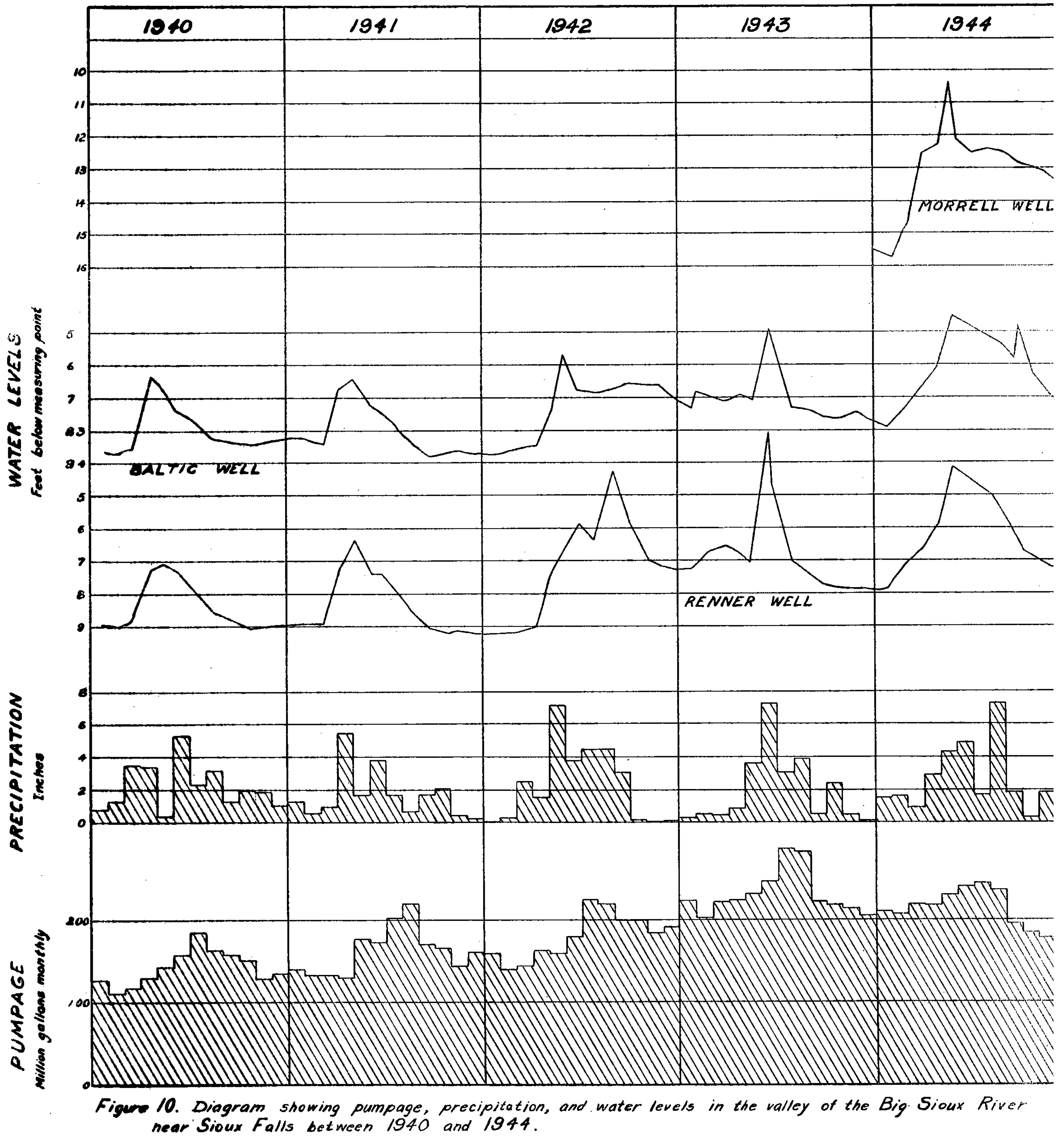


Figure 10. Diagram showing pumpage, precipitation, and water levels in the valley of the Big Sioux River near Sioux Falls between 1940 and 1944.

Annual Precipitation at Sioux Falls from 1891 to 1944

Year	Precipitation (inches)	Year	Precipitation (inches)	Year	Precipitation (inches)	Year	Precipitation (inches)
		1904	20.07	1918	25.62	1932	27.65
1891	18.75	1905	35.53	1919	27.88	1933	20.73
1892	23.88	1906	32.88	1920	32.89	1934	24.61
1893	22.33	1907	29.68	1921	24.18	1935	32.25
1894	10.44	1908	33.04	1922	23.10	1936	25.28
1895	20.28	1909	36.02	1923	29.23	1937	27.65
1896	30.07	1910	16.89	1924	20.28	1938	29.43
1897	25.54	1911	34.57	1925	20.04	1939	25.33
1898	26.89	1912	24.63	1926	24.64	1940	26.64
1899	29.00	1913	26.96	1927	23.95	1941	20.68
1900	29.06	1914	26.58	1928	26.23	1942	27.94
1901	22.53	1915	29.41	1929	34.09	1943	23.45
1902	25.92	1916	22.26	1930	23.76	1944	32.21
1903	30.90	1917	19.45	1931	17.73		

Average Monthly Precipitation at Sioux Falls
Based on 54 Years of Records, 1891 to 1944

Month	Average (inches)	Month	Average (inches)
January	.66	July	3.15
February	.73	August	3.28
March	1.29	September	2.58
April	2.61	October	1.52
May	3.82	November	1.04
June	4.34	December	.71

RECHARGE

If it were possible to conserve and utilize all the water that falls in the form of rain and snow, very few municipalities in a zone receiving annually 20 to 30 inches of precipitation would have serious water supply problems. However, much of this water is lost through evaporation, transpiration and unutilized stream flow. The results of this investigation have indicated that were it not for the presence of the Big Sioux River, which recharges the gravels underlying the well field, serious water supply problems would have confronted the city long ago.

Recharge as Indicated by Water Level Fluctuations

A study of all the hydrologic data concerning the Sioux Falls area makes possible some quantitative conclusions concerning the amount of ground water recharge in the Big Sioux Valley between the quartzite barrier south of the well field and the town of Baltic. Figure 10 shows that in the five year period from 1940 to 1944 the cumulative rise of the water level in Well 24 (Baltic well) averaged about 3.1 feet per year and the cumulative rise in Well 42 (Renner well) averaged about 4.1 feet per year. For the two wells this is an average cumulative rise of about 3.6 feet per year. However, a considerable part of this ground water increment is soon discharged into the river and during the summer months additional amounts are lost through transpiration. The hydrograph of the Renner well (No. 42) shows that during May and June, 1943, the water level rose 4 feet within about 30 days and then abruptly declined so that by the end of July the level had dropped to about the same altitude as prior to the sudden rise in May. Since there is no heavy pumping in the vicinity of this well the loss in storage represented by this decline is attributed to the drainage from the gravels into the surface streams and to transpiration and evaporation from the soil.

Recharge from the Big Sioux River

Considerable data have been accumulated to show that the Big Sioux River is a source of recharge to the Sioux Falls well field, and the county drainage ditch No. 1 functions in a like manner during at least eight months of the year. The basis for this conclusion is as follows:

(1) An examination of figure 11 shows that the water table averaged 8 feet lower in the well field than the water level in the straightened and deepened channel of the Big Sioux. Therefore, the water is moving from the river to the well field unless it is prevented from doing so by an impervious, silty river bottom, in which case it comes entirely from the other side, passing beneath the bed of the stream. It has been definitely ascertained that in the southwest corner of Section 7, T. 101 N., R. 49 W., about 1000 feet north of the bridge on State Highway 38, the river bed is composed of coarse gravel and sand. On January 7, 1945, four samples of this material were obtained through holes cut in the ice. Moreover, sand and gravel bars have been observed in at least a dozen places along the river channel between Sioux Falls and Baltic. It appears, therefore, that the present river bottom is composed largely of sand and gravel, though in some places it may be underlain by less permeable material.

(2) A study of the data in table VII indicates that the decline of water levels in wells in the adjoining well field is

considerably less than that which would be expected if the major portion of the ground water were obtained through a decrease in storage in the aquifer. From August 2, 1945, to December 26, 1945, the water level in Well 66 declined only 1.68 feet, and the level in Well 109 declined only 1.50 feet. The significance of these and other water level measurements are discussed further in the section of the report dealing with the well field.

The source of water for the Sioux Falls well field is thus twofold, although it is not possible to separate accurately the amount of recharge which occurs as a direct result of precipitation on the valley walls and floor from the amount of recharge which occurs through infiltration from the Big Sioux River near the well field. It is evident, however, that the source of a considerable portion of the Sioux Falls supply is run-off derived from the entire drainage basin of the Big Sioux above Sioux Falls, which comprises about 5,100 square miles as measured above the junction of Skunk Creek and the Big Sioux River in the southwest part of the city. There are very few measurements of river flow above the well field. The U.S. Geological Survey, in cooperation with various state agencies, has maintained a gaging station at the south end of the city, but this station has been in operation only since August, 1943. The record shows that during the year ending September 30, 1944, the total flow past the gaging station was about 115 billion gallons, or an average flow of about 315 million gallons per day. Since this quantity represents the combined flow of Skunk Creek and the Big Sioux River, the flow down the Big Sioux exclusive of Skunk Creek is somewhat less. However, 1944 was a year of higher than average precipitation. The minimum daily recorded flow of 34 cubic feet per second (22 million gallons per day) occurred during January. It has been reported, however, that during a drouth period in the middle of the last decade there was no flow in part of the channel below the well field. A study of the water table map (figure 11) and a review of the studies made by other investigators indicate that the major part of the water removed from the Sioux Falls well field is derived by recharge from the Big Sioux River and the county drainage ditch, although substantial contributions are also received by infiltration of rain and snow water in the well field and the underflow down the valley through the gravels. The role of the Big Sioux River in the water supply of Sioux Falls is that of an aqueduct conveying the water from the other parts of the drainage basin to the site of the well field.

NATURAL WATER LOSSES

Any shallow aquifer such as that formed by the valley gravels and sands between Sioux Falls and Baltic is subject to natural water losses resulting from transpiration and evaporation from the soil. Although it is possible to determine the amount of water lost by various species of plants by means of measuring devices and by other methods, (9) large errors are involved in attempting to apply this method to determine losses over large areas. However, a general method of estimating water losses can be used where sufficient data are available on surface run-off and on precipitation throughout a given drainage basin. Records of the flow of the Big Sioux at Akron, Iowa, have been maintained since October, 1928, and the precipitation records are available for a number of towns in the drainage area above that point. From these records the natural water losses in the vicinity of Sioux Falls have been estimated to average about 22 inches per year (19). A rough computation on the basis of more recent data shows that the natural water loss for the Big Sioux drainage basin amounted to about 20 inches in the water year 1940-41 and to about 28 inches in the water year 1941-42. On the basis of a loss of 22 inches of water a year, the loss in one year amounts to about 10 billion gallons in the 27 square miles of valley deposits between Sioux Falls and Baltic.

POROSITY AND SPECIFIC YIELD OF THE VALLEY DEPOSITS

As a preliminary to the discussion on the porosity and specific yield of the valley deposits, the following definitions of some of the terms used in this report are given:

(1) The <u>porosity</u> of a rock is its property of containing interstices. It is expressed quantitatively as the percentage of the total volume of the rock that is occupied by interstices, or the percentage that is not occupied by solid rock material.

(2) The <u>specific yield</u> is the percentage by volume of water that a formation will yield upon draining by gravity. Under water table conditions the specific yield is essentially the same as the ultimate value of the "coefficient of storage."

(3) The <u>specific retention</u> is the percentage by volume of the rock that is occupied by water after draining by gravity.

(4) The <u>effective grain size</u> is the diameter of a grain of such size that 10% of the material, by weight, consists of smaller grains and 90% of larger grains.

(5) The <u>uniformity coefficient</u> is the ratio of the diameter of a grain that has 60%, by weight, of the sample finer than itself to the diameter of a grain that has 10% finer than itself.

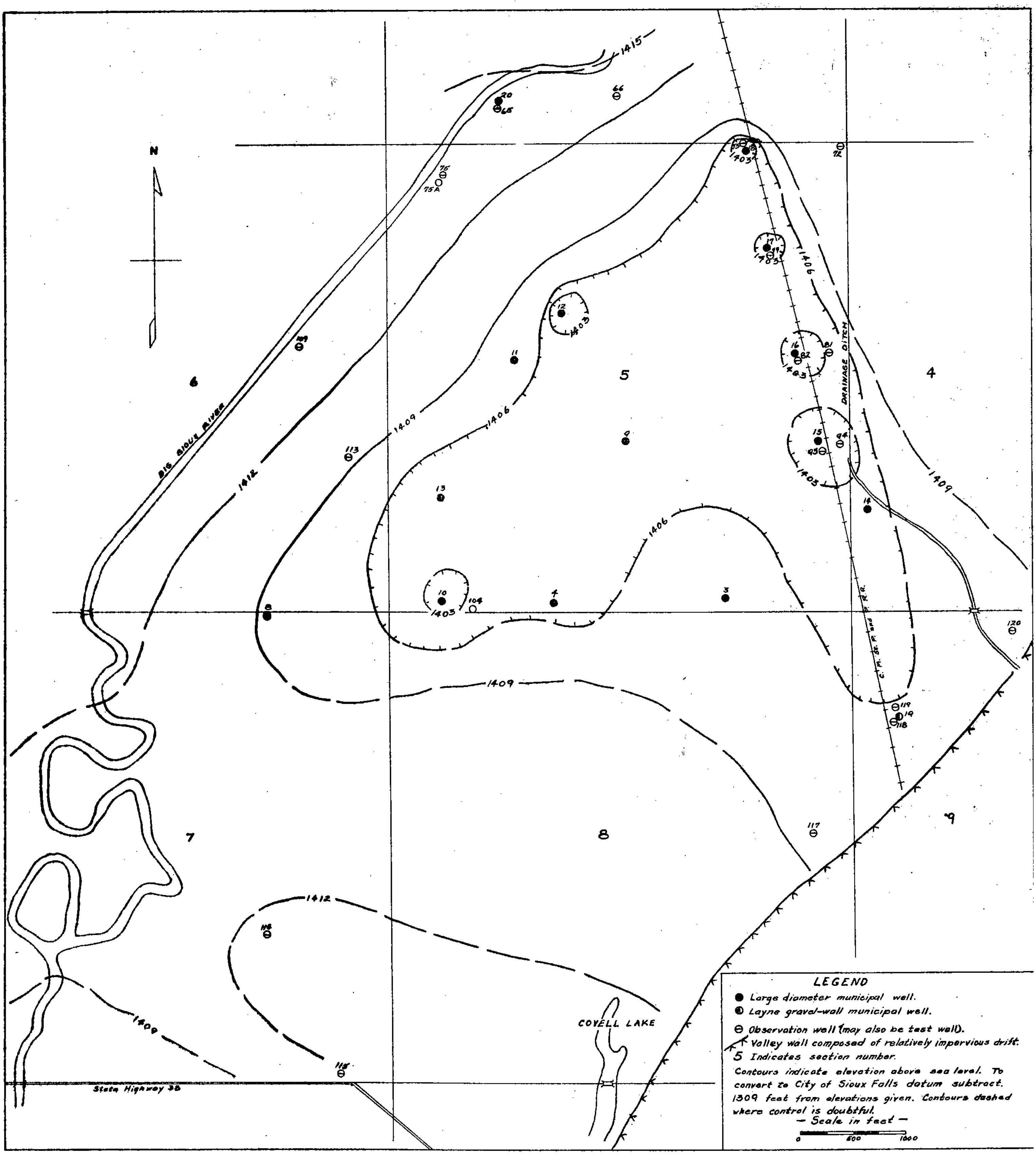


Figure 11. Insert map of the Sioux Falls well field contoured on the water-table surface for February 8, 1945. Contours not shown below 1403 feet. For key to well numbers see table.

During 1943 a number of samples of material were collected during the drilling of over 30 test wells in the Big Sioux Valley adjacent to and upstream from the well field. The logs of these wells and other pertinent data are given in tables I and IX. The South Dakota State Geological Survey made mechanical analyses of about 200 separate samples. The analyses were made to determine the percentages by weight of various sizes. The results of these analyses are presented in table II of this report. They show that for the most part the valley-fill material ranges in diameter from less than 0.06 mm. to about 4 mm. The greater proportion of the material would be classified as medium sand or larger, according to the usual system of size classifications. The classifications and corresponding diameters (in millimeters) used by the U.S. Geological Survey are as follows:

Fine gravel	2 to 1
Coarse sand	1 to 0.5
Medium sand	0.5 to 0.25
Fine sand	0.25 to 0.1
Very fine sand	0.1 to 0.05
Silt	0.05 to 0.005
Clay	less than 0.005

The mechanical analyses were used to determine the approximate porosity and specific yield of the gravels (8). There are various methods by which the porosity may be determined. The methods most commonly used involve direct laboratory determinations of the samples to be tested (18). However, in view of the limitations of time and personnel a method was selected to permit determining porosity and specific yield by indirect means. It has been noted by various observers (8) that a relationship exists between the uniformity coefficient of a sediment and the porosity and that this relationship is independent of absolute size. Accordingly, the uniformity coefficient was determined for 38 samples from the top zones in test wells drilled between Sioux Falls and Baltic. These uniformity coefficients were compared with published data (8) which shows that the porosity of a sample decreases with an increase in the uniformity coefficient. Although this method ignores the factor of compaction as an influence upon porosity, it is believed that the effect of compaction is relatively unimportant in the shallow Pleistocene gravels of the Big Sioux Valley.

Although the porosity of a sediment determines the maximum quantity of water that can be stored within it, this water is seldom, if ever, entirely removed even after long periods of draining. To obtain an approximate value for the amount of water that can be retained by the sands and gravels of the aquifer near Sioux Falls, use was made of the relationship between the effective grain size of a sample and the specific retention of similar samples as determined by laboratory means (8). This method is believed to be accurate within a few per cent, which is near the limit of error of laboratory work. The effective grain size was determined for the same samples for which the porosity had already been determined. By comparison with published data (8) the specific retention of the individual samples was determined. The results of this work are presented in the following table. It is to be noted that the samples selected were from 21 test wells located north of the well field, as far as Baltic. The samples came from depths ranging from 8 to 30 feet and the average depth of the samples used was slightly over 16 feet. Samples Nos. 6, 12 and 23 had porosities of 40 to 45 per cent, but the general lower limit of porosity was about 34 per cent and the general upper limit, about 38½ per cent. The average specific retention for the 38 samples was 8½ per cent. The specific yield is computed by subtracting the specific retention from the porosity. The samples that were tested are from relatively shallow depths and are doubtless somewhat finer grained and lower in specific yield than the deeper deposits. In this report a specific yield of 30 per cent has been used as a basis of calculation for problems involving unwatering of the valley deposits.

The southern boundary of the Big Sioux ground water reservoir is formed by the quartzite barrier in the south part of Sections 7, 8 and 12 in Sioux Falls township; the northern boundary is considered to be the road leading west from Baltic. Thus the reservoir is about 13 miles long. It is bounded on the east and west by the valley walls of glacial drift and has an average width of about two miles throughout the portion considered in this survey. With a specific yield of 30 per cent, computations indicate an average storage capacity of free water of about 62 million gallons per square mile for each foot of depth of the saturated aquifer or a volume equal to the pumpage for Sioux Falls during 9 average days of 1944. On the basis of 25 feet of thickness of saturated aquifer there are about 40 billion gallons of free water in storage in the entire ground water reservoir. This quantity is about 16 times the total pumpage by the city in 1944. Most of this water is, of course, not readily available to the public supply because of its distance from Sioux Falls. Moreover, it is not possible to remove more than a part of the free water from storage by means of wells. The water table rises sharply receding from each well and therefore cannot be lowered beyond a certain average level depending upon the number and spacing of wells and their effective diameters. Further limitations are imposed by economic considerations as to the number and size of wells that can be constructed.

An estimate was made of the volume of water that could be withdrawn from storage by the existing wells during a period when

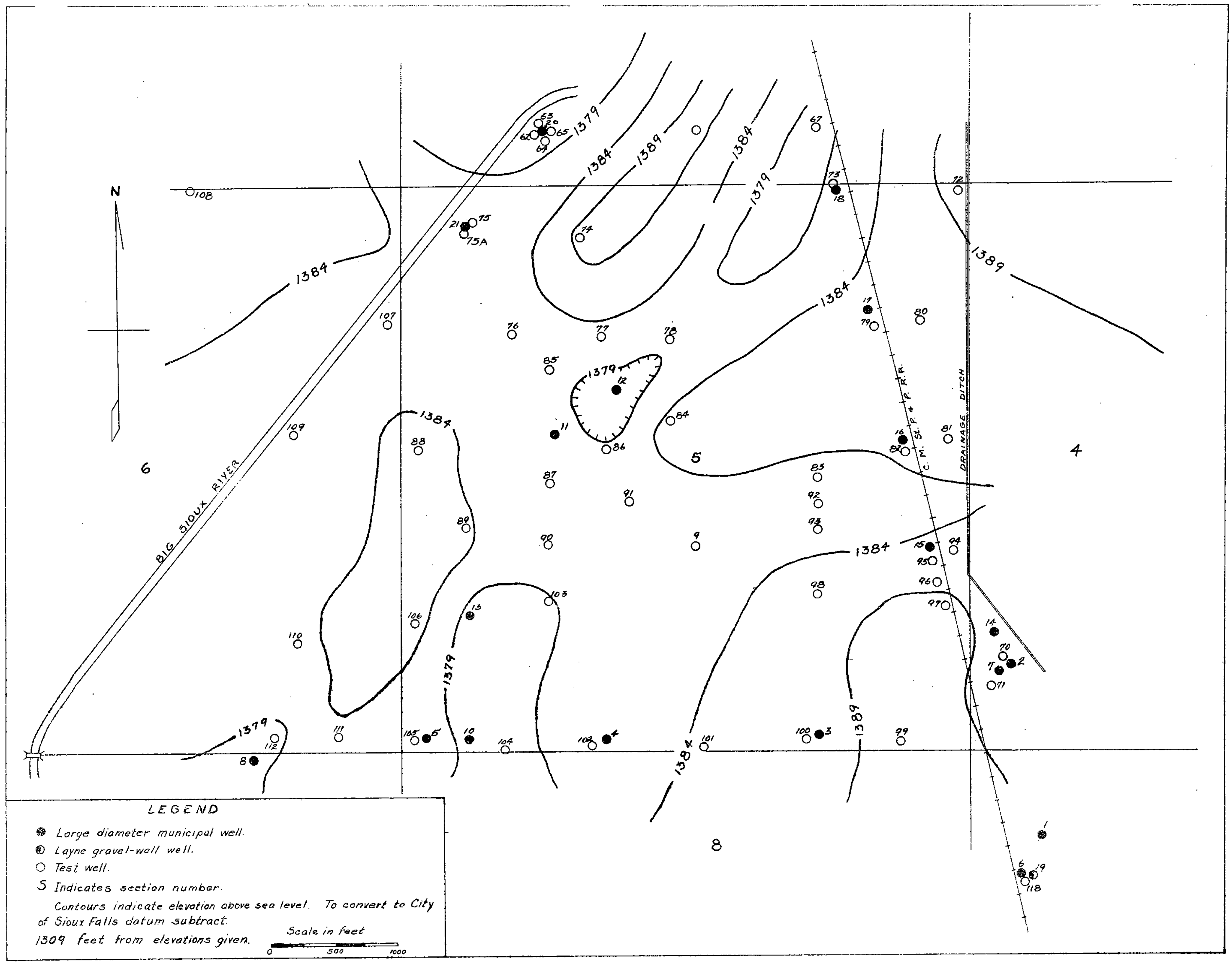


Figure 12. Insert map contoured on top of the basal Pleistocene clay in the vicinity of the Sioux Falls well field. For information on wells refer to table.

Physical Properties of Materials in the Big Sioux Valley
As Determined from Mechanical Analyses of Well Samples

See text for definition of terms

Sample Number	Number	Depth of sample (feet)	Uniformity coefficient	Effective grain size (mm.)	Porosity (approx.) %	Specific retention %	Specific yield %
1	25	15	6.8	.35	34-38	9	25-29
2	27	14	4.1	.27	37-40	9	28-31
3	33	10	10.2	.37	30-35	8	22-27
4	35	12	2.6	.25	39-44	9	30-35
5	44	10	5.0	.43	35-39	8	27-31
6	44	25	2.0	.23	40-45	10	30-35
7	52	10	6.3	1.20	34-38	7	27-31
8	52	12	5.0	.52	35-39	8	28-31
9	52	15	4.7	.40	36-39	8	28-31
10	53	8	3.1	.24	38-41	10	28-31
11	53	13	8.9	.37	30-36	9	21-27
12	53	18	1.9	.11	41-45	13	27-32
13	56	17	4.9	.64	35-39	8	27-31
14	56	20	7.7	.51	32-36	8	24-28
15	58	13	9.4	.52	30-36	8	22-28
16	58	17	2.9	.31	38-41	9	29-32
17	66	19	7.1	.51	33-37	8	25-29
18	66	21	3.8	.80	38-40	8	30-32
19	69	10	6.5	.27	33-37	9	24-28
20	69	15	5.5	.42	35-39	8	27-31
21	72	12	7.4	.28	32-26	9	23-27
22	72	18	8.5	.39	30-36	8	22-28
23	74	10	1.9	.27	41-45	9	32-36
24	74	14	6.2	.48	34-38	8	26-30
25	74	20	4.8	.90	36-39	7	29-32
26	75	11	3.2	.26	38-41	9	29-32
27	75	17	8.7	.40	30-36	8	22-28
28	79	19	7.9	.47	32-35	8	24-27
29	80	20	12.6	.36	20-30	9	11-21
30	82	19½	10.0	.21	30-35	10	20-25
31	82	24	5.8	.84	34-39	7	27-32
32	82	28	7.8	.54	32-36	8	24-28
33	88	19	7.8	.37	32-36	9	23-27
34	108	11	2.6	.26	39-43	9	30-34
35	108	13	9.0	.19	30-38	10	20-28
36	108	18	5.8	.29	35-39	9	26-30
37	108	25	3.9	.87	37-40	7	30-33
38	108	30	5.5	.45	35-39	8	27-31

the river would be dry, assuming that the wells were all pumped simultaneously with their water levels drawn down to the tops of the ports. Data given in the table show that when the wells were tested individually during this investigation, the pumping levels were on the average about 8 feet above the tops of the ports. It is reasonable to assume that through continuous operation of all the wells the water table could eventually be lowered 8 feet on the average over an area of about two square miles. That amount of lowering would yield approximately one billion gallons of water from storage. Inasmuch as the sum of the individual well capacities is nearly 20 mgd, the system could sustain a continuous withdrawal at the present rate of consumption during the early part of a protracted dry period in which there would be no recharge from local precipitation or the river. If the drought were to continue, however, interference among the several wells would increase to the extent that eventually the combined capacity of the wells would fall below the present rate of consumption. After a few months without recharge it would become necessary to sink additional wells outside of the depleted area in order to obtain more stored ground water. The depletion would develop gradually and with proper observations, there would be ample time to sink additional wells before a shortage in supply would occur.

PERMEABILITY OF THE VALLEY DEPOSITS

During the course of the present investigation five pumping tests were conducted on producing wells in the Sioux Falls well field and on two six-inch test wells--Nos. 50 and 160. The purpose of these tests was threefold; first, to determine the permeability of the aquifer in the vicinity of the pumped well; second, to learn the extent of interference between the existing large-diameter wells; and third, to obtain data on the specific capacity of individual wells. The last two items are discussed later in this report.

The sections which follow deal with the definitions of terms relating to the permeability of water bearing materials, the methods which were used in this investigation to determine the permeability of the valley deposits and the significance of such determinations.

Definition of Terms

The hydraulic permeability of a porous material is the characteristic property by virtue of which it allows the transmission of water or other fluids through its interstices (9). The degree of this property is generally expressed by a coefficient of permeability. The "field coefficient of permeability" is expressed as the rate of flow of water, in gallons per day, through each foot of thickness of a given aquifer, with a width of one mile, and with a hydraulic gradient of one foot per mile. The standard coefficient of permeability is the same as the field coefficient except that a correction is applied to convert the flow of water to that which would occur at 60° F. The coefficient of transmissibility is the field coefficient of permeability multiplied by the thickness of the saturated portion of the aquifer.

Laboratory Tests to Determine Permeability

A number of samples of material from the drilled wells were tested in the laboratory to determine their capacity to transmit water. In the apparatus the material to be tested is placed in a small brass cylinder which is attached to one end of a U-tube, the opposite end of which is fastened to a graduated glass cylinder. The water percolates upward through the sample under a variable head. A more complete description of this apparatus can be found in U.S. Geological Survey Water Supply Paper 887 (18). Most of the samples tested came from wells drilled in the valley of Skunk Creek because only one pumping test of short duration was conducted in this valley. The results of the laboratory tests are as follows:

Results of Laboratory Tests on Materials from Wells Drilled in the Valley Deposits Near Sioux Falls

Sample number	Well number	Depth at which sample was taken (feet)	Standard coefficient of permeability gpd/ft^2
1	75A	12	3320
2	75A	20	7260
3	75A	25	1580
4	75A	30	2300
5	75A	35	1930
6	75A	39-40	1860
7	174	9-10	3270
8	174	15	630
9	174	25	3020
10	174	30	5470
11	173	5	3770
12	173	10	14800
13	173	15	5180
14	177	20	5480
15	177	25	740
16	177	30	1190
17	177	40	4490
18	177	50	5260
19	177	55	6260
20	177	65	1610

An average coefficient of permeability of 4,080 gpd per square foot was obtained from the laboratory tests on six samples from well 75A, located in the Sioux Falls well field, and an average coefficient of permeability of 4,370 gpd per square foot was obtained from the laboratory tests on the 14 samples from the wells in the Skunk Creek valley listed above.

Permeability as Determined by Pumping Tests

Because of inherent limitations in the laboratory determination of permeability of the valley materials, use was made of procedures utilizing the measured drawdowns in one or more observation wells near a pumped well for which discharge measurements are available. The main advantages of this method are (1) that the material composing the aquifer remains in its original condition, and (2) that the properties of the aquifer are determined as a unit, at least in the vicinity of the well tested.

Certain assumptions and conditions are necessary to satisfy the theoretical requirements of the method. The effect of the absence of these idealized conditions has been discussed by various investigators (18). The factors adversely affecting the results can be summarized as follows: (1) heterogeneity of the materials composing the aquifer, (2) recharge to the aquifer which may have occurred during the test in the vicinity of some of the wells upon which observations are made, and (3) partial penetration of the aquifer by the pumped well or the observation wells. A detailed analysis of the development and formulation of these tests can be obtained by consulting U.S. Geological Survey Water Supply Paper 887.

Two general methods were used in computing the coefficients of transmissibility and permeability from the data obtained in pumping tests. One of these in known as the Theis graphical method, which has been modified for use in pumping tests made under water table conditions. The formula for this method is as follows:

$$T = 2.30\ Q/2\ s'$$

in which T is the coefficient of transmissibility of the aquifer; Q is the discharge from the pumped well measured in gallons per day and s' is the change in drawdown in feet over one logarithmic cycle of the distance scale on a semi-logarithmic graph on which adjusted drawdowns are plotted against $\log_{10} r$. The other general method is known as the Recovery method, the formula for which is as follows:

$$T = \frac{Q}{4\ s'} \log_{10} \frac{t}{t'}$$

in which s' if the residual drawdown in feet, t is the time since pumping began, in any unit, and t' is the time since pumping stopped, expressed in the same unit.

Pumping Tests of Individual Wells

During the fall of 1944 several observation wells were put down near test wells 50, 160 and Sioux Falls public supply wells 10, 19 and 20. Most of these observation wells were constructed by driving a $1\frac{1}{4}$ inch pipe, headed by a well-point and bronze screen, nearly to the base of the valley deposits. Wherever existing 6 inch wells were available these were also used as observation wells. Pumping from Wells 50 and 160 was by means of a portable gasoline-powered centrifugal pump. Discharge from this pump was measured volumetrically by means of a stop watch and a 54 gallon steel drum. Pumping from the public supply wells was by means of electrically driven turbine pumps, and discharge measurements were obtained from propellor type flow meters. With the exception of Well 20, the water was pumped into the service line leading to the filter plant.

Well 10.--A detailed test was made on Well 10 from November 6 to 10, 1944. The well was pumped continuously for 61 hours and 6 minutes, and periodic measurements were made of the water level in the pumped well and in 10 observation wells during and after the pumping. The water levels in four of these 10 wells were not noticeably affected by the pumping of Well 10, but noticeable drawdowns were observed in the six observation wells located within 350 feet of the pumped well. Below are listed the diameters and depths of these six observation wells and their distances from the center of the pumped well.

Records of Six Observation Wells
Used in the Pumping Test on Well 10

Well	Diameter (inches)	Depth (feet)	Distance from center well 10	Mode of construction
10A	$1\frac{1}{4}$	26	100	driven
10B	$1\frac{1}{4}$	29	50	driven
10C	$1\frac{1}{4}$	26	50	driven
10D	6	43	16	drilled
10E	$1\frac{1}{4}$	26	50	driven
104	6	42	331	drilled

By means of computations based on the Theis graphical method modified for use under water table conditions, the transmissibility of the aquifer in the vicinity of Well 10 was computed to be 180,000 gpd per foot. There were $27\frac{1}{2}$ feet of saturated sands and gravels in the vicinity of the well. Thus the field coefficient of permeability is determined to be 6,700 gpd per square foot. The average pumpage during this test was 890 gallons per minute, and the drawdowns in observation wells used as a basis for computations were those measured 36 hours after pumping was begun. These measurements are not presented in this report, but interested persons may obtain this information from the files of the U.S. Geological Survey. On the basis of calculations involving the use of the recovery formula and on water level measurements made on the pumped well after pumping stopped a transmissibility of about 100,000 gpd per foot was obtained. The discrepancy between the two coefficients can be explained by the fact that the wide diameter of the pumped well influences the recovery of the water level in the pumped well. The effect of this is to introduce a factor of 100 per cent porosity within the estimated 8,700 cubic feet of aquifer displaced by the well.

Well 16.--Beginning on November 19, 1944, Well 16 was pumped continuously for over 48 hours, during which time measurements were made of the water level in the well and of the discharge from the well for the purpose of obtaining the specific capacity of the well. At the completion of this test the pumping was stopped and an automatic water stage recorder was installed to measure the recovery of the water level in the well. Through the use of the recovery formula, the coefficient of transmissibility in the vicinity of this well was computed to be 83,000 gpd per foot and the field coefficient of permeability, 5,500 gpd per square foot. It is interesting to note that these results are lower than those obtained from the test on Well 10. It was not possible to compute the transmissibility by means of the Theis graphical method in the vicinity of this well.

Well 18.--Well 18 was pumped continuously for over 26 hours on November 3 and 4, 1944, and the drawdowns in the pumped well and three 6 inch observation wells were measured during the test. Based on the observation drawdowns of the water levels in two observation wells (numbers 72 and 73) and on an average pumpage of 1,084 gallons per minute, computations indicate that the transmissibility in the vicinity of this well is about 180,000 gpd per foot and the permeability is about 8,000 gpd per square foot. These calculations were made by means of the Theis graphical method. The recovery of the water level in Well 18 was not measured.

Well 19.--Well 19 was pumped continuously for 36 hours at an average rate of 410 gallons per minute, and the drawdowns of water level were measured in two observation wells located 48 and 100 feet from the pumped well. On the basis of drawdowns as measured in the two observation wells near the end of the period of pumping, the coefficient of transmissibility was computed by the Theis graphical method to be 49,000 gpd per foot. However, the drawdown measured in the nearest observation well (No. 118) was apparently affected by the existence of the old, abandoned public supply Well No. 1. This well is located only a few feet west of Well 118 and the debris-filled cement casing of this well acted as a barrier to the normal flow of ground water to Well 19. Calculations based on the recovery of the water level in the pumped well indicate a transmissibility to be 76,000 gpd per foot and a permeability 3,700 gpd per square foot. In the case of this well, the coefficient of transmissibility computed by the recovery method is probably more nearly correct than that based on the drawdown of water level in the two observation wells. Both methods of computation show that the deposits in the vicinity of Well 19 are not as permeable as those in other parts of the well field.

Well 20.--A pumping test was made on Well 20 from April 2 to 4, 1945. The well was pumped continuously for 47 hours and 35 minutes at an average rate of 1311 gallons per minute. Drawdowns of the water level were measured at approximately four-hour intervals in four nearby observation wells (Nos. 62, 63, 64 and 65) and in the pumped well during the test. A few measurements were made during the test of the water level in Wells 66 and 75. The depths, dimensions and types of construction of these wells are given in table IX. A compilation of the drawdown measurements in these wells is not given in this report.

The data from this test were analyzed and studied by P.D. Akin, of the U.S. Geological Survey, and on the basis of computations involving the use of the equilibrium and non-equilibrium formulas, coefficients of transmissibility were obtained which range from 106,000 to 171,000 gpd per foot. The average of all the coefficients determined was 155,000 gpd per foot. The nature of the drawdown curves, especially for Well 63, suggests that the volume of water derived from the river was small. This does not indicate that Well 20 is not receiving any water from the river or that it will not receive a considerable part of its water from the river after prolonged pumping, but it does indicate that the conditions along the river are such that seepage from the river to the ground water near the well occurs very slowly in the immediate vicinity of the well. This test indicates that some silting may have occurred in the river bottom adjacent to Well 20.

Well 50 (Test well C-3)--This well was drilled to a depth of 38 feet and the casing was pulled back to 30 feet in the spring of 1943. In September, 1944, a few cubic feet of gravel was placed in the casing and a 3 foot, 50 slot iron screen was lowered in the well and the casing pulled back sufficiently far to leave the base of the well screen at a depth of 26½ feet below the surface. Four temporary observation wells were constructed on an east-west line from this well. Two of these wells were 1¼ inch drive-point wells located 20 and 50 feet west of Well 50. The remaining two wells were 5 inch bored wells located 20 and 50 feet east of Well 50. The well adjacent to Well 50 was bored to a depth of 12 feet and the easternmost well to a depth of 15 feet.

This well was pumped with a small portable pump for 12 hours and 9 minutes at an average rate of 52 gallons per minute. Periodic measurements were made of the discharge and of the water levels in the pumped and observation wells during this time, and measurements were made of the recovery of the water level for several hours after pumping stopped. The tabulated measurements of these wells are not presented in this report but are available in the files of the U.S. Geological Survey. Calculations based on the Theis graphical procedure show the coefficient of transmissibility of the valley deposits to be about 135,000 gpd per foot and the field coefficient of permeability to be about 4,200 gpd per square foot. Calculations based on the use of the Recovery formula give a coefficient of transmissibility of 125,000 gpd per foot and a coefficient of permeability of 3,900 gpd per square foot.

Well 160 (Test well J-4).--Well 160 was pumped at an average rate of 57 gallons per minute for six hours and eight minutes on September 1, 1944. The gravel at the base of this well is beleived to be exceptionally permeable, as the well was not equipped with a screen nor was the casing punctured. The decline in water levels near the pumped well was measured in two bored observation wells located 25 to 65 feet southwest of Well 160. Drawdowns in the observation wells amounted to 0.38 foot and 0.05 foot respectively, after 6 hours of pumping. Calculations based on the Theis graphical method indicated the coefficient of permeability was about 10,000 gpd per square foot in the vicinity of this well. However, hydrologic conditions are not otherwise favorable for the development of large water supplies in the locality of this well. The total thickness of sand and gravel was 17 feet, of which 9 feet were saturated. The conclusions based on this test are discussed further in the section dealing with the potential water supplies of the Skunk Creek valley.

Significance of the Permeability Determinations

The results of the pumping tests indicate that the coefficients of permeability of the valley deposits of the Big Sioux ground water reservoir range from about 2,400 gpd per square foot (Well 19) to about 8,000 gpd per square foot (Well 18). The average coefficient of transmissibility in the part of the valley between the quartzite ridge and the town of Renner is believed to be about 150,000 gpd per foot. This means that with a gradient of one foot to the mile 150,000 gallons per day would flow through a strip of the valley deposits one mile in width. This figure is based on the coefficients of transmissibility obtained from the several pumping tests and the laboratory tests on six samples from Well 46A. In view of the extensive preparation for and the duration of the pumping test on Well 10, the figure for average transmissibility was weighted in favor of the result obtained from this test.

The valley is approximately two miles wide in the stretch between the Sioux Falls well field and the town of Renner, and the hydraulic gradient averages about six feet per mile for the distance of four miles between the closed 1406 foot water table contour, as shown in figure 11 and the vicinity of Renner. Thus the water moved down the valley during the fall and winter of 1944 at the rate of about 1,800,000 gallons per day. Accordingly the underflow, under the gradient existing at that time, would have provided about 25 per cent of the pumpage during 1944. The pumped water not obtained by underflow came chiefly through recharge from precipitation in the vicinity of the well field and recharge from the Big Sioux River. Owing to the heavy precipitation in 1944 there was an increase in ground water storage during the year.

One of the most significant conclusions to be drawn from the above computations is that the present pumpage from the well field greatly exceeds the capacity of the valley deposits to transmit water from the upper stretches of the valley to the well field. Thus the role of the Big Sioux River is to conduct water to the present well field.

THE SIOUX FALLS WELL FIELD

The city of Sioux Falls has obtained its water since 1906 from large-diameter dug wells. Data concerning the dimensions of these wells is given in table IX along with information about some 170 additional wells in the vicinity of Sioux Falls. Of the nine public supply wells constructed prior to 1934, only four (Nos. 3, 4, 8 and 9) are now in use. Wells 1 and 2 were abandoned because of the clogging of the well screens with silt and sand and Wells 5, 6 and 7 were abandoned and filled because of their small yield. Wells 13, 14, 15, 16, 17, 18 and 20 are known as "Bragstad" wells after R.E. Bragstad, City Engineer. They possess unique features of construction. The diameter of these wells is 40 feet and the depth ranges between 35 and 40 feet. Near the base of each well are 18 ports, or openings, 2 feet in height and 4 feet in width. These ports are designed to admit water through a graded gravel envelope about 4 feet thick which surrounds the well from the base of the ports to the top of the well. The purpose of the gravel screen is to retain the fine sand and silt which collects in the bottom of the well and around the wall at the base of the well. The wells are so designed that the graded gravel can be bailed out from the center of the well and replaced by fresh gravel from the outside. The large diameter of the well and the existence of ports at the base of each well are features which permit the water to enter with a much lower velocity than could be obtained through small-diameter wells under the same limitation of a maximum depth of drawdown of about 20 feet. It is significant that the basal Pleistocene clay underlying the water bearing stratum of the well field is composed chiefly of ground up fragments of the Pierre shale, which occurs extensively under the glacial drift in areas to the north and west of Sioux Falls. Apparently there is a gradual tendency for material from this stratum to be forced upward during the removal of water from a well. This material forms a gray, silty "sludge" which causes a progressive clogging of the voids in the sands and gravels at the base of the wells and has resulted in decreased yield and eventual abandonment of several wells, as previously mentioned. Figure 15 shows a cross-section of a typical Bragstad well.

Specific Capacities of Individual Wells

During the course of the Sioux Falls investigation, tests were run on a number of the producing wells to determine their specific capacities, or discharge per unit of drawdown. The measurements of pump discharge were made by means of propellor-type meters installed in the discharge line of each well. These data should form the basis for comparison with future tests to learn of any progressive decrease in the efficiency of individual wells. They are presented in the following table:

Data from Pumping Tests of Municipal Supply Wells
Sioux Falls, South Dakota

Well	Date (1944 or 1945)	Duration	Total Pumpage (gals.)	Average Pumpage (gpm)	Maximum Drawdown (feet)
3	1/3 & 4	35 h., 49 m.	1,745,800	812	14.12
4	1/30 & 31	36 h., 24 m.	2,509,700	1,148	10.35
8	10/26 & 27	29 h., 35 m.	826,000	504	10.25
10	11/6, 7 & 8	61 h., 6 m.	3,265,000	890	18.5
13	4/2 & 3	26 h., 57 m.	955,400	590	7.5
15	11/19, 20 & 21	48 h., 42 m.	3,651,100	1,249	10.48
16	11/19, 20 & 21	48 h., 38 m.	2,969,000	1,017	8.4
17	11/3 & 4	27 h., 40 m.	1,922,000	1,201	9.48
18	11/3 & 4	26 h., 38 m.	1,738,000	1,084	8.8
19	1/3 & 4	36 h., 39 m.	905,000	410	11.2
20	4/2, 3 & 4	47 h., 35 m.	3,745,000	1,311	11.2

Data from Pumping Tests of Municipal Supply Wells
Sioux Falls, South Dakota

Specific Capacity gpm/ft.	Alt. of Wtr. Surface at End of Test (feet)	Altitude Top Well Ports (feet)	Difference	Water Temp. 11/20-22/44 (°F.)	Water Temp. 1/26/45 (°F.)
57	1391.0	1389.7 a/	1.3	50½	46
111	1386.6	1383 + a/	3.5	50½	51
49	1399.8	1380 ± a/	19 ±	49½	51
48	1388.1	1385 ±	3 ±	50½	50
79	1401.5	1389.0	12.5	---	--
119	1394.3	1387.2	7.1	55	53
121	1397.3	1390.7	6.7	--	55
126	1396.9	1393 ±	4 ±	50	51
122	1401.0	1392 ±	9 ±	50	50
36	1396 +	1392.0 b/	4 +	--	--
117	1404.7	1386 +	18 ±	57	

a/ Altitude base of well wall

b/ Altitude top of bronze screen

Additional Notes on Wells in the Preceding Table

Well No.	
3	Pumpage varied as much as 321 g.p.m. during test. The maximum measured pumpage was 978 g.p.m. and the minimum was 657 g.p.m. Variations in pumpage due mainly to changes in back-pressure in service line caused by intermittent use of other wells on the line. Measurements indicate that this well has only 1.3 feet of additional allowable drawdown.
4	Pumpage during test varied from 1078 g.p.m. to 1267 g.p.m. due to intermittent operation of other wells on line. Rated capacity reported at 725 g.p.m. 11/23/42.
8	Pumpage varied during test due to intermittent use of other wells on line. Capacity of well reported 800 g.p.m. 11/23/42. Pump replaced October, 1944.
10	Pumpage during test varied from high of 950 g.p.m. to low of 851 g.p.m. due to current variations and intermittent use of other wells on the line. Capacity of this well reported 600 g.p.m. 11/23/42.
13	Capacity reported to be 930 g.p.m., 11/23/42. Flow meter failed during last few hrs. of test. Pumpage varied from 719 g.p.m. to 529 g.p.m.
14	On January 30 and 31 a test was made on this well to determine its specific capacity. However, due to failure of the flow meter to function properly the results of the test were inconclusive. Measurements made during the test showed a drawdown of 8.18 feet after 36 hours of pumping during which time the well is believed to have yielded 1000 to 1200 g.p.m. Water temperature on Nov. 21, 1944, 55° F.; on Jan. 26, 1945, 52° F.
15	Pumpage during test varied from 1278 g.p.m. to 1187 g.p.m. due mainly to intermittent use of other wells on line.
16	Pumpage varied during test from 1,070 g.p.m. to 889 g.p.m. due to intermittent use of other wells on the line.

17	Pumpage during this test varied from 1,201 g.p.m. to 1,190 g.p.m. Data suggests a decrease in efficiency of about 600 g.p.m., during the 14 months between the two tests although the decrease in pumping rate may be due to a throttling of the discharge line since the first test.
18	Pumpage varied during test from 1,112 g.p.m. to 1,048 g.p.m. due to intermittent use of other wells on line.
19	Pumpage varied during the test from 429 g.p.m. to 392 g.p.m.
20	Well tested with open discharge. Pumpage varied from 1350 to 1298 g.p.m. Well expected to pump at lower rate when discharging into service line.

On the records of the specific-capacity tests given in the foregoing table and previous ratings given for wells not tested, the total capacity of the 14 wells in the field (exclusive of Well 11) was 13,800 gallons per minute, or 19,800,000 gallons per day, as of April, 1945. Thus in April, 1945, the capacity was over 7 million gallons greater than the pumpage during the peak day of 1944. It should be noted, however, that this is the sum of capacities of individual wells operating separately. Interference would make the combined long-term capacity much smaller.

Interference between Wells

As a result of the detailed and extensive pumping test made on Well 10 during the period November 6 to 10, 1944, it is possible to arrive at definite conclusions concerning the interference caused by pumping two or more of the wells simultaneously. The use here of the term interference implies the decrease in yield of individual wells brought about as a result of the lowered head outside the well caused by the spread of the cone of depression of a nearby well or wells. A different type of interference occurs when several wells discharge water into the same conduit. An increase in the number of pumps forcing water into the conduit causes an increase of pressure in the line and results in a decreased yield from each pump. It was difficult to prevent this latter type of interference from occurring during the tests conducted on the Sioux Falls wells, although it was possible to control it to a certain extent.

Well 10 was pumped continuously for 61 hours during the test. During this entire period the water level in Well 8, located approximately 1700 feet west of Well 10, continued to rise slowly after having been shut off two days previous to the start of the test. Measurements showed this rise to be 0.16 foot. The water level in Well 13, located approximately 1,000 feet north of Well 10, showed a net rise during the test of 0.15 foot. Pumping from this well was also stopped two days prior to the beginning of the test. The water level in Well 4, located approximately 1,100 feet east of Well 10, rose 0.65 foot during the test. Pumping from this well was also stopped two days before the beginning of the test on Well 10. The water level in Well 104, located 331 feet east of Well 10, dropped only 0.65 foot after 61 hours of pumping from Well 10. The changes in the water level of Well 10 and the adjacent observation wells are shown graphically in figure 14.

On the basis of the test of Well 10 and the high specific yield of the aquifer as determined from the well samples, it is concluded that the present well spacing is adequate and that interference between existing wells is small and is developed only after long pumping.

On the basis of the pumping tests, the permeability determinations, the measurements of the altitudes of the top of the well ports and an examination of figures 7 and 12 it is possible to plan the pumpage from various wells in the Sioux Falls well field so that the general cone of depression of the water table within the field is spread uniformly through the field and not steepened excessively near a few wells. A study of the map showing the altitude of the water table in the well field on February 8, 1945, (figure 11) reveals that the deepest part of this cone is in the vicinity of Well 15 and extends north along Wells 16, 17 and 18 and south almost to Well 19. Based on their specific capacities, Wells 14, 15, 16, 17, 18 and 20 are the best wells in the field, and during 1944 these wells delivered most of the water pumped from the field.

Because of their proximity to the drainage ditch, Wells 14, 15, 16, 17 and 18 are well located to induce infiltration of water from the ditch. The flow of this ditch is believed to be very effective in recharging this part of the well field throughout at least 8 months of the year. Some observations made in mid-February, 1945, however, showed that the water in the ditch was frozen and that there was no surface flow down this portion of the ditch at that time.

Well 16 can be depended upon to yield large quantities of water for some time to come. Although Well 17 had only 4 feet of additional allowable drawdown this well was observed to have the highest specific capacity of any of the wells tested. The fact that Well 18 is situated near the north end of the cone of depression of the field and had over 9 feet of additional allowable drawdown indicated that this well can be counted upon to deliver large volumes of water for rather long intervals of time. Wells 3 and 4, situated in the general cone of depression, may be among the first to fail if they are pumped heavily during a period of declining water levels. Well 10 is more favorably situated than Wells 3 or 4, but its yield will be affected by heavy pumping from Wells 13, 8 and 4 during a period of declining water levels. Well 8 is located a considerable distance from the center of pumping of the well field and its yield will not be appreciably affected by the pumping from the other wells.

In the section on the quality of water mention is made of effect on the hardness caused by heavy pumping from Wells 14, 15, 16 and 20. Heavy pumping of these wells during the spring and summer will decrease the hardness of the water, although such a decrease will probably not be noticed by the ordinary consumer of the water.

Data presented in table VI show that the temperature of the water in the Big Sioux River reached a maximum of 88° F. on July 23, 1941. Based on weekly measurements, the average temperature of the river water was 74° F. for the months of May, June, July, August and September, 1941. The temperature of the water in Wells 14 and 15 was 55° F. when measured on November 21, 1944, or about 5° F. higher than the average ground water temperature for the area. The temperature in Well 20 was 57° F. at that time although this well had not been pumped since its completion. The temperature of the water in these wells may have been slightly higher during the summer months. To prevent the water from reaching an undesirably high temperature in the later part of the summer it may become necessary to limit the amount of water pumped from Wells 14, 15, 20 and the proposed Well 21.

Water Levels in the Well Field

The recorded measurements of water levels in the Sioux Falls well field are listed in chronological order in table VIII. The earliest of these measurements was made on Well 105 in 1921 and the latest measurements listed in the table were made in February, 1945. The records are not entirely comparable, but they indicate that the current water levels throughout the well field are about 3.7 feet lower than the water levels in 1921. If it is assumed that the withdrawal of water that caused this lowering occurred within an area of two square miles and that the specific yield is 30 per cent, only about 450 million gallons have been removed from storage. This is less than 20 per cent of the pumpage in 1944 and only a small fraction of the total pumpage during the entire period since 1921. The records indicate that the water levels have risen since 1942 and that conditions of ground water storage have improved even though the pumpage from the field has increased.

In August, 1944, a program of water level measurements in both pumped and non-pumped wells was inaugurated in the Sioux Falls well field. The record for Well 66 reveals that the lowest water level in the period from August 2, 1944, to April 2, 1945, occurred on February 5, 1945, and the highest on March 26, 1945. Thus the net change in water level of 2.80 feet occurred within less than two months. Since this well is over 1,000 feet from the nearest pumped wells, the fluctuations of the water level in the well are only slightly affected by the intermittent use of the nearest wells.

Well 109 is located within a few hundred feet of the Big Sioux River and the water levels observed in this well are affected more by the stages of the river than by pumpage from the field. The lowest measured level during the period August 2, 1944, to April 2, 1945, occurred on November 2, 1944, at which time the water level stood 9.53 feet below the measuring point. The highest occurred on March 5, 1945, at which time the water level was 4.47 feet below the measuring point. The net change of 5.11 feet was due chiefly to the effect of the flood stage of the nearby Big Sioux River. A dike constructed by the U.S. Army Engineers prevents the flood waters of the river from spreading eastward over the Army air field and the city well field, but the head created by such flood waters is effective in increasing the recharge to the well field and thus raising the water levels in the wells.

Well 104 is located about 300 feet east of Well 10 and within the 1,406 foot closed contour of the cone of depression around the well field (figure 11). The water level in this well showed a net rise of only 1.29 feet during the period of measurement from November 20, 1944, to April 2, 1945. Although this well is close to Well 10, measurements made during the pumping test on Well 10 from November 6 to November 10, 1944, showed a drop of only 0.65 feet in the water level of Well 104 after 61 hours of continuous pumping. Thus, even though the water level in Well 104 is affected somewhat by pumping from Well 10, it does not show the sudden and pronounced rises observed in the wells near the Big Sioux River.

The periodic measurement of the water levels in wells in the Sioux Falls well field should be continued for an indefinite period, although measurements need not be made in all the wells that were measured during the investigation. Weekly measurements should be made in Well 66 (Sioux Falls test well 42), Well 109 (Sioux Falls test well 51), and Well 104 (Sioux Falls test well 13, series 1922); monthly measurements should be made in the pumped wells Nos. 3, 9, 15 and 19. These wells should be shut down at least 48 hours prior to measuring their water level. The fulfillment of this program of water level measurements will assure an ample warning of any serious lowering of water levels before such a lowering will interfere drastically with the ability of the wells to yield water.

Undeveloped Resources

Factors to be considered when sites for additional wells are chosen in the Sioux Falls field include the thickness of the saturated part of the valley deposits, the permeability of the saturated deposits, the opportunity of inducing infiltration of surface water and the spacing of wells with respect to mutual interference.

A well placed 1000 to 1200 feet north of Well 18 would probably penetrate an optimum thickness of saturated gravel, but this site would not be adapted for inducing infiltration of surface water. Wells located on the sites of test holes 109 (Sioux Falls test hole 51) and 107 (Sioux Falls test hole 50) should be located favorably to intercept a part of the flow of the Big Sioux. For additional supplies test drilling might well be done along a northeast-southwest line on the west side of the river and within a quarter of a mile of the river, in the north one-half of Section 6, Sioux Falls township; also at a site located 800 to 1000 feet northeast of Well 20. The locality south of Wells 3, 4, 10 and 19 is not favorable for additional development but the locality between Well 8 and the river might be considered as a possible location for one or two additional supply wells.

It has already been explained that the Big Sioux ground water reservoir underlying the valley of the Big Sioux River extends northward to Baltic and Dell Rapids. Large additional water supplies can be developed in this stretch of the valley north of the present Sioux Falls well field for the public water works or for institutions or industries. Developments in Section 29 or the north half of Section 32, T. 102 N., R. 49 W., and farther north would not interfere seriously with the supply from the present well field, as the water would be derived chiefly by (1) local infiltration of rain and snow water that is otherwise discharged by evaporation and transpiration or by seepage into the river and (2) infiltration from the river in case of heavy pumping. The results of this investigation, however, show that considerable additional supplies can be developed in the area of the present well field, as above explained, if consideration is given to the proper spacing of wells and their location with reference to the river and drainage ditch.

QUALITY OF THE WATER

Analyses of raw ground water from wells in the valley deposits adjacent to Sioux Falls show that the water may be classed as a hard bicarbonate water containing objectionable quantities of both iron and manganese.

An iron removal plant with treatment consisting of chlorination, aeration, sedimentation and filtration was installed in 1922. Although this plant is effective in reducing the iron content of the water, the presence of manganese in the water still constitutes a problem. However, experiments have shown that the manganese content can successfully be reduced to such an extent that it is no longer objectionable. Treatment for the removal of manganese has been considered by the city along with the installation of a softening process.

Table IV presents the results of analyses of water from 18 wells, most of which are public supply wells of the city of Sioux Falls. The total hardness indicated for the public supply wells by these analyses ranges from a high of 588 parts per million (in Wells 4 and 10--analyses dated March 9, 1945, and Jan. 31, 1945, respectively) to a low of 276 parts per million (in Well 16--analysis dated August 11, 1943).

The maximum iron content of 6.4 parts per million was found in a sample from Well 9, analyzed on February 20, 1945. The fluoride content ranged from 0.1 to 0.4 parts per million in the 18 public supply wells for which analyses are available. This quantity is believed to be beneficial rather than detrimental.

Table V shows in chronological order the results of analyses of composite samples of the Sioux Falls public supply. It shows the important fact that the use of the new public supply wells has resulted in softer and less highly mineralized water. The footnotes following tables IV and V give the date when the recently constructed large-diameter wells were placed in operation. All of these wells, with the exception of Well 14, were put into service after May 1, 1943. Accordingly, this date was selected as the point of arbitrary division and averages of the chemical elements and radicals in the water were computed for the total of analyses of composite samples prior to this date and for the analyses after this date. Analyses made prior to January, 1930, were not included in these computations because procedures of water analysis had not been well standardized prior to that date and because the name of the analyst of these early samples is not known.

The average sulfate content of composite samples was 237 parts per million prior to May, 1943, and only 145 parts per million after that date. Likewise, the average total hardness was 480 parts per million before May, 1943, and only 403 parts per million after that date; the average calcium content was 124 parts per million before and 108 parts per million after; the magnesium was 39 parts per million before and 32 parts per million after; and the total solids were 640 parts per million before and 535 parts per million after May 1, 1943. It should be noted, however, that the most recent analyses show an upward trend in mineralization. The reason for this is not clear, but it may be caused by the fact that at the time of taking the samples only a few of the newer wells were in operation.

An explanation is in order as to the cause for the decline in mineralization since May, 1943. It is believed that the heavy pumping of Wells 14, 15 and 16 since their installation in 1943 has been responsible for the observed change in the quality of water. Although the analysis of the water from Well 20 indicates that this water is similar in quality to that from the older wells in the field, it is expected that heavy pumping from it will produce the same effect as was produced in the three wells mentioned above. These wells obtain a considerable part of their water through immediate recharge from the drainage ditch. The four analyses of surface water presented in table VI indicate that the sulphate, calcium and magnesium contents are substantially below the content of these constituents in the waters from the older wells in the field. Although no analyses are available for water from the drainage ditch, presumably this water is similar in quality to that from the river. Of course, it should be recognized that the quality of water in surface streams is subject to changes due to seasonal factors, etc.

The effect of placing into operation new wells drawing large parts of their supplies from water derived from the river will be to continue the trend of decreasing mineralization of the water supply.

SKUNK CREEK VALLEY AS A POTENTIAL SOURCE OF WATER SUPPLY

An investigation was made of the low valley area west of Sioux Falls, near the confluence of Skunk Creek with the Big Sioux

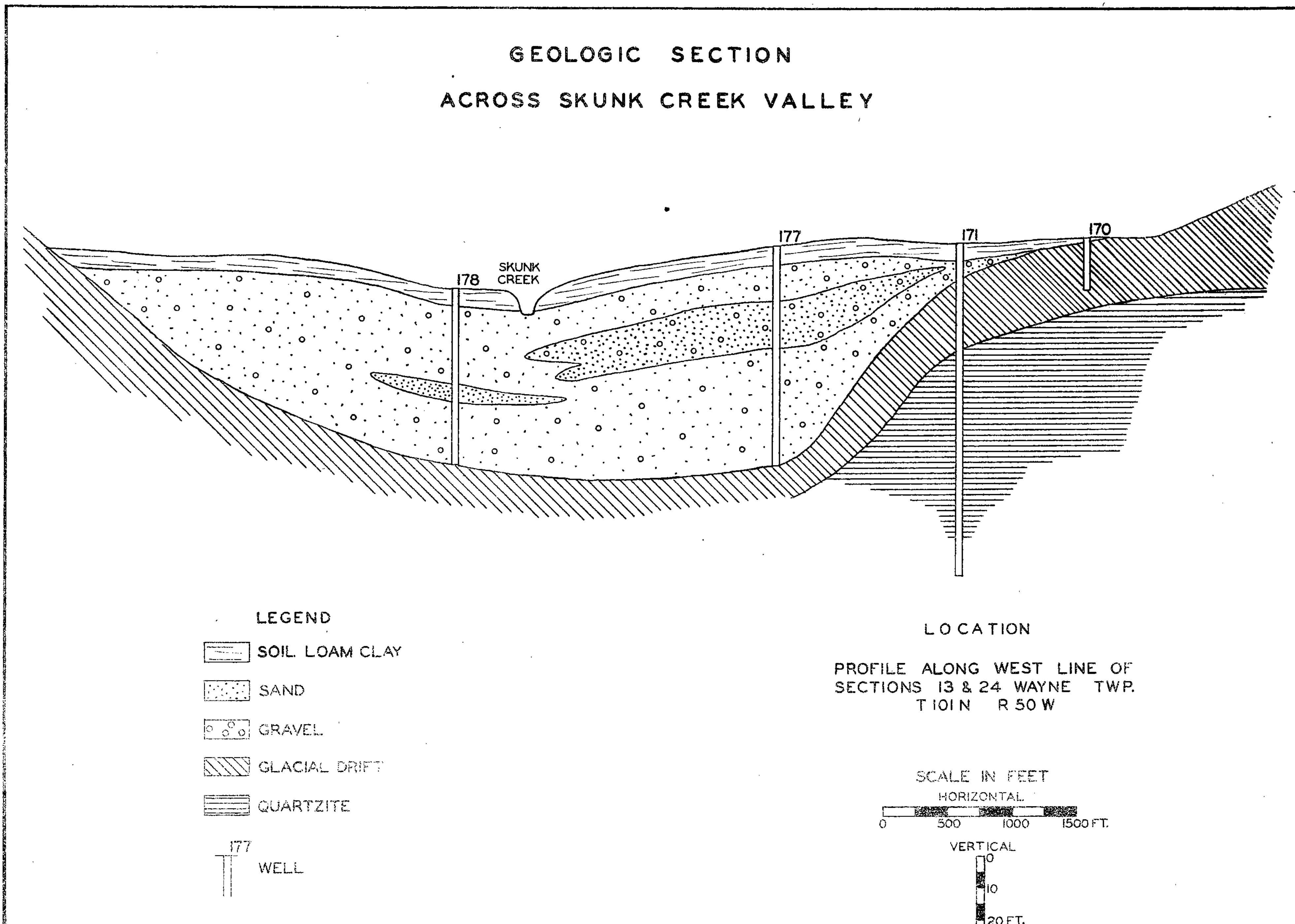

GEOLOGIC SECTION
ACROSS SKUNK CREEK VALLEY
178
SKUNK CREEK
177
171
170
LEGEND
SOIL LOAM CLAY
SAND
GRAVEL
GLACIAL DRIFT
QUARTZITE
177
WELL
LOCATION
PROFILE ALONG WEST LINE OF SECTIONS 13 & 24 WAYNE TWP.
T 101 N R 50 W
SCALE IN FEET
HORIZONTAL
0 500 1000 1500 FT.
VERTICAL
0 10 20 FT.

FIGURE 13

River. This area is approximately bounded on the north by Sections 7 and 8, Sioux Falls township; on the south by Section 36, T. 101 N., R. 50 W.; on the west by Sections 9 and 16, T. 101 N., R. 50 W. (the Ellis road); and on the east by the valley wall, which forms approximately the west limits of Sioux Falls.

In order to obtain information as to the thickness and character of the valley deposits underlying this area and the position of the underlying quartzite, 14 test wells, ranging in depth from 17 to 73 feet, were drilled during the summer and fall of 1944. The records of these wells are given in table IX. They indicate deposits similar to those in the Sioux Falls well field and an average thickness of saturated deposits of 25 to 30 feet. A cross section (figure 13) prepared from the data obtained from the test holes along the north-south road on the east side of Sections 14 and 23, T. 101 N., R. 50 W., shows the quartzite barrier which forms the dominant geologic feature of the region. This barrier forms the falls of the Big Sioux River and outcrops extensively in Sections 7, 8 and 18, T. 101 N., R. 49 W.

The existence of the quartzite barrier is important in the consideration fo any ground water development near the junction of Skunk Creek and the Big Sioux River. There is considerable proof that it is effective in preventing the southward movement of ground water from the gravels of the Big Sioux Valley in the vicinity of the Sioux Falls well field to the part of the valley south of the south line of Sections 7 and 8 (Madison Avenue). Although some ground water leakage may occur in the vicinity of Covell Lake or through the deposits adjacent to the channel of the present river, the volume of ground water that can pass the barrier at these points is insignificant in comparison to the underflow in parts of the valley to the north. However, the ground water reservoir south of the barrier may receive recharge from the flow of the Big Sioux and also from the flow of Skunk Creek.

Recharge of the Valley Deposits

Water level observations have been made in two wells in the valley of Skunk Creek since August, 1944, but these records do not cover a long enough period to serve as a basis for estimating the future recharge. However, it is reasonable to believe that the changes of water level and rates of recharge are of the same magnitude as those indicated by the Baltic and Renner wells for the Big Sioux Valley above the barrier. The recharge is more or less balanced by discharge of ground water by seepage into the river or creek and by evaporation and transpiration. Heavy pumping would increase the recharge from the river and creek.

Storage Capacity and Related Stream Flow

Test wells were drilled only as far west as the west line of Sections 10 and 15, T. 101 N., R. 50 W., but previous investigations have shown the presence of deposits of sand and gravel in the valley of Skunk Creek as far north and west as the Lake County boundary line. As these deposits occur in a band over 2 miles wide in some areas above Ellis, they undoubtedly contain a large quantity of water in storage. During periods of low flow, the drainage of these gravels may maintain the flow of Skunk Creek in its downstream parts and may thus provide water for recharge of the formation in the vicinity of Sioux Falls. On January 6, 1945, engineers of the U.S. Geological Survey measured a flow of 2.62 cubic feet per second (1,700,000 gallons a day) near the bridge 1 mile south of U.S. Highway 16 and 2 miles west of Sioux Falls. It has been reported that there has been no flow in Skunk Creek for varying short periods during the past decade. No mechanical analyses were made of gravels obtained from the test drilling in Skunk Creek Valley. If the specific yield is 30 per cent, the valley deposits, as limited in the first paragraph of this section, contain about 450 million gallons of free water for each foot of saturation.

Permeability of the Deposits

The results of a pumping test made in September, 1944, on Well 160 and the results of laboratory tests made on 14 samples from three additional test holes are presented in an earlier part of this report. The pumping test showed that the materials in the vicinity of Well 160 are highly permeable. The results indicate a field coefficient of permeability of about 10,000 on the basis of computations by means of the Theis graphical method. The samples collected during the drilling of this well showed that the material below a depth of 5 feet was unusually coarse gravel and it is probable that most of the deposits in the valley are finer and less permeable than the gravel near this well. The average coefficient of permeability determined in laboratory tests on 14 samples from three additional holes was 4,370.

The average gradient of the undisturbed water table between Wells 160 and 173 and Well 184 is 6.3 feet per mile. This gradient is almost twice that of the average gradient of the water table in wells in the Big Sioux Valley north of Sioux Falls. On the basis of an average gradient of 6.3 feet per mile, a coefficient of permeability of 5,000 and an average saturated thickness of aquifer of 28 feet, the underflow through the deposits Skunk Creek Valley from Ellis to a point near Well 184 occurs at a rate of 660,000 gallons per day. The valley of Skunk Creek narrows from a maximum width greater than ~~2~~ miles in Sections 9 and 16, Wayne Township, to a width of only three-fourths of a mile near the middle of Section 23, Wayne Township. This constriction of the valley floor considerably reduces the amount of ground water which can move in a day into the part of the valley at the junction of the Big Sioux and Skunk Creek (Sections 13, 24 and 25, T. 101 N., R. 50 W.).

Quality of the Water

The analysis made October 5, 1944, of a sample of water from test hole 181, in the Skunk Creek Valley, shows that this water is considerably harder that the water from other nearby sources for which analyses are available. The analysis indicated a total hardness of over 1,000 parts per million. Any future ground water development in the vicinity of this well should not be undertaken without adequate sampling of the water. Water of this hardness would interfere seriously with the operation of the existing treatment plant, but might be satisfactory for uses in which the quality of water is not important. It is possible that this sample is not representative of the quality of most of the water available from the Skunk Creek deposits.

Conclusions

The data obtained in this investigation indicate that a moderately large ground water development is practicable in the vicinity of the junction of the Big Sioux River and Skunk Creek. The water would be derived from the penetration of local rain and snow water, the underflow down the Skunk Creek Valley, and the local recharge that could be induced from both surface streams. The storage capacity would be sufficient to maintain the supply for considerable pumping in dry periods. It is probable that 3 to 5 million gallons per day could be safely withdrawn from wells here. The most favorable site for the location of wells is in the south one-half of Section 24 or the north one-half of Section 25, T. 101 N., R. 50 W. The records of the test holes drilled in Sections 24 and 25 show that in some places over 40 feet of saturated aquifer is present. Pumping in this vicinity would not have a pronounced effect on the water in storage near the existing Sioux Falls well field, as the localities are separated by the quartzite ridge in the south part of Sections 7, 8 and 12, T. 101 N., R. 49 W. Before the construction of wells for large production is begun, test holes should be drilled at the sites selected and the water from several existing wells in the locality should be analyzed for mineral content. Water from these deposits may be considerably harder than the water from the present public supply.

SUMMARY OF CONCLUSIONS

The Big Sioux Valley is underlain by water bearing deposits throughout the entire stretch extending from the present Sioux Falls well field northward to the vicinity of Baltic. It was computed that, with the water table at the levels that prevailed in 1944, a total of about 40 billion gallons of free water is stored in the deposits within this stretch. The average coefficient of transmissibility of these materials was determined to be about 150,000 and the rate of underflow toward Sioux Falls, about 1,800,000 gallons per day. The ground water levels in the Sioux Falls well field averaged approximately 3.7 feet lower in 1944 than in 1921. This shows that only a very small part of the pumpage has been derived by depletion of the storage. The records indicate that the water levels have risen since 1942. As the average daily pumpage in the Sioux Falls well field during 1944 was about 7 million gallons and there was no reduction in ground water storage during that year, the remainder of the water pumped, or an average of about 5 million gallons a day, was derived from precipitation in the vicinity of the well field and recharge from the Big Sioux River and the drainage ditch.

It was estimated that about one billion gallons of water could be obtained from storage in a period of prolonged drought by pumping the present city wells. The capacity of the wells would, however, gradually decrease, and after a few months without recharge, it would become necessary to sink additional wells outside of the depleted area in order to recover more stored ground water and thus prevent a shortage in water supply.

In order to keep a current account of the water supply, periodic measurements of water levels in Wells 3, 19, 15, 66, 104 and 109 should be continued for an indefinite time. Before the static water level in a public supply well is measured the pump should be shut off for at least 48 hours. Periodic measurements should also be made of the water levels in at least two wells a few miles north of the well field.

There has been a decrease in the hardness and mineral content of the water pumped from the Sioux Falls well field since the wells constructed early in 1943 came into use. This decrease is not the same for the different mineral components but approximates about 15 to 20 per cent. It is believed that the reduction is due to the fact that the new wells are relatively near the river or drainage ditch and induce infiltration of the river water, which on the average, is relatively low in hardness and mineral content. Further improvement in mineral content can be attained by drawing more of the supply from wells situated near the river or ditch.

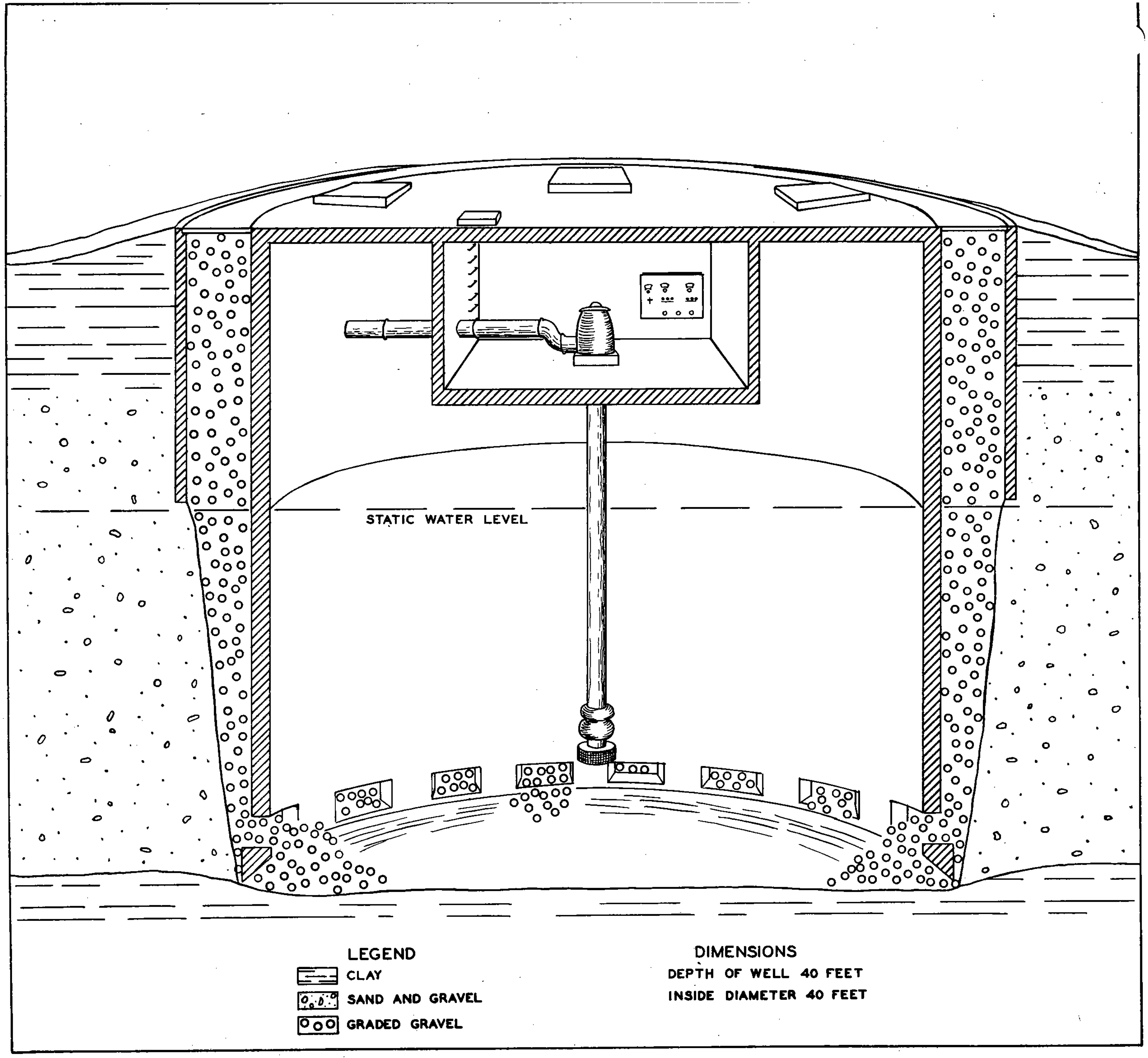


FIGURE 15. SECTION ACROSS A BRAGSTAD LARGE-DIAMETER WELL WITH A REPLACEABLE GRAVEL ENVELOPE.

The valley area west of Sioux Falls near the mouth of Skunk Creek is a potential source of water supply in which the safe yield is believed to be between 3 and 5 million gallons per day. However, the water may be more mineralized than the present municipal supply. Pumping from wells in the Skunk Creek Valley will not reduce the amount available for the present municipal supply.

The geological character of the valley of the Big Sioux River indicates that no large water supplies can be developed from the valley deposits in the portion of the valley between the line where U.S. Highway 77 crosses the valley and the falls of the Big Sioux.

Considerable additional water supplies can be developed in the area of the present well field if consideration is given to the proper spacing of wells and their location with reference to the river and the drainage ditch. No additional large-capacity wells should be located closer than 1,000 feet from existing wells, except that wells near the river could be located somewhat nearer to existing wells because they would derive much of their water by recharge from the river. The construction of any public supply wells should be preceded by at least one test hole drilled on the site chosen. Good locations for additional wells are (1) 1,000 to 1,200 feet north of Well 18. (2) 800 to 1,000 feet northeast of Well 20, (3) the site of test hole 109, (4) the site of test hole 107, (5) anywhere along a northeast-southwest line west of the Big Sioux River in the north half of Section 6, T. 101 N., R. 49 W., and (6) 800 to 1,000 feet west of Well 8. Conditions are not favorable for wells south of Wells 3, 4, 10 and 19.

Wells in Section 29 or the north half of Section 32, T. 102 N., R. 49 W., would not interfere seriously with the supply from the present well field. Large additional water supplies for the public water works or for institutions and industries can be developed in the valley of the Big Sioux between the present well field and the vicinity of Baltic.