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PROBLEMS OF THE SOFT-WATER SUPPLY OF THE DAKOTA SANDSTONE

WITH SPECIAL REFERENCE TO THE CONDITIONS AT CANTON, SOUTH DAKOTA

BY

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PROBLEMS OF THE SOFT-WATER SUPPLY OF THE DAKOTA SANDSTONE, WITH SPECIAL REFERENCE TO THE CONDITIONS AT CANTON, SOUTH DAKOTA

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INTRODUCTION

The Dakota sandstone, which is recognized as the basal formation of the Upper Cretaceous rock series, underlies most of North Dakota, South Dakota, and Nebraska, the western parts of Minnesota, Iowa, and Kansas, and considerable parts of several States farther west and southwest. In most of the area that it occupies it is deeply covered by younger formations, but it appears at the surface in widely separated localities. It is exposed in the bluffs of Missouri and Big Sioux Rivers in the vicinity of Sioux City, Iowa, where it is identified by the fossils that it contains, especially the fossil leaves. Over wide areas, however, it is known only from drilling operations, which rarely produce any fossils. In sinking deep wells in most parts of South Dakota the drill, after penetrating the surficial deposits, passes through several hundred feet of strata that consist chiefly of soft shale, and then through alternating beds of sandstone and shale that range in aggregate thickness from less than a hundred to a few hundred feet. It is generally assumed that the first distinct sandstone stratum encountered by the drill marks the top of the Dakota sandstone and that the entire succession of alternating shales and sandstones belongs to this formation, though it is recognized that the lowest strata may belong to the Lakota sandstone or to some other formation of the Lower Cretaceous series.[1]

The water supplies from different parts of the Dakota sandstone differ greatly in their chemical character—that is, in the kinds and amounts of mineral matter that they hold in solution. They differ from place to place and in successive strata in the same place. In a broad sense the waters of the Dakota sandstone may be grouped in two main classes—hard water and soft water. In general, in North

[1] Darton, N. H., Geology and underground waters of South Dakota: U. S. Geol. Survey Water-Supply Paper 227, p. 41, 1909.

Dakota, South Dakota, and Minnesota the soft water occurs in the upper part and the hard water in the lower part of the Dakota sandstone. This relation was first determined in 1895 by Shepard,[2] who

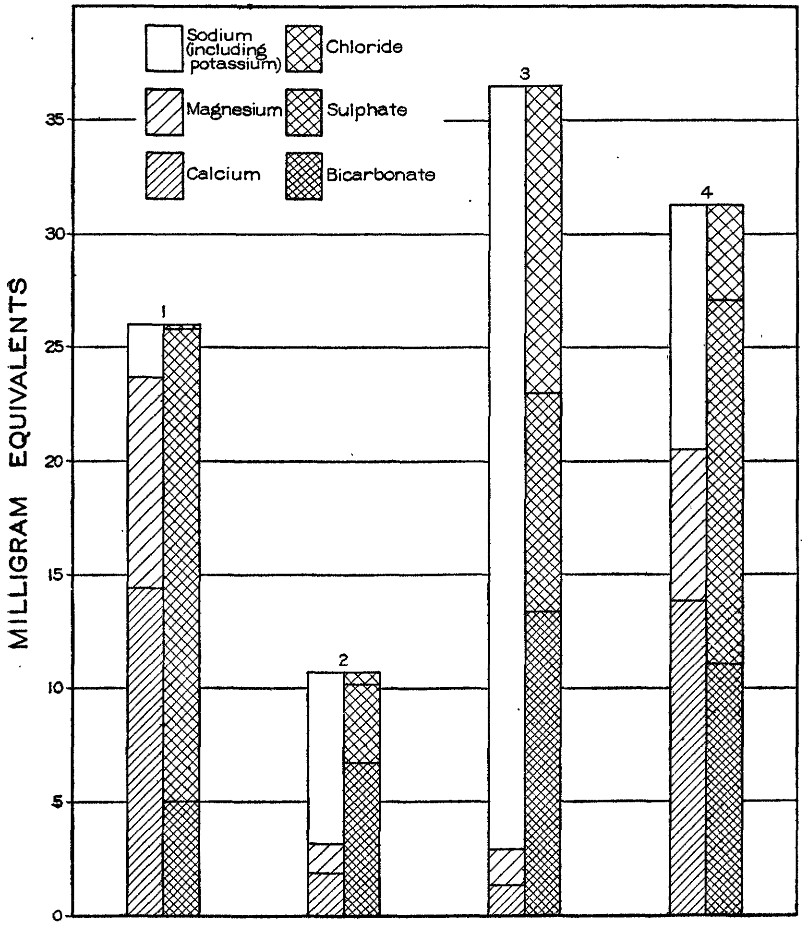


FIGURE 15.—Diagram showing chemical composition of water from the Dakota sandstone and from the terrace gravel at Canton, S. Dak. 1, Water from terrace gravel at Canton (average of 2 analyses on p. 161); 2, water from Dakota sandstone at Canton (average of A, E, G, and H on p. 161); 3, water from "first flow" of Dakota sandstone (average given on p. 149); 4, water from "second flow" of Dakota sandstone (average given on p. 149)

made analyses of 10 samples of water from the "first flow" and of 10 samples from the "second flow" of the Dakota sandstone in South Dakota, with the results shown in the following table and graphically represented in Figure 15.

[2] Shepard, J. H., The artesian waters of South Dakota: South Dakota Agr. Coll. and Exper. Sta. Bull. 41, 1895.

Average content of dissolved mineral matter in the two types of water from the Dakota sandstone in South Dakota

[Determined from analyses by J. H. Shepard. Parts per million]

	"First flow"	"Second flow"
Calcium (Ca)	27	279
Magnesium (Mg)	20	79
Sodium (Na)	773	249
Sulphate radicle (SO_4)	465	770
Chloride (Cl)	480	145
Total solids	2,261	2,019

Investigations in southwestern Minnesota in 1907 showed that the two types of water found in South Dakota occur also in the Dakota sandstone in Minnesota.[3] It was found that there are several soft-water and several hard-water strata here and that their relations are somewhat complicated, but that the principal soft-water strata

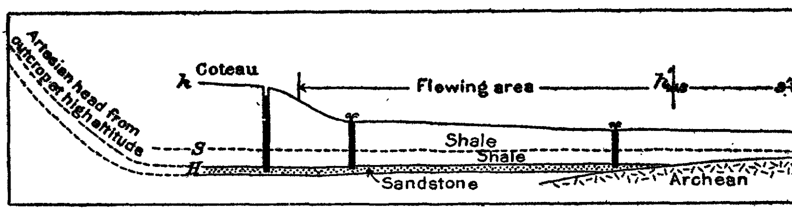


FIGURE 16.—Diagrammatic section through southwestern Minnesota showing the relation of stratigraphy and structure to the geographic distribution of hard and soft water in the Dakota sandstone

occur in the upper part and the principal hard-water strata in the lower part of the formation. The recent work of Simpson and Riffenburg[4] has shown that in North Dakota also the Dakota sandstone contains the two kinds of water and that in general the soft water occurs in the upper part and the hard water in the lower part of the formation.

Over large areas in southwestern Minnesota where the basal granite occurs relatively near the surface the lower strata of sandstone are cut off, but the upper strata lap over the granite and yield soft water.[5] (See fig. 16.) These conditions seem to give the clue to the conditions at Canton, S. Dak. Darton[6] has shown that in a con-

[3] Hall, C. W., Meinzer, O. E., and Fuller, M. L., Geology and underground waters of southern Minnesota: U. S. Geol. Survey Water-Supply Paper 256, pp. 68–74, pl. 4, 1911. See also the county reports in this paper.

[4] Simpson, H. E., and Riffenburg, H. B., Geology and ground-water resources of North Dakota: U. S. Geol. Survey Water-Supply Paper 598 (in press). See also Riffenburg, H. B., Chemical character of ground waters of the northern Great Plains: U. S. Geol. Survey Water-Supply Paper 560, pp. 50–51, 1925; Meinzer, O. E., and Hard, H. A., The artesian-water supply of the Dakota sandstone in North Dakota, with special reference to the Edgeley quadrangle: U. S. Geol. Survey Water-Supply Paper 520, pp. 79–80, 1925.

[5] Hall, C. W., Meinzer, O. E., and Fuller, M. L., op. cit., pp. 54, 55, 68–73. See also county reports and pl. 4.

[6] Darton, N. H., op. cit., p. 41, pl. 11.

siderable part of southeastern South Dakota where the Sioux quartzite is relatively near the surface it cuts off the Dakota sandstone, but that the Benton shale, which lies next above the sandstone, overlaps upon the quartzite throughout a wide belt. Although no certain correlations can be made, it appears that in the vicinity of Canton the quartzite occurs at such an altitude that it cuts off the lower part of the Dakota sandstone but not the uppermost stratum, which contains soft water.

The Dakota sandstone extends far eastward from South Dakota and Nebraska and occurs as a thin and somewhat interrupted formation throughout much of the western halves of Minnesota and Iowa. However, practically no soft-water wells have until recently been known in the Dakota sandstone in Iowa or in adjacent parts of South Dakota or Minnesota, and it has been a question how far southeast soft water may be found in this formation. The most southeasterly point at which soft water was reported by Shepard [7] was at Iroquois, S. Dak., about 100 miles northwest of Canton. In the ground-water survey of southern Minnesota careful attention was given to the southward extension of the soft-water horizons, but no soft-water wells were found near the southern margin of the State. In the ground-water survey of Iowa no samples of really soft water were obtained from the Dakota sandstone.[8] It is therefore a matter of considerable economic significance that soft water has been found in the vicinity of Canton. It is still uncertain to what extent soft-water supplies can be found in the Dakota sandstone of western Iowa and adjacent parts of Minnesota, South Dakota, and Nebraska. Many wells have been drilled without finding soft water, and it appears that where the Dakota sandstone rests as a thin and interrupted formation upon rocks of the Paleozoic systems, which yield hard water,[9] the prospects of finding soft water are not so good as where the Dakota sandstone rests on relatively impermeable rocks, such as the granite and quartzite. However, the soft-water strata where they have been found in Minnesota are thin and do not yield water freely, and hence a driller might easily drill through them without finding the soft water or without separating it from the hard water of other horizons. It is, therefore, very desirable that in future deep drilling in this region the drillers should keep this problem in mind and make an effort to obtain an unadulterated sample of water from each water-bearing stratum that is penetrated in order to find the soft water wherever it occurs.

[7] Shepard, J. H., op. cit., pp. 21, 66.

[8] Norton, W. H., Underground water resources of Iowa: U. S. Geol. Survey Water-Supply Paper 293, pp. 142–177, 1912.

[9] Hall, C. W., Meinzer, O. E., and Fuller, M. L., op. cit., pp. 74–75. Norton, W. H., and others, op. cit., pp. 139–183 and county reports.

The conditions at Canton were brought to the attention of the Geological Survey on account of the trouble caused by sand in the city wells, which are pumped much harder than the farm wells that end in the same soft-water stratum of the Dakota sandstone. This is not a new or uncommon problem. In the work in northwestern Iowa in 1906 and in southwestern Minnesota in 1907, it was found that in these areas and in adjacent parts of South Dakota most of the drilled wells ended in sand belonging to the glacial drift or the Dakota sandstone, that in many localities these wells had given so much trouble that nearly all had been abandoned, and that the successful finishing of wells in sand was one of the most difficult problems in connection with water supplies in the region. Therefore the entire problem was investigated in the field and laboratory. As a result practical advice was given that has in large measure been followed by the drillers and has resulted in general improvement in the methods used in finishing wells in sand. This advice consisted essentially in recommending wells of larger diameter than the 2-inch "tubulars"; driving the casing to the proper depth; having the metal screen (where one is required) attached tightly to the bottom of the casing and of small enough diameter so that it can be removed when it becomes clogged without pulling the casing; developing a natural screen or an artificial gravel screen; and installing a pump that is independent of the casing. In regard to gravel screens, the following statement was made:[10]

> Glacial deposits and to some extent also Cretaceous strata are poorly sorted, fine sand and coarser grit generally being more or less mixed together. When a well is to be finished in one of these deposits it should be pumped for a protracted period in such a manner as to remove the fine silt and leave a natural screen of coarser material. This frequently makes it possible to finish the well without a screen where otherwise one would have been required, but it should be done even where a screen is inserted. Proper treatment in this respect requires patience and skill, but it undoubtedly results in superior wells.
>
> The process of developing a natural screen is sometimes supplemented by introducing into the well a quantity of gravel or crushed tile of the proper coarseness. This method has proved successful with drillers who are willing to devote sufficient time and effort to it and often makes it possible to finish a well without putting in an ordinary screen.

Although the trend among drillers has been in the direction of better methods of finishing wells, in ways such as are indicated above, the sand problem still presents many difficulties, and there is still much room for improvement in developing and applying effective methods.

The present report is in no sense a treatise on the quality of water or the methods of finishing wells in the Dakota sandstone. It is

[10] U. S. Geol. Survey Water-Supply Paper 256, pp. 82–87, 1911; Water-Supply Paper 293, pp. 190–195, 1912.

essentially a by-product of the study that was made as a basis for a recommendation to the United States Office of Indian Affairs in regard to drilling a well at the Asylum for Insane Indians, near Canton. The report presents data as to the occurrence of soft water in an area where its existence has not until recently been known and calls attention to the possibilities of finding it in other localities in this general region in which at present only hard water is known. Furthermore, the report presents, almost for the first time in hydrologic literature, detailed information as to the performance of wells in a sand whose physical and hydrologic properties were determined in the laboratory. It is hoped that this contribution to hydrology will be of service especially to the water-well drillers of the Northwest in improving the water supplies of that region. The writer considers the drillers his colaborers, for they have contributed generously not only to this investigation but to virtually all the ground-water investigations that have been made by the Geological Survey.

GENERAL CONDITIONS AT CANTON, S. DAK.

GEOLOGY

The city of Canton, the seat of Lincoln County, is on the west side of Big Sioux River, which here forms the boundary between South Dakota and Iowa. (See fig. 17.)

The area about Canton is underlain at a depth of a few hundred feet by the Sioux quartzite, which is the hard pink rock exposed at Sioux Falls. This is a very ancient rock belonging to the Algonkian system. Above the Sioux quartzite is a thin series of sandstone and shale of Cretaceous age. The sandstone is believed to be an upper member of the Dakota sandstone, and the overlying shale is probably a part of the Benton shale.[11]

The Cretaceous strata are completely buried under glacial deposits of several kinds. Old glacial drift apparently underlies all of this region and belongs chiefly to what is known as the Kansan drift sheet but may include still older drift known as the Nebraskan drift sheet. Throughout Lincoln County, however, except along Big Sioux River and in the southeastern part of the county, the Kansan drift sheet is overlain by much younger drift that is known as the Wisconsin drift sheet. East of the river, in Iowa, the Wisconsin drift is absent, but great deposits of buff wind-blown silty material, called loess, rest on the Kansan drift and largely cover it. This is, in part at least, the reason why the bluffs on the east side

[11] Wilder, F. A., Geology of Lyon and Sioux Counties: Iowa Geol. Survey Ann. Rept., vol. 10, pp. 96–117, 1900.

of the river are so much higher than those on the west side. Loess occurs also on the west side of the river on the upland a few miles south of Canton. Along the Big Sioux there are extensive deposits of gravel that were laid down by the river in the last glacial stage.

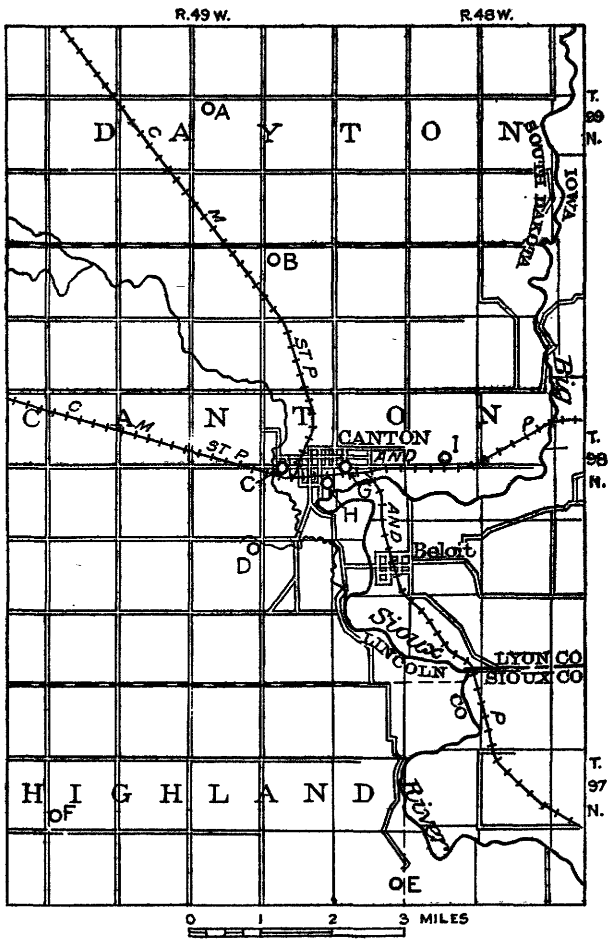


FIGURE 17.—Map of the vicinity of Canton, S. Dak., showing location of soft-water wells. The letters give the designations of the wells used in the table and text

After the river had deposited this gravel it cut its channel somewhat deeper, and hence the gravel now occurs chiefly under benches or terraces that lie somewhat above the bottom lands.[12]

The materials penetrated in drilled well 1 of the Canton waterworks were reported by Mr. Norman Harrison, the driller, as shown

[12] Carman, J. E., The Pleistocene geology of northwestern Iowa: Iowa Geol. Survey Ann. Rept., vol. 26, pp. 294–307, 1917. The information regarding the glacial drift was obtained chiefly from Carman's paper.

below. This report was given from memory, however, and Mr. Harrison emphasized the fact that it is very inaccurate as to the thickness and depth of the different materials. Apparently the "blue clay" is glacial drift; the "gray and bluish shale," "brown rock," and "blue muck" belong to the Benton shale; and the "sandstone" belongs to the Dakota sandstone.

Log of drilled well 1 at Canton waterworks

[Depths and thicknesses given are approximate]

	Thickness	Depth
	Feet	*Feet*
Clean "river-bed" gravel, water bearing in lower part	20	20
Blue clay, containing some pebbles and boulders	40	60
Gray and bluish shale, containing no pebbles but some slaty streaks	140(?)	200(?)
Brown rock, somewhat hard	30	230(?)
Blue muck	40	270+
Sandstone, water bearing	32 or 34	306

The log of the well drilled at the United States Asylum for Insane Indians, as reported by Mr. E. C. Archibald, the driller, is given below. Three samples were submitted from the 252-foot "shale." The sample taken near the top is bluish pebbly clay that is doubtless glacial drift; the samples taken near the middle and near the bottom consist of very uniform and fine-grained clay or shale, probably Benton shale. Two samples of the sandstone, one taken near the top and the other near the bottom of the stratum, consist of fine, even-grained sand. (See p. 163.)

Log of well drilled in 1926 at the United States Asylum for Insane Indians, Canton, S. Dak.

	Thickness	Depth
	Feet	*Feet*
Soil and subsoil	5	5
Gravel	30	35
Shale [a]	252	287
Sandstone [b]	33	320
Shale	2	322

[a] See description of samples given above. [b] See description of samples, pp. 162-165.

GROUND WATER

Most of the farms in the vicinity of Canton obtain their water supplies from wells that end in the glacial drift. No investigation was made of these wells. Most of them apparently yield enough water for farm use, but on some farms it has been difficult to obtain satisfactory wells. The water is hard but is used for drinking and cooking as well as for watering livestock.

The city of Canton has for many years obtained its public water supply from large dug wells in the terrace gravel that occurs along Bix Sioux River. The supply for the United States asylum near Canton has also been obtained from this gravel. The gravel yields water in considerable quantity, but the water is hard and otherwise highly mineralized.

On several farms in the vicinity of Canton wells have been drilled to the Dakota sandstone in order to obtain the relatively soft water that occurs in this sandstone. These wells have been drilled within the last 15 years, according to Mr. Harrison, who put down most of them. In 1920 a successful soft-water well was drilled by Mr. Harrison and Mr. E. E. Adair at the electric plant in Canton. A little later five wells were drilled by the same drillers for the city of Canton, but these wells have given much trouble under the heavy pumping to which they have been subjected. Recently a well was drilled at the United States asylum by Mr. E. C. Archibald.

WATER IN THE TERRACE GRAVEL

DUG WELLS OF THE CANTON WATERWORKS

The oldest pumping plant and well field of the waterworks of the city of Canton are on Dakota Street, between the railroad station and the river. (See fig. 18.) An old abandoned well, 8 feet in diameter, is situated at the foot of Dakota Street, about 40 feet from the river bank and only a few feet above the level to which the river is impounded. It is understood that this well was abandoned because of pollution from the river; it is so situated that it could easily have been polluted by river water. Later a number of well points were driven on the low ground on the east side of Dakota Street, but it seems that these became clogged and incrusted and hence failed to yield as much water as was required. Wells were then dug on ground somewhat higher and somewhat farther from the river. Two dug wells are at present equipped to furnish water to the waterworks, one on Dakota Street and the other on Bartlett Street, and these two wells furnished the entire supply to the city waterworks until recently, when the soft-water wells were drilled. (See p. 159.) No accurate information is available as to the consumption of water from the city waterworks, but it probably ranges between 150,000 and 300,000 gallons a day, and this was the approximate range of daily pumpage from the two wells before the soft-water wells were drilled.

The Dakota Street well is at the corner of Ninth Street, about 500 feet from the river and nearly midway between the river and the railroad station. It is on a terrace fully 10 feet above the abandoned well near the river. It is about 20 feet in diameter and about 30 feet deep and is cased with brick. The water level in the well stands about 20 feet below the surface when it has not been lowered by pumping. This well has in recent years supplied a large part of the city water.

FIGURE 18.—Map of a part of the city of Canton, S. Dak., showing location of the city wells and of the well at the electric plant. Open circles indicate dug wells that end in terrace gravel; solid black circles indicate drilled wells that end in Dakota sandstone. Dashed line indicates abandoned channel of Big Sioux River

The Bartlett Street well is on a small knoll about a third of a mile southwest of the Dakota Street well, at the corner of Twelfth Street. It is 400 feet from an abandoned channel of the river and considerably farther from the present channel. It is about 12 feet in diameter and 35 feet deep and is reported to yield 120,000 gallons a day.

Before the soft-water wells were drilled these two dug wells were barely adequate to supply the city waterworks, but the supply could easily have been increased by sinking more wells into the water-bearing gravel. The principal objection to the dug wells was, however, the poor quality of their water, both as to bacterial pollution and as to mineralization. It is practically certain that neither of these wells is polluted by the river, and any bacterial pollution could probably be completely overcome. The hardness of the water and its high content of mineral matter, however, constitute a detriment that can not be wholly remedied.

The table on page 161 gives an analysis of the hard-water supply of Canton. The sample was collected by Dr. H. R. Hummer, superintendent of the United States Asylum for Insane Indians, in October, 1925, presumably from the Dakota Street well. The water was clear when it was received in the laboratory.

DUG WELLS AT THE UNITED STATES ASYLUM FOR INSANE INDIANS

The United States Asylum for Insane Indians is about a mile east of Canton, in the SE. 1/4 sec. 18, T. 98 N., R. 48 W. The two dug wells that furnished the water supply up to 1926 are near the southwest corner of the asylum grounds, not far from the road. They are on a low terrace of Big Sioux River. The water is lifted by an electrically driven pump from the wells to an elevated tank with a capacity of about 30,000 gallons, which is on the high ground to the north, where the asylum buildings are situated.

The following information was furnished by Doctor Hummer:

> The wells are 24 feet deep and end in gravel. The water level normally stands about 21 feet below the surface. The wells are pumped simultaneously at a combined rate of about 5,000 gallons an hour, or 80 gallons a minute. With this rate of pumping the water level is drawn down about 1¾ feet, but it is restored virtually to its normal position within 15 minutes after pumping ceases. The wells have never failed to supply water at this rate of pumping. The daily consumption amounts to about 15,000 gallons.

A sample of the water was collected by Doctor Hummer in October, 1925. The analysis, given in the table on page 161, shows that this water, like that from the shallow wells of the city waterworks, contains very large quantities of calcium and magnesium, chiefly as sulphates. These constituents render the water very hard and unsatisfactory for washing and also cause it to deposit excessive amounts of scale in steam boilers. The raw water can, of course, be improved for washing and boiler use by application of soda ash or other treatment. One favorable feature of this water for washing and general use is its very low content of iron.

WATER IN THE DAKOTA SANDSTONE

WELLS DRILLED INTO THE SANDSTONE

The wells drilled to the Dakota sandstone in or near Canton in regard to which definite information was obtained are shown on Figure 17 and are listed in the following table. Apparently they do not differ greatly in the altitude at which they end, most of the differences in depth being due to surface irregularities. A few other soft-water wells were reported in this general area, some of them on the east side of the river, in Iowa.

Wells in or near Canton, S. Dak., that end in Dakota sandstone

Map designation (fig. 17)	Owner	Location	Diameter	Depth
			Inches	*Feet*
A	M. B. Kennedy	NW. ¼ sec. 28, T. 99 N., R. 49 W	3	[a] 362
B	M. L. Syverund	NW. ¼ sec. 2, T. 98 N., R. 49 W	3	[a] 442
C	Norman Harrison (Holsey Place)	NW. ¼ sec. 23, T. 98 N., R. 49 W.; on south side of Fifth Street, about 300 feet east of Beaver Creek.	3	[a] 316
D	Irving Seapy	NE. ¼ sec. 27, T. 98 N., R. 49 W	3	[a] 323
E	Newton Hill Farm, C. B. Kennedy estate.	SE. ¼ sec. 13, T. 97 N., R. 49 W	3	[a] 502
F	Ernest Wendt estate	SW. ¼ sec. 8, T. 97 N., R. 49 W		[a] 530
G	Northern States Power Co	NW. ¼ sec. 24, T. 98 N., R. 49 W.; Duff Street between Kimball Street and Milwaukee Avenue.	8	301
H	City waterworks:			
	No. 1	Southwest corner Dakota and Ninth Streets.	8	306
	No. 2	130 feet west of well 1	8	300+
	No. 3	300 feet west of well 2, on south side of Ninth Street between Lincoln Street and Broadway.	8	[b] 316
	No. 4	300 feet northwest of well 3, on north side of Ninth Street between Broadway and Main Street.	8	321
	No. 5	North side of Martin Street, east of Dakota Street, 300 feet south of railroad and 500 feet northeast of well 1.	12	311
I	United States Asylum for Insane Indians.	SE. ¼ sec. 18, T. 98 N., R. 48 W	6	322

[a] The depths given are based on the memory of the driller and may be somewhat inaccurate.
[b] Later deepened to about 329 feet. (See p. 160.)

So far as information was obtained, the private farm wells (A to F) yield enough water for farm use and have proved generally satisfactory, except well F, which gave trouble with sand and has been abandoned. These wells were drilled with hydraulic percussion or so-called jetting rigs. The hole was usually drilled to the sandstone, and then a 3-inch casing was inserted and was driven down so as to be seated in the sandstone. A somewhat smaller hole was then drilled into the sandstone to a depth of 7 to 16 feet below the bottom of the casing, no attempt being made to drill to the bottom of the sandstone. The well was then cleaned out, and a cylinder pump, attached to an independent pump pipe, was installed. The water generally rises 200 feet or more above the bottom of the well by artesian pressure, and the cylinder is usually placed 50 or 60 feet below the water level in the well.

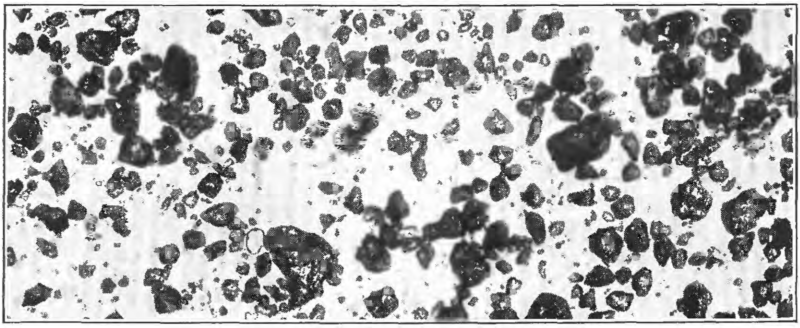
Information in regard to the well at the electric-light plant, now owned by the Northern States Power Co., was obtained largely from Mr. G. G. Dokken, the manager. This well, the location of which is shown in Figure 18, was drilled in 1920, after the existence of soft water had been demonstrated. The casing was driven down into the sandstone to shut out the overlying soft material, and it extends within about 6 feet of the bottom of the well. The water is reported to have risen by artesian pressure to a level about 100 feet below the surface. A 3¾-inch single-acting cylinder pump was inserted at the end of a 4-inch pipe. It was first placed about 280 feet below the surface, but on account of trouble with sand it was later raised to a level only about 200 feet below the surface. Since this change was made there has been no serious trouble with sand, and the well is regarded as a success. The well was formerly pumped at about 20 gallons a minute during a large part of each day and apparently never failed to supply water at this rate of pumping. Mr. Dokken estimated that on many days the pumpage exceeded 15,000 gallons. It is said that after the city wells were drilled the pump in this well ran more heavily, presumably on account of a lowering of the water level.

It was some time after the well at the electric-light plant was completed that the city of Canton drilled similar wells to provide soft water for the public supply. The log of well 1 is given on page 154; other information in regard to the five city wells is given in the foregoing table. These wells were presumably drilled and cased to the sandstone and were then drilled with a somewhat smaller diameter for a depth of 30 to 34 feet through the entire bed of sandstone and to a hard rock that was believed to be the Sioux quartzite. Double-acting deep-well cylinder pumps were installed in all the wells; their capacities were as follows: Nos. 1 and 2, about 55 gallons a minute each; Nos. 3 and 4, about 30 gallons a minute each; No. 5, about 135 gallons a minute. These wells have not given satisfactory service. They have not produced the relatively large quantities of water required for the public supply, and with the large pumps that were used they have caused much trouble and expense on account of the fine sand that is drawn into the wells. This sand either settles at the bottom and clogs the well or else is lifted with the water and damages the pump. Considerable improvement was effected by work done on the wells in the later part of 1925 and in January, 1926. Mr. William Tank, the mayor, reported that after this work had been done wells 1, 3, and 5 were in service, were producing, respectively, about 35, 30, and 50 gallons a minute, and were furnishing the entire public supply of about 150,000 gallons a day. (See p. 167.)

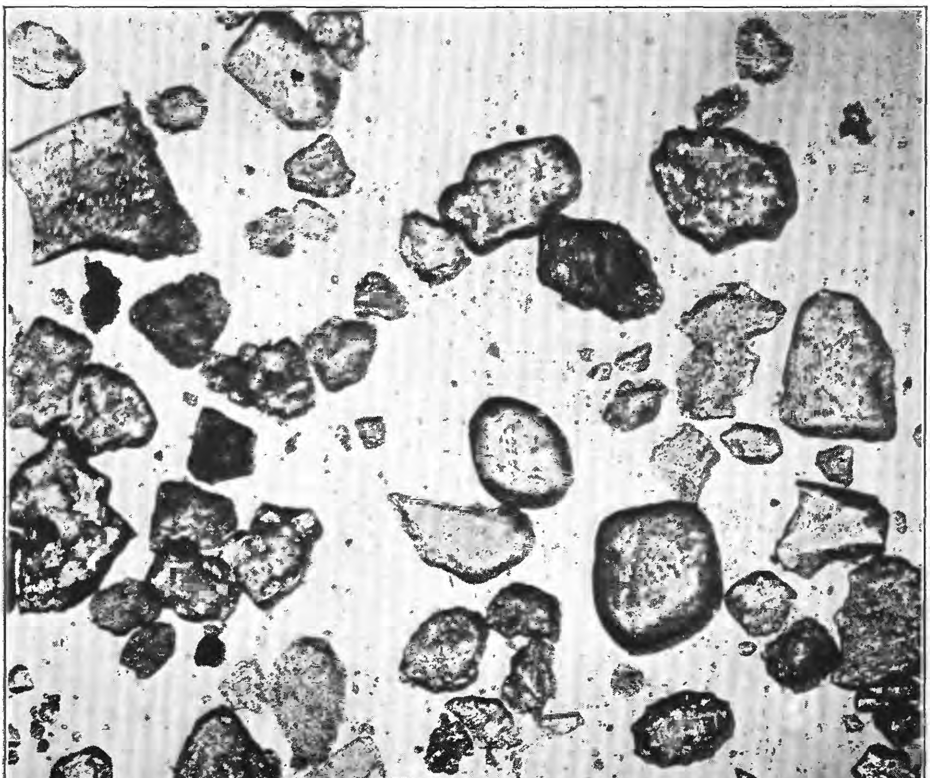
Information as to the height to which the water normally rose in the city wells is indefinite and conflicting. According to the driller the water in well 1 at first rose within 65 feet of the surface. In a memorandum furnished by Mr. Tank June 12, 1925, he stated that at that time the water level in well 4 was about 175 feet below the surface and the cylinder about 265 feet below the surface; also that the water level in well 5 was about 150 feet below the surface and the cylinder 275 feet below the surface. On September 29, 1925, the water level in well 3, according to a measurement by Mr. Tank, was 162 feet below the surface; at the time of this measurement wells 1 and 4 were being pumped and there may still have been a slight drawdown in well 3 due to withdrawal of water from this well. The available information, although not conclusive, indicates that considerable lowering of the head has resulted in the vicinity of these wells owing to the heavy pumpage from them during the period since they were drilled.

In 1926 the United States Office of Indian Affairs had a soft-water well drilled at the Asylum for Insane Indians near Canton. (See fig. 17 and tables on pp. 154 and 158.) According to Mr. Archibald, the driller, the stratum of sandstone was struck in this well at a depth of 287 feet and was found to be 33 feet thick and to rest on shale. The water level was about 90 feet below the surface. The well was cased to a depth of 290 feet and was successfully pumped at 25 gallons a minute. This rate of pumping, however, was reported to produce a drawdown in the water level of about 220 feet.

Work done on city well 3 in September, 1925, indicated that this well had not been drilled to the quartzite; its original depth was reported to be 316 feet, but during the cleaning operations in 1925 the hole was carried at least to 329 feet, the cuttings at that depth being a soft, shaly rock. It is improbable that the quartzite is even approximately level over any large area; moreover, the sandstone stratum encountered in these wells does not have the usual character of a shore deposit. Hence, there are independent reasons for expecting that in some places in the vicinity of Canton other sedimentary beds—some of them possibly water-bearing—may be found between the recognized soft-water stratum and the Sioux quartzite. The



A



B

SAND FROM THE SOFT-WATER STRATUM PENETRATED IN THE WELL OF THE UNITED STATES ASYLUM FOR INSANE INDIANS, CANTON, S. DAK.

***A*, Enlarged about 35 diameters; *B*, enlarged about 100 diameters**

water prospects have obviously not been fully tested in any well that has not reached the quartzite.

CHEMICAL CHARACTER OF THE WATER

Samples of water were collected by Doctor Hummer in October, 1925, from four of the wells drilled to the Dakota sandstone; in November, 1926, from the new well at the asylum; and in August, 1927, again from the new well. The first sample from the asylum well was too small for complete analysis. All these samples, as also the two from the terrace gravel, were analyzed in the Geological Survey, and the results are given in the following table:

Analyses of water from wells in or near Canton, S. Dak.

[Analyst, Margaret D. Foster. Parts per million]

	Terrace gravel		Dakota sandstone					
	City waterworks (dug well on Dakota Street)	U. S. Asylum for Insane Indians (2 dug wells)	M. B. Kennedy (A, fig. 17)	Newton Hill Farm (E, fig. 17)	Electric plant (G, fig. 17)	City well No. 1 (H, fig. 17)	U. S. Asylum for Insane Indians (I, fig. 17)	
							First sample [a]	Second sample [b]
Silica (SiO_2)	26	25	11	16	9.6	9.4		15
Iron (Fe)	.06	.07	.57	.38	1.0	.48		4.1
Calcium (Ca)	312	267	45	42	38	30		62
Magnesium (Mg)	118	108	18	17	17	13		27
Sodium and potassium (Na+K)	57	48	97	211	181	194		[c] 185
Carbonate radicle (CO_3)	0	0	0	0	0	0	24	0
Bicarbonate radicle (HCO_3)	325	283	361	405	429	432	205	361
Sulphate radicle (SO_4)	1,067	931	81	263	163	164	329	306
Chloride radicle (Cl)	3.8	7.0	5.5	22	14	15	36	32
Nitrate radicle (NO_3)	1.2	0	7.7	.10	25	10		.27
Total dissolved solids at 180° C.	1,752	1,512	449	776	659	666	[d] 700-800	824
Hardness as $CaCO_3$ (calculated)	1,264	1,110	186	175	164	128	[e] 191	266

[a] Incomplete analysis of small sample collected in November, 1926.
[b] Analysis of sample collected in August, 1927. The comparatively large quantity of iron probably comes from the sand that was in the sample when received. Dissolved iron almost always separates by the time the sample is received in the laboratory. Therefore, it is customary to determine the iron in the sediment and to add it to the very small amount that is in solution when the water is received. It is probable that a sample of the water free from sediment would have a much smaller quantity of iron.
[c] Sodium, 164; potassium, 21.
[d] Estimated.
[e] Determined by soap method.

The samples from the Dakota sandstone obviously represent water of the same general character, although the water from the M. B. Kennedy well is notably lower in sodium and potassium and in sulphate and chloride than the average, whereas the water from the Newton Hill well is relatively high in all these constituents. The water from the asylum well is relatively high in most of the constituents and is somewhat harder than the other sandstone waters.

The Dakota sandstone water is notably different from that in the gravel in its content of mineral matter and hence in its chemical behavior. (See fig. 15.) The gravel water contains large quantities of calcium and magnesium, which make it hard, whereas the sandstone water is low in these constituents and hence relatively soft. The large amount of magnesium and sodium sulphates in the gravel water makes it somewhat objectionable for drinking and cooking. The sandstone water is therefore much better for drinking, for domestic uses, and for use in steam boilers. The gravel water is, however, superior in containing only a negligible amount of iron, whereas the sandstone water contains an appreciable amount of iron, which is objectionable for toilet and laundry uses.

The water from the well at the electric plant, according to Mr. Dokken, is very satisfactory for boiler use. Before this well was drilled great trouble was experienced with scale in the boilers, and attempts to soften the water were not entirely successful. The soft water cleaned off the scale and is said to form practically no scale at all. It has no serious tendency to cause foaming. Much water from this well was formerly sold to the people of Canton, who filled their cisterns with it and used it for washing.

The soft water at Canton is less highly mineralized and of better quality for nearly all uses than most of the soft water that is obtained from the Dakota sandstone in other areas. Thus the average of 10 samples of other soft waters from South Dakota, shown on page 149, compares unfavorably with the Canton soft water in showing a much higher content of the sodium salts, especially sodium chloride, which renders much of the soft water in other areas distinctly salty.

PHYSICAL PROPERTIES OF THE WATER-BEARING SANDSTONE

The stratum of sandstone that yields the soft water in the vicinity of Canton is about 30 to 34 feet thick and consists of fine but clean quartz sand that is sufficiently consolidated to form a soft, friable rock. Some of the physical properties of four samples of the material, as determined in the Geological Survey, are given in the table below. The two samples from the asylum well were tested by A. M. Piper according to standard methods;[18] the other two had previously been partially examined by Norah D. Stearns. Some of the sand from sample 4 is shown, greatly magnified, in Plate 20.

[18] Stearns, N. D., Laboratory tests of physical properties of water-bearing materials: U. S. Geol. Survey Water-Supply Paper 596, pp. 124–149, 1927.

Laboratory tests of physical properties of the water-bearing stratum of the Dakota sandstone at Canton, S. Dak.

	1	2	3	4
Mechanical analysis: [a]				
Fine gravel (larger than 1 mm.)	1.2	0.3	2.8	2.0
Coarse sand (1 to 0.5 mm.)	2.0	.5	2.2	.8
Medium sand (0.5 to 0.25 mm.)	1.8	.4	3.3	1.1
Fine sand (0.25 to 0.1 mm.)	89.0	81.9	41.3	36.7
Very fine sand (0.1 to 0.05 mm.) } Silt and clay (smaller than 0.05 mm.)	[b] 6.0	16.9	48.6	56.5
Silt and clay (smaller than 0.05 mm.)			1.8	2.9
	100.0	100.0	100.0	100.0
Moisture equivalent: [c]				
Per cent by weight			2.5	2.4
Per cent by volume			3.9	3.6
Porosity (per cent of total volume)			[d] 42.1	[d] 44.3
Permeability coefficient [e]		57	81	69

[a] The actual sizes of the sieves used, as determined by the U. S. Bureau of Standards, are as follows: 1.00, 0.59, 0.26, and 0.09 millimeter. About 25.4 millimeters is equal to 1 inch.

[b] Nearly all very fine sand—that is, more than 0.05 millimeter in diameter.

[c] The moisture equivalent is the moisture that remains in the sample after it has been saturated and then subjected to a centrifugal force 1,000 times the force of gravity, expressed as a percentage of the dry weight of the sample or as a percentage of the volume of the sample.

[d] The samples were obtained from well drillings and are not volumetric. The volume was determined in the laboratory after the sample had been compacted as much as possible by shaking and tamping.

[e] The permeability coefficient of a water-bearing material is the quantity of water, in gallons a day, that will flow through a cross-section area of 1 square foot of the material under a hydraulic gradient of 100 per cent.

1. Sample sent to the Geological Survey by William Tank, mayor, in June, 1925, and described as "a sample of the sand pumped out with the water."
2. Sample from the well of Norman Harrison (C in table on p. 158), collected by him when he drilled the well.
3. Sample from upper part of sandstone stratum in the asylum well, collected by E. C. Archibald, driller.
4. Sample from lower part of sandstone stratum in asylum well, collected by E. C. Archibald.

The sandstone is sufficiently consolidated so that the well remains open in it without casing, yet it is so feebly cemented that the drillings come up as incoherent sand and not as chips of sandstone. Under the microscope the drillings are seen to consist of separate quartz grains that are not cemented to one another, and there is no evidence of any cementing material. (See pl. 20.) On the other hand, many of the grains have a mottled appearance indicating that they have been etched by the solvent action of the water. In the wells that are pumped hard there has been rather persistent trouble due to sand rising with the water. According to Mr. Archibald, the upper 3 feet of the stratum in the asylum well consists of soft sand, but the rest is in general a rather firm sandstone. Even under pumping with great drawdown it yielded very little sand.

The samples analyzed consist essentially of fine to very fine sand, with only small amounts of medium and coarse sand and fine gravel (more than 0.25 millimeter in diameter) and only small amounts of silt or clay (less than 0.05 millimeter in diameter). In samples 2, 3, and 4 the 10 per cent size—that is, the size that is just larger than the finest 10 per cent by weight—is between 0.1 and 0.05 millimeter. It is believed that samples 2, 3, and 4 are fairly representative of the material as it occurs in the earth and that the fine material has not been washed out to any great extent in taking the samples. This can not, however, be definitely asserted.

In Plate 20, *B*, the largest grains shown are about 0.2 millimeter, or less than a hundredth part of an inch, in average diameter; the bulk of the material falls into the classes described as fine sand (0.25 to 0.1 millimeter) and very fine sand (0.1 to 0.05 millimeter); the smallest grains showing definite boundaries—those less than a fifth of an inch in diameter in the photograph—are classed as silt; and the swarms of minute particles are classed as clay. The smallest particles shown in the photograph are close to the maximum size of material that has Brownian movements. Though the silt and clay particles are very numerous they are so small that they do not form any large part of the material—not enough to fill much of the interstitial space or to prevent the sample from having the appearance of clean sand. Some of the largest grains are well rounded, but others have sharp angles; the smaller particles are angular or subangular.

The high porosity, or large amount of void space, as determined in the two samples from the asylum well (Nos. 3 and 4) is due to the scarcity of silt and clay and the general uniformity in size of grain. The fine material does not form a large enough part of the total volume to reduce the porosity appreciably by occupying the void spaces.

In each of the two samples from the asylum well the moisture equivalent is less than 4 per cent of the total volume of the sample. This remarkably low moisture equivalent for so fine a sand is evidently due chiefly to the scarcity of the very fine material, which is the most effective in holding moisture against centrifugal force or the force of gravity. The moisture equivalent of a material is often taken as a rough measure of the specific retention, or quantity of water that is held by the material against the pull of gravity; and the porosity minus the moisture equivalent is often taken as a rough measure of the specific yield, or quantity of water that is free to drain out of the material. If this assumption is permissible for these samples, the material of the soft-water stratum at Canton has a high specific yield.

Tests of permeability were made on samples 2, 3, and 4, but it should be understood that if the samples differ in compactness and texture from the material in its natural condition the results of the permeability tests may be misleading. These three samples did not differ much in permeability, and their average permeability coefficient was 69. This means that 69 gallons of water would percolate in a day through each square foot of the material under a hydraulic gradient of 100 per cent. Originally the hydraulic gradient of the Dakota sandstone in the southeastern part of South Dakota was approximately 10 feet to the mile in a general easterly direction,[14] but there is no information as to the present gradient in the vicinity of Canton. If the water-bearing stratum is 33 feet thick and has a hydraulic gradient of 10 feet to the mile and a permeability of 69, about 23,000 gallons a day percolates laterally through each mile of width of the stratum. Accordingly, a well or group of wells would have to draw from a distance of half a mile in each direction to yield a supply of 23,000 gallons a day, or from a distance of 6½ miles to yield 300,000 gallons a day.

Further computations indicate that if the permeability of the sandstone is as great as is indicated by the tests, water can be drawn to the Canton city wells at a rate of 300,000 gallons a day, but that this is nearly the maximum possible inflow.[15] The available data as to the performance of the wells indicate that the actual permeability in the compact sandstone may be less than that obtained in the laboratory, and hence that the supply perennially available at Canton may be less than has been computed. The plain lesson from these considerations is that while the city should develop its soft-water supply so far as practicable, it should keep its hard-water wells in repair and in sanitary condition so that they can be drawn upon whenever it may be necessary. Measurements of depth to the water level should be made from time to time in one of the wells, under similar pumping conditions in all the wells, in order to obtain information as to a progressive lowering in head. As the asylum-well is 1½ miles from the city wells there will be no serious interference between it and the city wells. Unless mechanical difficulties develop in that well, a supply of as much as 15,000 gallons a day will doubtless be perennially available at the asylum.

METHODS OF FINISHING WELLS

The small size of grain and slight coherence of the Dakota sandstone make it difficult to finish a well in this sandstone, especially a well that is to be subjected to heavy pumping. The more rapidly a well is pumped the farther the water level in it is lowered and the greater the pressure of the water into the well becomes. With increased pressure the velocity of the water percolating into the well is increased and hence also the tendency for the water to dislodge the fine grains of sand and to carry them into the well. The character of the water-bearing material in the soft-water stratum at Can-

[14] Darton, N. H., Geology and underground waters of South Dakota: U. S. Geol. Survey Water-Supply Paper 227, pl. 11, 1909.

[15] Slichter, C. S., Theoretical investigation of the motion of ground water: U. S. Geol. Survey Nineteenth Ann. Rept., pt. 2, pp. 358–363, 1899.

ton is such that, even with the most skillful work in developing and finishing the wells, it is not to be expected that a large supply can be pumped from one well without causing trouble with sand.

The trouble with the city wells was first brought to the attention of the Geological Survey by Mr. Tank. In a letter of June 12, 1925, he described the conditions, in part, as follows:

About the time the pumps were started to operate the four wells (Nos. 1, 2, 3, 4) furnished about 30 gallons of water a minute, but this water contained a large quantity of fine sand or sandstone, the abrasive quality of which was such that it destroyed the pump leathers and valves in a week and cut out the brass cylinders in about six months. Two men are kept at work almost continuously changing the leathers and grinding the valves and at times installing a new cylinder; also cleaning out the well chamber below the casing, which fills up with sand. This work has been carried on with the expectation that eventually the sloughing off of the sandstone surrounding the well would clear itself and that the abrasive action of the sand would thus be eliminated. However, this has not been the case, for we are still bothered with the sand. * * *

The four wells thus failing to supply a sufficient amount of water, a well with 12-inch casing was sunk (No. 5) and was equipped with a pump of the same type but much larger. The same conditions were found at the bottom of this well; in fact, the conditions were much worse than in the other four.

In response to Mr. Tank's letter the following statement of advice was prepared:

This is very fine sand in which to develop a well of considerable yield. If the undisturbed material in the sand bed includes coarser sand, it might be possible to get a satisfactory yield by developing a natural strainer by pumping out the fine sand; otherwise, the only hope appears to be in developing a gravel strainer by inserting gravel into the well. A metal strainer fine enough to keep out this sand will not give satisfactory results, and not much improvement can be expected by changing the position of the cylinder.

I suggest undertaking to develop well No. 5 by the following procedure: Put in a 6-inch casing with about 30 feet of coarse strainer or perforated casing at the bottom. This will leave an annular space between the 6-inch casing and the 12-inch casing at the bottom of about 3 inches. Insert fine clean gravel into this annular space and withdraw water and sand from the 6-inch casing until the water clears. Presumably, as sand enters the well and is withdrawn, the gravel will settle down and more gravel should be added at the top. The best device for cleaning out wells and developing gravel strainers is an air lift, but with a low-water level this might not be an economical way of lifting the water after the wells are put into service. It might be advisable first to use as large a bailer as can be advantageously operated. If this gives promising results it might be well to use an air compressor, or possibly, for the sake of economy, endeavor to complete the cleaning process with the pumps now at hand. If this method of finishing the well proves successful, the cleaning out process should be continued until the water clears with as large a discharge as possible. When the well is put into service it should not be pumped more rapidly than perhaps half the rate at which it furnished clear water at the end of the cleaning process. It is understood that in well No. 5, as in the others, the casing extends only to the top of the sand bed, about 30 feet from the bottom. The strainer or perforated casing at the bottom of the proposed 6-inch casing should extend to the bottom of the well.

At the time the field work was done at Canton, in September, 1925, wells 1 and 4 were in service, wells 2 and 5 were idle and said to be in bad condition, and well 3 was being cleaned out. Well 1 was yielding little or no sand and was giving fairly satisfactory service, but well 4 was bringing up fine bluish sand and was not giving satisfactory service. According to Mr. Harrison, the driller, well 1 was thoroughly cleaned out by means of an air compressor under the direction of the engineer in charge. He stated that the air lift was used for over a month, that occasionally back pressure was applied by means of the compressor, and that eventually the water cleared up under the air lift and yielded about 50 gallons a minute without bringing up sand. Mr. Harrison further stated that the air lift was not used on the other wells and very little effort was made to clean them out before putting them in service.

Mr. Archibald was employed by the city of Canton in the fall of 1925 to finish the wells, if possible, in a more satisfactory manner. He began work soon after the writer's visit to Canton. In a letter of January 26, 1926, Mr. Tank furnished the following information in regard to work done on wells 1, 3, 4, and 5:

In general we proceeded to remove the pump pipe, clean out the well thoroughly by use of hydraulic drills to what is supposed to be granite [Sioux quartzite] lying below the sandstone stratum. After cleaning out the well throughly we inserted in the uncased portion of the well from 30 to 40 feet of perforated and slotted pipes ranging from 4 to 5 inches in diameter. We then proceeded to pump the water out of these wells as long as the condition of the plungers permitted this to be done. Immediately upon the wearing out of the plungers we replaced the cup leathers and ground the valves and started to pump again. By this procedure we removed from these wells a considerable portion of the finer sand and left the coarser sand surrounding the slots in the newly inserted casing and thereby retaining the sand from coming in the casing. Nos. 1, 3, and 5 are doing exceptionally well and are furnishing, respectively, 35, 30, and 50 gallons a minute. No. 4 is still giving considerable trouble. We have had soft water for a period of eight weeks continuously without having been compelled to use any of the hard-water wells except once during a fire. We are using now about 150,000 gallons daily, and it is furnished by three wells.

In a letter of February 13, 1926, Mr. Archibald stated that the wells were greatly improved but were not yet finished to his satisfaction. He stated that the casings did not extend down to the sandstone and that the shale had caved and filled the wells and that it was still doing so. In his opinion further casing was necessary to shut out this fine material effectively.

The considerations above set forth seem to lead to the following conclusions: The water-bearing sandstone is sufficiently firm and coherent so that wells of small yield can often be finished successfully in it as rock wells—that is, with the holes left uncased and without strainers of any kind where they extend through the sandstone. In such wells care should be taken to seat the casing in firm sandstone and when the well is put into service to operate the pump slowly enough so that the sand grains will not be carried into the well. In some places the material is probably so incoherent that wells of this type will not be successful even at slow rates of pumping, and even the most successful wells may in time accumulate sand that will have to be cleaned out. The water-bearing stratum does not contain enough coarse material to be adapted for developing a natural strainer merely by the process of cleaning out the fine sand. Better results should be obtained and a more stable well assured by inserting fine gravel in the manner described above. But in whatever manner a well is finished in such material it should not be subjected to too heavy pumping. When it is put into service it should be pumped at a slower rate than the rate at which it produced water while it was being developed.

CONTRACT FOR DRILLING WELL AT THE UNITED STATES ASYLUM FOR INSANE INDIANS

Within certain limitations, the ground water belongs to the owner of the land under which it lies, and when he has a well drilled to it he pays the driller for effective service in developing a natural resource to which he already has legal title. Wells are commonly drilled at a certain price per foot. In localities where the prospects for obtaining successful wells are known to be good the driller may guarantee a water supply, but in localities where there has not been much drilling or where it is known that there are considerable chances of failure the driller usually guarantees only to make the hole. Well drilling involves many uncertainties, and even without a guaranty as to water the driller assumes much financial hazard. Unless he has ample financial backing and can obtain adequate extra pay for such a guaranty, he should not assume the extra hazard that it involves in territory where the ground-water conditions are uncertain.

If the water is obtained from hard rocks, the driller may have performed his entire duty when he has sunk the hole to the required depth. If, however, the water occurs in beds of sand or other incoherent material the driller's work is not complete when he has made the hole but only when he has, so far as possible, developed or finished the well in such a manner that it will yield a water supply without inflow of sand, silt, or clay and will remain in good condition for a period of years. The process of developing or finishing the well requires quite as much skill as the process of making the hole, and, if properly done, it may consume much time. A reliable driller will not leave a well in an unfinished condition or in a condition that will cause trouble in the future. However, if he is paid only at a certain rate per foot for making the hole, he can hardly afford to spend much time in developing the well, and if he does so he is at a great disadvantage with his less scrupulous competitors. In localities where wells end in sand it is therefore desirable to devise a form of contract that will give the driller adequate reward for skillful work in finishing a well without requiring him to assume undue hazards. Such a form of contract will also be advantageous to the persons for whom the wells are drilled, for it will tend to give them the services of skillful drillers on competitive terms.

The problem of a proper form of contract confronted the United States Office of Indian Affairs when it asked for bids for drilling the well at the asylum at Canton. The following specifications are essentially as they were prepared by the Geological Survey with a view to meeting the conditions outlined above:

Specifications for one well to be sunk at the Asylum for Insane Indians, Canton, S. Dak., into the sandrock that bears soft water:

The bidder shall furnish all equipment and labor necessary properly to construct and finish the well and shall furnish the casing and strainer and any other material or element that may be required to construct the well in a workmanlike manner. He shall case the well from top to bottom with 8-inch standard casing or pipe. [Diameter was later specified to be 6 inches.] He shall so construct the well at the bottom as to shut off and seal the well from any water entering from above the soft-water sandrock. He shall also construct the well in the soft-water sandrock at the bottom in such a manner that it will furnish at least 15,000 gallons of water in 24 hours without interference or trouble from sand or any other cause during a pumping test of at least two days' duration. He shall commence sinking the well within a reasonable period after the approval of his contract, shall continue operations without any unnecessary delay until the well is finished, and shall complete the well by November 1, 1926. When the well is completed with the above-mentioned guaranty as to yield and freedom from interference by sand or from other trouble, he shall receive full payment at the rate of $—— per foot of well drilled.

It is understood that the well shall be drilled to a maximum depth of 350 feet, if necessary, unless the hard Sioux quartzite, or "Sioux Falls granite," is struck before that depth is reached. It is further understood that in case it is impossible, on account of the absence or unsatisfactory character of the sandrock, to fulfill the above-mentioned guaranty, the contractor shall be paid at the rate of one-half of the above-mentioned price per foot drilled.

Because of the guaranty of "15,000 gallons in 24 hours without interference or trouble from sand or any other cause during a pumping test of at least two days' duration," the contract was attractive only to skillful drillers, and it gave the successful bidder a strong inducement and a proper reward for doing his best work. On the other hand, by specifying half price if the driller should not succeed in fulfilling the guaranty, he was protected from assuming an excessive hazard. In general, Government contracts for drilling wells have been very exacting in their requirements, and this has resulted in discouraging bidders and in making the bids excessively high. It is believed that an equitable and reasonable contract is to the interest of the Government in procuring the services of skillful and reliable drillers at moderate prices.

The advantages of this form of contract could, of course, have been obtained with specifications of other kinds. For example, the driller might be paid a certain price per foot for making the hole and an additional sum for fulfilling the guaranty. This would not be very different in effect from the actual specifications but would have the disadvantage of requiring a more complicated bid and of being a more radical departure in form from the usual contracts.

The successful bidder for the contract for the asylum well was Mr. E. C. Archibald, Council Bluffs, Iowa, whose bid of $5 a foot was the lowest submitted. As the well stood the prescribed test, the driller received the full price, which, for a total depth of 322 feet, amounted to $1,610.