DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 256

GEOLOGY AND UNDERGROUND WATERS OF SOUTHERN MINNESOTA

BY

C. W. HALL, O. E. MEINZER, AND M. L. FULLER

WORK DONE IN COOPERATION WITH THE MINNESOTA
STATE BOARD OF HEALTH

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CONTENTS.

ILLUSTRATIONS.

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INTRODUCTION.

AREA INVESTIGATED.

The region described in the present report includes approximately the southern two-fifths of the State of Minnesota and has an area of 28,265 square miles (fig. 1). Aside from the area occupied by the cities of Minneapolis and St. Paul, this is essentially an agricultural region. According to the census of 1905 it is inhabited by 1,295,850 persons, of whom 519,750 live on farms, 317,100 live in villages and small cities, whose existence depends on the agriculture of the region in which they are situated, and 458,800 live in Minneapolis and St. Paul, whose commercial importance depends upon an area reaching far beyond the limits of the district considered. Though southern Minnesota has passed the pioneer stage of agricultural development, there is yet in store for it great industrial progress and an accompanying increase in population.

PURPOSE AND SCOPE OF THE INVESTIGATION.

Importance and character of the work done.—Although this is a region of abundant precipitation and contains a large store of both surface and underground water, yet the economic and sanitary problems connected with its water supplies are numerous and important. Their importance is great if only the present development is considered; it is vastly greater if consideration is had of the inevitable future increase of urban population and the multiplication of industrial requirements.

The purpose of the present investigation has been to determine to the fullest practicable extent the principal facts in regard to the underground waters—their quantity, head, mineral quality, sanitary conditions, and their depths beneath the surface—as well as the best methods of drilling to them and finishing wells for their utilization and to consider all other questions relating to their recovery for human use. Furthermore, to make the investigation of the greatest practical service, the results have been applied as definitely as possible to particular localities, much emphasis having for this reason been placed on the county reports.

The principal problems involved in the investigation are summarized below.

Available sources of water.—In any given locality, what water-bearing formations occur, at what depths do they lie, and how much

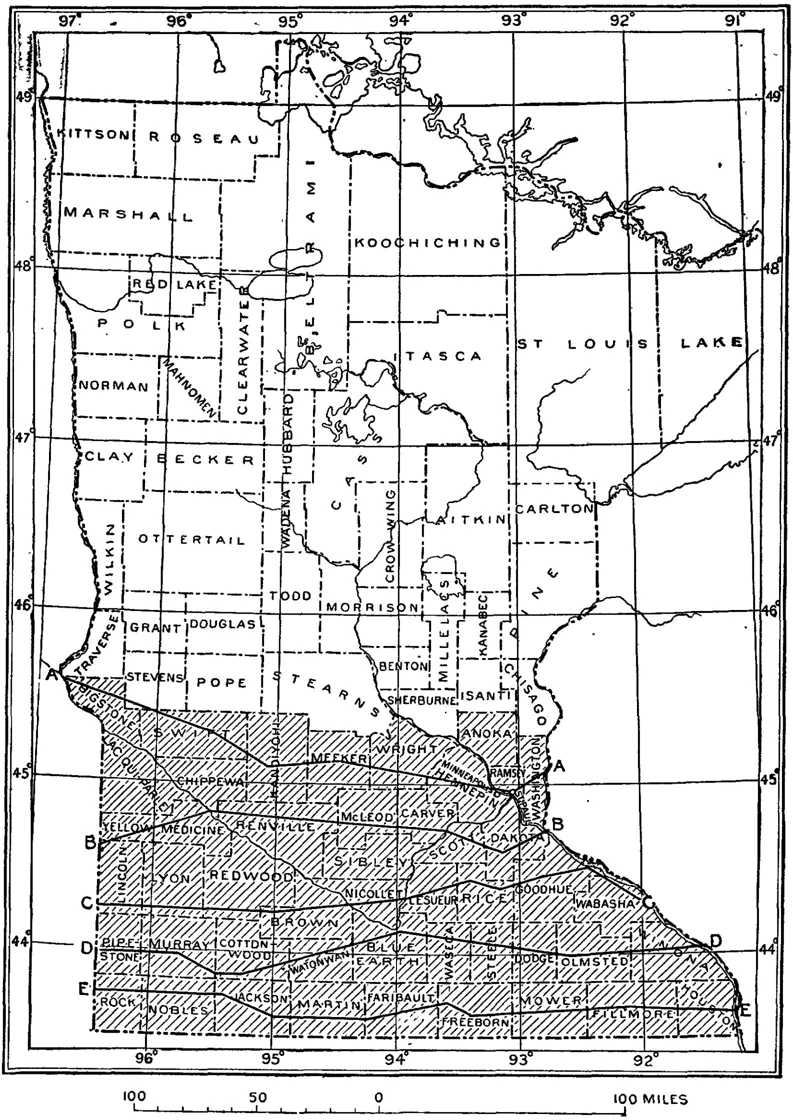


FIGURE 1.—Map showing area considered and location of sections on Plate V.

will they yield? As a result of lack of knowledge on these questions, on the one hand, communities have been content to rely on unsatisfactory supplies obtained near the surface, though better water may be had at greater depths, and, on the other hand, expensive drilling has been continued long after the lowest water horizon has been passed. By assembling all available data obtained from outcrops and well records it has become possible in large measure to answer these questions for each locality, and for places for which the data at hand are not sufficient to warrant positive statements the probabilities can at least be presented in order to give a reasonable basis for intelligent action.

Artesian prospects.—A question in which nearly all communities are interested is whether flowing wells can be obtained by drilling to the deeper horizons. Much blind optimism prevails in regard to this subject. Many communities have at one time or another borne the loss of expensive drilling at places where there was no real prospect of obtaining flows, and other communities are likely to suffer in the same way unless they are properly informed. In making this investigation it has been found that the deep wells already drilled give ample data for determining definitely for most communities whether or not there is any prospect of obtaining flowing wells. It is by no means necessary that every village or city should drill a deep well in order to learn whether flows can be obtained. Even where there are no prospects for flowing wells, the question of head is important. If the water rises higher from the deeper than from the shallower beds, it is important that the community should know it.

Mineral character of the water.—The underground waters of southern Minnesota differ widely in their mineral content. Even in the same locality waters obtained from different horizons may be radically different. As the mineral character of any water is highly important and determines to a great extent its value for domestic and industrial uses, this subject has here been fully considered, and the results of many analyses of Minnesota waters have been presented.

Sanitary conditions.—That there is an important relation between the character of the water supply of a community and its health is a fact now well recognized. Accordingly, in the present survey, the sanitary quality of the water supplies of nearly all the villages and cities in southern Minnesota was carefully examined.

Public supplies.—The problems connected with the source, lifting, storage, and distribution of public supplies are numerous, and, because of the several variable factors involved, they are not precisely the same for any two communities. Many serious mistakes are made in connection with the public supplies of villages and small cities, and it is hoped that the presentation of facts and the discussion of conditions in southern Minnesota will be of general value.

Construction of wells.—The drillers and the people of the area investigated are at present contending with a number of vexatious problems, partly mechanical and partly geologic in character, pertaining to the successful construction of wells. A discussion of these problems is presented in this report.

HISTORY OF THE INVESTIGATION.

The underground water survey upon which this report is based has been conducted under the general supervision of Prof. C. W. Hall, of the University of Minnesota. The field work for the eastern part of the area was done in 1906 by M. L. Fuller, who was assisted by F. G. Clapp and H. S. Spaulding; that for the western part was done in 1907 by O. E. Meinzer, who was assisted by E. B. Tourtellot. The investigations in 1907 were made in cooperation with the Minnesota state board of health, which has already rendered to the State much admirable service in connection with the sanitation of the public water supplies. In general, Professor Hall and Mr. Fuller are responsible for the maps and sections of the eastern part and Mr. Meinzer for those of the western part. The authorities for most of the well sections are given in connection with the sections, but the correlations were made by the authors unless otherwise stated.

In the preparation of this report the authors are indebted to many persons for assistance, suggestions, and criticisms, but especially to Mr. H. A. Whittaker and Mr. A. W. Johnston. Mr. Whittaker has given valuable aid in connection with the presentation of analyses of the waters; Mr. Johnston has done much good work on the maps and sections of the eastern area. Further acknowledgments are made in the chapters on the mineral quality of the underground water and on public water supplies.

PHYSIOGRAPHY.

By C. W. Hall and O. E. Meinzer.

GENERAL STATEMENT.

Southern Minnesota as a whole is a low plateau which, generally speaking, is just starting a new cycle of denudation. In describing the topography it will be convenient to discuss, first, the general contour of the upland surface; second, the minor irregularities of this surface; and, third, the erosion features of the new cycle, the dissection of the plateau that has thus far been accomplished by the streams which are to-day vigorously gnawing into it at a thousand points.

GENERAL CONTOUR OF THE UPLAND SURFACE.

A glance at the topographic map (Pl. I) will show that the plateau surface of southern Minnesota lies at two distinctly different levels. The southwestern portion, forming only a small part of the total area, stands fully 500 feet above the adjacent upland plain and the transition from the one level to the other, although gradual, is relatively well defined, especially toward the northwest. This higher plateau, extending from Minnesota far into the Dakotas, has long been known as the "Coteau des Prairies."

The upland surface of the area, exclusive of the coteau, exhibits a few large flexures, which are extremely gentle but which influence profoundly its topography and underground water and have great significance in the interpretation of its geologic history. Its highest portion, in the southeastern part of the State, forms a flat dome culminating at an elevation of about 1,400 feet above sea level in Mower County, whence it declines very gradually in all directions. Toward the east it slopes downward to the cliffs of the Mississippi, the tops of which have an elevation of about 1,200 feet above sea level. Toward the west it slopes to the valley of Blue Earth River, which stands about 1,100 feet above sea level, beyond which it rises gently in the direction of the coteau. Toward the north it slopes to the northeast corner of the area under consideration, where the plateau is lowest, its altitude there scarcely exceeding 900 feet.

Taking a different viewpoint, it will be seen that the Minnesota Valley, from Bigstone Lake to the great bend at Mankato, occupies essentially the axis of a trough in the western portion of the plateau. That is, from the crest of the uplands bordering the valley, where the average altitude is 1,050 feet, the surface rises gently in either direction, reaching an elevation of about 1,200 feet at the foot of the coteau on the one side and at the north-central margin of the area on the other. Although the average upland altitude along this stretch of the Minnesota Valley is about 1,050 feet, the axis of the trough itself slopes downward from Bigstone Lake, where it is only slightly less than 1,100 feet above sea level, to Mankato, where it is somewhat below 1,000 feet. This slope is shown by the contour lines on the topographic map, the 1,100-foot contours diverging from Bigstone Lake southeastward, and the 1,000-foot contours diverging from Minnesota River to Mankato.

In the same sense the valley of Blue Earth River occupies the axis of a trough between the coteau on the west and the Mower County dome on the east. This axis has a north-south trend and declines from somewhat less than 1,200 feet above sea level at the state line to less than 1,000 feet at Mankato, where it converges with the axis first described. A third trough has an axis extending from the convergence of the other two at Mankato to the low district comprising the northeastern part of the area.

In other words, the upland surface of southern Minnesota culminates in three elevated regions. The most prominent is the coteau, occupying the southwestern part of the State; a much lower one is the dome in the southeastern part; and a still lower and less conspicuous one lies near the center of the northern boundary of the area here considered. Between these three elevations there are three troughlike depressions whose axes slope away from the highest elevation in the southwest toward the lowest depression in the northeast.

MINOR IRREGULARITIES OF THE UPLAND SURFACE.

All but the southeastern corner and perhaps the extreme southwestern corner of the region is covered with glacial drift deposited during the most recent ice invasion, and hence the upland topography is essentially that produced by glaciation. Nowhere is there a more typical example of ground moraine left in the wake of a continental ice sheet than is exhibited by the extensive, slightly undulating, monotonous expanses of southern Minnesota, dotted with countless shallow lakes and ponds and covered with an interminable network of swamps. This ground moraine gives to the region its characteristic topography, but it is interrupted at intervals by belts of terminal or recessional moraine, which have a surface that is equally poorly drained but much more irregular and hummocky, and that stands conspicuously above the surrounding ground moraine (Pl. II).

The topography includes several other groups of modifying features, among them (1) flat areas that once lay at the bottom of extensive glacial lakes; (2) sharp ridges of quartzite which, in a few localities in the southwest, project abruptly above the smooth surface of the drift beneath which they are nearly buried; (3) outliers of resistant, horizontally bedded limestones, forming low mounds or mesas in the southeast, where the drift is thin or absent; (4) depressions due to sink holes where the limestone is near the surface; (5) sand dunes; and (6) areas in the southeast quarter in which the topographic rugosities have been covered over by a smooth, thin veneer of wind-driven loess.

FEATURES OF EROSION.

A glance at the topographic map will give a general idea of the amount of stream erosion in this area. One deep broad gorge—the valley of Minnesota River—has been cut through the heart of the area; another much deeper gorge—the valley of Mississippi River—forms its eastern boundary. The gorge of the Minnesota is not at many places cut more than 200 feet below the upland level; the gorge of the Mississippi locally reaches a depth of 500 feet.

The southeastern part of the region is much more thoroughly dissected than the rest, and the difference is so great that the region can be divided into two distinct physiographic provinces. The southeastern province, adjacent to the Mississippi and approximately 500 feet above it, is traversed by an intricate drainage system which has cut innumerable steep, rugged valleys and ravines several hundred feet into the hard rocks, in some localities leaving only remnants of the plateau surface. Here there are no lakes or swamps, for the drainage is good. A thousand steep-graded ravines conduct rain water to the Mississippi. The erosion features are conspicuous, for the present cycle of denudation is well under way and has nearly reached the stage when the denuding processes shall have attained their maximum activity.

The other province, which includes much the greater portion of the total area, has an entirely different aspect. It is, indeed, dissected by one great gorge, the Minnesota Valley, the physiographic development of which, as shown by its width and depth, is anomalous as compared with that of the region through which it passes. The monotony of the upland surface is also interrupted by several smaller gorgelike valleys, most conspicuous among which are those of the upper Mississippi, Blue Earth, and Des Moines. Moreover, these major valleys are joined by many rugged, canyon-like tributaries that are incised into the uplands, locally producing a surface similar to that found in the southeastern province. But this stream erosion is local and exceptional. Nearly all these tributary gorges are very short and affect the topography for only a few miles back from the major valleys. Extensive interstream areas are virtually untouched by stream action. In other words, in this province the cycle of denudation is just beginning, and the region is still in its physiographic infancy. The interstream regions, which comprise vastly the greater portion of the total area, constitute the unmodified drift plain, with its ground moraine and belts of terminal and recessional moraines. The numerous lakes, ponds, and swamps in this region show the lack of adequate drainage. Here and there sluggish streams meander lazily over the surface, conducting the water from one swamp to another and bringing it slowly toward some distant drainage channel.

One district in this province—the slope from the coteau to the lower plain—is unique. Although the gradient of the general surface here is so slight that it is scarcely perceptible, yet it has been ample to allow the surface water to run off and erode to sufficient depths to tap the ground waters, and hence to start springs that give rise to perennial streams. The little canyons thus formed, like those tributary to the Minnesota and other major valleys, are being actively eroded headward, and are encroaching more and more on the upland surface, draining lakes and swamps and diverting the sluggish creeks which meander across the uplands. Here is a great arena of stream piracy. As the cycle advances, the lazy streams of the uplands, which are entirely consequent upon the slight original irregularities of the drift plain, will be captured at many points by the vigorous subsequent streams that are aggressively developing headward.

Each of the streams that rise on the coteau and empty into Minnesota River encounters a diversity of conditions. It runs swiftly down from the coteau, eroding actively, but as it reaches the foot of the slope its grade is abruptly lessened and it is compelled to make its way across a broad, nearly flat plain. It is in much the same situation as a mountain torrent that descends through precipitous canyons and emerges suddenly on a broad plain where its velocity is checked and it is obliged to deposit its load and build up a great alluvial fan. Where the stream coming down from the coteau reaches the foot of the slope, it is no longer able to erode, and, indeed, can hardly transport the sediment it accumulates in its swift course. At first it flows virtually at the general level of the plain, but gradually, as it proceeds, it cuts a shallow valley. When at last it nears its mouth, it undergoes another profound change. The Minnesota is flowing at a level 100 or 200 feet lower, to reach which the stream must descend by leaps and bounds. Hence, when the stream leaves its shallow valley it enters a rugged and often picturesque gorge, from which it emerges into the broad Minnesota Valley, where it mingles its water with that of the greater stream. These are the vicissitudes of a youthful stream—one which has not yet adjusted its gradient to the topography of the region through which it flows.

The topography of the extreme southwestern part of Minnesota differs somewhat from that of any considerable adjacent part of the State, although it is similar to that of a large area in Iowa. It is not notably dissected and has only shallow valleys, but its drainage is complete, lakes and swamps being few and far between.

The topographic map (Pl. I) shows that lakes are present throughout most of the territory described, but that they are absent (1) in the southeastern province, (2) on the slope from the coteau, and (3) in the southwestern corner. Their scarcity in Lac qui Parle County and adjacent parts is explained in the report on that county.

RELATION OF DRAINAGE TO UPLAND CONTOUR.

It will be instructive at this point to inquire, What would be the directions of drainage if all the valleys made by recent erosion were filled and the original plateau surface were everywhere restored? It is evident that the southwest corner would be drained southward, that the extensive northwestern trough would drain toward and along an axis nearly corresponding to the present Minnesota River from Big Stone Lake to Mankato, that the south-central trough would in like manner drain toward and along an axis roughly corresponding to Blue Earth River, and that the water from both these troughs would drain northeastward, nearly along the line of the present Minnesota River below Mankato. In other words, the drainage of most of southern Minnesota in its general features is consequent upon the contour of the upland surface. But in the southeast this is not true. If the upland surface were here restored no Mississippi River would flow southward, providing the outlet for the drainage of most of southern Minnesota, but, on the contrary, the surface waters would flow, in general, northward from the high ground in the southeast toward the lower region in the northeast. In going from St. Paul down the Mississippi this discordance between the direction of drainage and the direction of the upland slope is apparent. At St. Paul the cliffs from the valley bottom to the upland level are only of moderate height, but they become increasingly higher downstream, at a rate entirely out of proportion to the gradient of the stream, until they tower above the river in picturesque grandeur. Farther south, along the eastern margin of Iowa, the upland surface slopes southward and the cliffs diminish in height.

The influence of the topography on the level of the ground-water table, the general underground circulation, the occurrence of springs, and the artesian pressure or conditions of the region is fully considered in this report, both in the general discussion and in the various county reports.

GEOLOGIC HISTORY.

By O. E. Meinzer.

GENERAL OUTLINE.

Five great rock divisions occur in southern Minnesota. Named in the order of their age, these are the Archean, Algonkian, Paleozoic (here including the Cambrian, Ordovician, and Devonian systems), Cretaceous, and Quaternary. Tertiary stream deposits doubtless exist in some localities, but they are so unimportant that they have not been differentiated and are here considered with the Quaternary.

In the northwestern and the north-central parts of the area the Archean system, consisting of granite and allied crystallines, outcrops in a number of localities and everywhere lies within a few hundred feet of the surface, but toward the south and east it slopes downward abruptly and is found only at considerable depths (Pl. III). In the southwest the Sioux quartzite, which is of Algonkian age, projects up through younger formations in four districts and appears at the surface at numerous localities (Pl. III). The contact between the quartzite and the granite is nowhere exposed, and has only rarely been reached in drilling.

In the east and south, where the granite is far below the surface, it is overlain by a succession of indurated sandstones, shales, and limestones, aggregating many hundreds of feet in thickness, at least the upper part being of Paleozoic age. Throughout most of the western part, and probably in isolated areas of the eastern part, of southern Minnesota, Archean, Algonkian, and Paleozoic rocks are covered by Cretaceous deposits consisting of soft, plastic shales and incoherent sandstones which together attain a maximum thickness of at least 500 feet, though they are generally much thinner. Spread out over all of these formations is a mantle of glacial drift which was laid down in the Pleistocene epoch, and which, except for the alluvium recently formed in stream valleys, is the youngest deposit in the region.

PRE-PALEOZOIC TIME.

It is difficult to outline, even in a general way, the pre-Paleozoic history of southern Minnesota. That the Sioux quartzite originated as a deposit of sand is shown by the cross bedding and ripple marks that are still preserved. Later it became thoroughly indurated, at least in some parts; it was affected by diastrophic movements, the character and intensity of which are unknown; and through these movements it came to be subjected to erosion, which, no doubt, was long continued. The prevailing features of the now nearly buried quartzite surface seem to be elevated table-lands here and there dissected by canyons, and generally ending in abrupt escarpments,

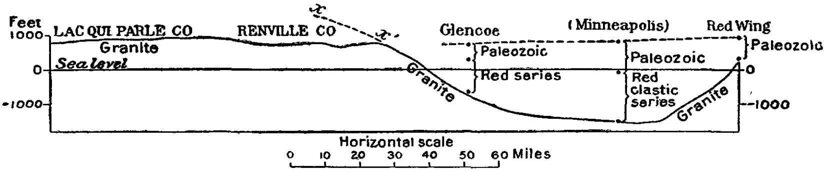


FIGURE 2.—Diagrammatic section across southern Minnesota.

beyond which the quartzite disappears to depths not reached even by deep wells; but just what processes produced this fossil topography is a matter of speculation.

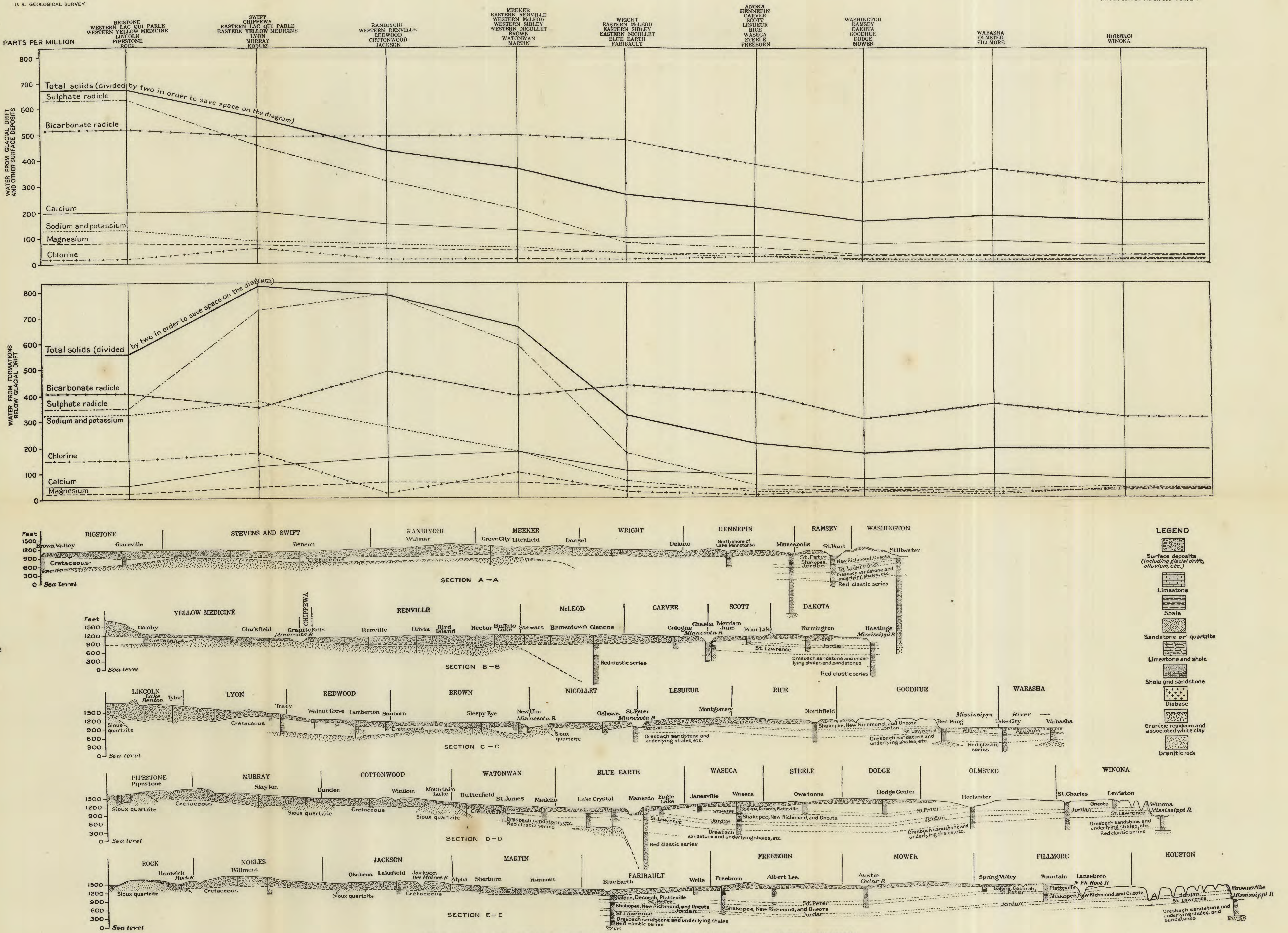
As has been indicated, in the eastern part of the area here considered, the granitic surface is low and is deeply buried beneath sedimentary rocks, while in the northwest it is everywhere relatively near the present surface. When the sedimentation in the east began, the granitic surface probably had even greater relief than it has at present; the sinking of this surface in the east, which seems to have taken place since that time, probably being more than counterbalanced by the erosion that has reduced the elevation in the northwest. These relations are shown in Plates III and V, and, with less detail, in figure 2, in which the dotted line x–x' represents, in a conservative generalization, the projection of the pre-Paleozoic granitic surface, and hence suggests the relief of that surface in the west before it was reduced by erosion.

The depression formed in the east by the granitic surface is filled with indurated sediments (fig. 2). The upper strata of these sediments outcrop and, by the fossils which they include, are known to be of Paleozoic age; the lower part consists of a great thickness of red clastic beds which are not known to come to the surface, and whose age and relations are therefore problematic. Their exact relations to the red Sioux quartzite, on the one hand, and to the recognized Paleozoic strata, on the other, remain undetermined. N. H. Winchell and Warren Upham, the former then state geologist, believed that the Sioux quartzite, the Keweenawan series of the Lake Superior region, and the red clastic beds encountered below the recognized Paleozoic strata in deep drilling in southeastern Minnesota are all Paleozoic (equivalent to the Potsdam of New York); that the red clastic beds are younger than the Keweenawan series; and that they lie conformably below the recognized Paleozoic sediments.[a] Their view as to the age of these rock series has never been generally accepted and appears to have all the probabilities against it. Recently C. W. Hall has restudied the red clastic series. He has indicated his disbelief in the assumption that it is closely related to the Sioux quartzite, and has shown that its lithologic character, stratigraphic situation, and geographic relations suggest that it is the sedimentary extension of the Keweenawan rocks of the Lake Superior basin, and may represent a transition from Proterozoic to Paleozoic time.[b] In this paper it is tentatively called Algonkian (?).

PALEOZOIC PERIODS OF SEDIMENTATION.

During much of the first part of the Paleozoic era the sea extended into the southern and eastern part of the area, but there is no evidence that at any time it covered the northwestern part. In order to understand the physical history of this period it is necessary to revert to the subject of the contour of the granitic surface. In the northwestern and north-central parts of the area this surface is everywhere within a few hundred feet of the present surface; in the eastern and southern parts it lies very much lower; and the transition from the higher level of the northwest to the lower levels of the southeast is strikingly abrupt (Pls. III and V and fig. 2). It is as if the elevations of an irregular surface of great relief were beveled off to a certain level, and the most rational explanation seems to be that such a beveling has in fact taken place. At the beginning of the Paleozoic there was probably a high granitic area in the northwest. As the era progressed this elevated district was worn down and furnished sediments which were deposited in the southeastern depressions and regions beyond, into which the sea had come, the base

[a] Final Rept. Geol. and Nat. Hist. Survey Minnesota, vol, 1, 1882, pp. 422, 424, and 537.
[b] Unpublished manuscript.



SECTION SHEET SHOWING GEOLOGIC STRUCTURE AND QUALITY OF UNDERGROUND WATER IN SOUTHERN MINNESOTA.

level to which the denudation was carried varying more or less, of course, with the oscillations of the sea. At first, when the land was high and erosion was rapid, the sediments were all clastic, and a portion of them were gravelly; later, when the land had been reduced to a lower relief, there were long epochs in which only small quantities of fine sediments were borne seaward, and in the clear waters, teeming with lime-secreting animals, were formed thick beds of limestone. At last the submerged depressions became nearly filled with sediments and only a slight change in the level of the sea was necessary to drain the southeastern area.

The Paleozoic rock succession of southern Minnesota contains one prominent unconformity, with others, no doubt, of minor importance. The stratigraphic record proves that the sea extended into this area during at least the latter portion of the Cambrian period and nearly all of the Ordovician, and again during a part of the Devonian period. It further proves that the area emerged at some time during the late Ordovician, the Silurian, or the early Devonian, for the Devonian strata rest upon an erosion surface of the Ordovician. The Paleozoic history can therefore be summarized as follows: A long period of submergence and sedimentation with many vicissitudes of relatively minor importance; a gradual but probably complete emergence; a period of erosion; a second submergence less extensive; and a complete and final emergence, followed by a long period of erosion.

PRE-CRETACEOUS ERA OF EROSION.

The era of erosion which followed the Devonian sedimentation must have been long. From all indications it continued without interruption during the latter part of the Paleozoic and throughout all of the Triassic, Jurassic, and early Cretaceous periods of the Mesozoic. Not until the middle or late Cretaceous did the sea again invade the region. During all this time none but the most gentle diastrophic movements took place, and it is improbable that the region was ever lifted to any great height above the sea or had any pronounced relief.

In the area in which the Cretaceous sediments rest upon the Archean, the upper part of the latter is almost everywhere thoroughly decomposed to a considerable depth. The granitic residuum and the deposits immediately derived therefrom are described at some length in the reports on Redwood and Renville counties, and it is only necessary to peruse the reports on the various counties in which the Cretaceous rests on the Archean in order to understand how widespread and profound was the decomposition of the Archean surface at the time the record was sealed. This condition can not be without significance. It must mean that the region was low and that the erosive agents had become inoperative in removing the products of weathering, which were consequently allowed to accumulate to great depths.

Another significant fact shown by the numerous sections given in this report and by all other available data is that the sediments which comprise the Cretaceous system, even in its basal members, consist almost exclusively of impalpable clay and of quartz sand such as would result from the complete decomposition of the granite. Basal gravels would probably not be so generally wanting if the region as a whole had possessed any great relief.

What was the topography when the Cretaceous sedimentation began? Was southern Minnesota then a peneplain? The upland surface formed by the Paleozoic rocks of southeastern Minnesota and adjacent parts of Wisconsin and Iowa have long been regarded as an ancient peneplain (fig. 2), but, because Cretaceous sediments are not found here to any extent, it is not certainly determined whether this supposed peneplain was pre-Cretaceous or post-Cretaceous. But farther west, where Cretaceous strata rest directly upon the weathered Archean surface, the topography that existed immediately preceding the sedimentation has been preserved, except in so far as more recent deformations have produced modifications. Plates III and V show essentially what is known about this fossil topography. It is evident from these plates that, while it appears nearly level when compared with the topography of the granitic surface preserved beneath the more ancient sediments, it has a relief of several hundred feet. Although changes of elevation have taken place since Cretaceous time, many of the irregularities are of such a character that they must have been present at the time of the Cretaceous sedimentation. If a further allowance is made for a certain amount of possible rejuvenation of the streams concomitant with the submergence, it still remains a question how nearly the ancient surface may at one time have approximated a base level. The Sioux quartzite areas certainly rose several hundred feet above the surrounding country and formed ridges or mesas of striking prominence, comparable to the present quartzite ridges near Baraboo, Wis., while much lower and yet distinct elevations also existed in the granite areas.

CRETACEOUS PERIOD OF SEDIMENTATION.

The Cretaceous seas encroached upon southern Minnesota from the west, and extended eastward an indefinite distance. The areas of Sioux quartzite were apparently not submerged, but were surrounded by the sea, thus forming rocky islands. A maximum of fully 500 feet of sediments were laid down, consisting chiefly of impalpable clay with some interbedded strata of sand. (See the report on Lyon

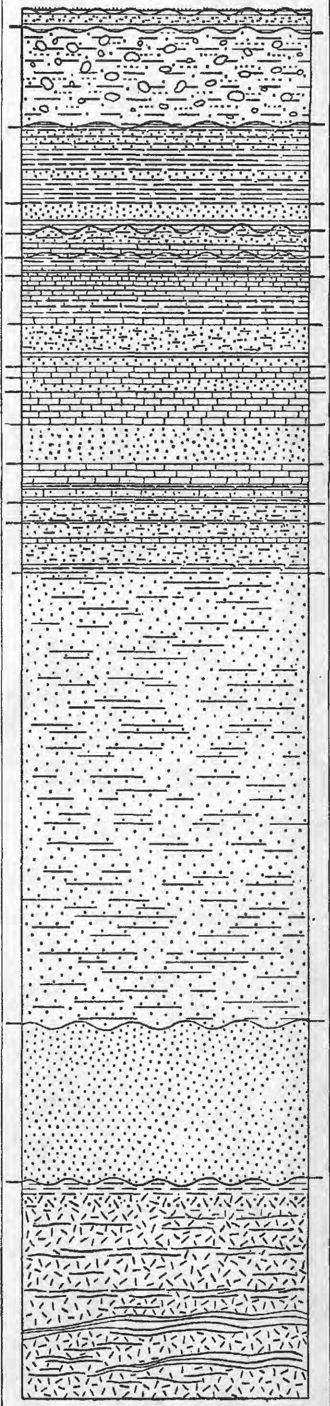
County.) The submergence probably began in the Dakota epoch and ended in the Niobrara, although this is not definitely known.

POST-CRETACEOUS TIME.

Since the sea retreated in Cretaceous time it has not again returned, and throughout the Tertiary the entire area was once more subjected to stream erosion. Several times the Pleistocene or "Glacial" continental ice sheets invaded the region from the north, eroded the surface, and finally retreated, leaving thick deposits of glacial drift. All but the southeastern corner was at one time covered with ice, and by far the greater part was overridden by the ice of the last advance. The slight amount of postglacial stream erosion accomplished upon the youngest drift sheet has been described in connection with the physiography.

The uplands of southeastern Minnesota and adjacent parts seem to represent a surface which was first beveled and then gently bowed up. Mississippi River flows through this elevated area in a direction nearly opposite to the inclination of the upland surface. Such a condition could be brought about in several ways, but probably the river existed before the present elevation, and was able to cut down its valley rapidly enough to maintain its course in spite of the regional uplift. The amount of erosion effected by the Mississippi and its tributaries in this area gives a rough measure of the time that has elapsed since the uplift and present denudation cycle began. The time represented by this erosion is certainly brief when compared to the total time involved in the geologic history recorded in southern Minnesota; it is certainly very long when compared to the time since the youngest drift sheet was deposited.

The preglacial topography of the region in the southwest known as the Coteau des Prairies is still imperfectly understood, mainly owing to the great thickness of the drift deposits, at least in some localities. But this thickness of the drift itself proves that the present plateau-like elevation of the coteau is not entirely preglacial in origin. (See the report on Lincoln County, pp. 232–236.) Nevertheless, the high quartzite areas were there at the time of the ice invasions, and associated with them there was probably other relatively high ground; and these elevations were together competent to block the ice or divert its course to some extent. Thus in the last glacial epoch, and perhaps in a measure in earlier invasions, the ice assumed the shape of a huge tongue which was pushed across southern Minnesota and far into Iowa, occupying the relatively low region represented by the Minnesota and Blue Earth basins, and confined between the quartzite ridges and associated high land on the one side and the elevated area of southeastern Minnesota on the other. Plate II

Era.	System and series.		Formation.	Columnar section.	Character of strata.	Approximate maximum thickness.	Water-bearing value.
						Feet.	
Cenozoic.	Quaternary.	Recent.			Alluvium, etc.	....	Yields freely in some valleys.
		Pleistocene.			Glacial drift, consisting of bowlder clay, sand, gravel, etc.	575	Yields copious supplies from sand and gravel beds; and small supplies from upper part of bowlder clay.
Mesozoic.	Cretaceous.		Benton shale.		Soft blue shale and incoherent sandstone.	500	Yields small or moderate supplies from sandstone.
			Dakota sandstone.		White sandstone, etc.		Yields small or moderate supplies.
Paleozoic.	Devonian.				Limestone and sandstone.	100	Locally yields moderate supplies.
	Ordovician.		Maquoketa shale.		Shale, dolomite, and argillaceous sandstone.	100	Locally yields small supplies.
			Galena limestone. Decorah shale. Platteville limestone.		Limestone and shale.	350	Yields moderate or large supplies.
			St. Peter sandstone.		White or yellow sandstone, with some shale.	200	Yields large supplies.
			Prairie du Chien group: Shakopee dolomite.		Yellow, buff, pink, or red dolomite.	75	Locally yields small supplies.
			New Richmond sandstone.		White sandstone.	40	Yields moderate supplies.
			Oneota dolomite.		Buff to reddish dolomite.	200	Generally yields moderate supplies.
	Cambrian.		Jordan sandstone.		Coarse-grained white sandstone.	200	Yields large supplies.
			St. Lawrence formation.		Dolomite, shale, and sandstone.	225	Yields little water.
			Dresbach sandstone.		Fine-grained white sandstone; shaly beds toward base.	450	Yields large supplies.
					Shale, white sandstone, and thin limestone.		Yields freely in some parts.
Proterozoic.	Algonkian (?).		Red clastic series.		Red sandstone and shale. Partly volcanic clastic rocks.	2,250	Yields little water.
	Algonkian.		Sioux quartzite.		Red quartzite.	Unknown.	Yields small supplies.
	Archean.				White clay. (Decomposition product. In part reworked and then belonging properly to the Cretaceous.)	....	Rarely yields small supplies from sandy beds.
					Decomposed granitic rock of red, yellow, or green color.	....	Rarely yields small supplies.
					Granite, gneiss, and schist.	Unknown.	Not water bearing.

GENERAL GEOLOGIC SECTION OF SOUTHERN MINNESOTA.

reveals a remarkable variation in the thickness of the drift, and also makes it evident that this variation has a relation to the path of ice movement. The drift is thin along the central portion of the tract followed by the ice tongue of the last invasion; it is thick—locally very thick—along the margins of this tract as delineated by the moraines. The explanation appears to be that the ice tongue tended to erode along the central portion of its course where it was thick and the axial velocity relatively great, while it deposited its load along the margins toward which it deployed. The data at hand seem to show that the Cretaceous deposits have been removed to a greater extent along the axis of the ancient ice tongue than on either side. This may be the result of preglacial stream erosion, but it may also be due to the greater erosive activity of the ice along this line.

GEOLOGIC FORMATIONS AND THEIR WATER-BEARING CAPACITY.

By C. W. Hall.

The five great geologic divisions recognized in this area have already been described. In the order of their age and superposition they are the Archean, Algonkian, Paleozoic (which here includes Cambrian, Ordovician, and Devonian rocks), Cretaceous, and Quaternary (including the Pleistocene series, the Recent series, and some undifferentiated Tertiary stream deposits). (See Pl. VI.) In regard to their importance in furnishing water supplies, the Pleistocene ranks first and the Paleozoic second, while the Cretaceous and Algonkian are of minor value, and the Archean is virtually destitute of available supplies, everywhere marking the lower limit of water horizons.

SURFACE DEPOSITS.

DEFINITION.

The term "surface deposits" will be used throughout this paper to include all Pleistocene and Recent formations, together with such pre-Pleistocene materials as can not well be differentiated from them—for example, Tertiary stream deposits, which without doubt exist in some localities. In other words, it is made to include the glacial drift and all associated water and wind deposits, as well as the alluvium laid down in the valleys outside of the drift-covered area. Such a term is open to numerous criticisms, but is here employed because of its great convenience in describing underground water supplies. In discussing the surface deposits the following convenient but rather arbitrary subdivisions are recognized: (1) Glacial drift, (2) outwash and terrace deposits, (3) recent alluvium, (4) loess, and (5) dune sands.

GLACIAL DRIFT.

The bulk of the glacial drift consists of a matrix of clay in which are imbedded, in the most promiscuous manner, pebbles and bowlders of various sizes and composition, the whole forming an impervious mass known as bowlder clay or till. This material was deposited by the various ice sheets which invaded southern Minnesota in the Pleistocene epoch. It was laid down either at the base of the ice as ground moraine or at the margin of the ever-melting ice sheet as terminal or recessional moraines. Intermingled and interbedded with this impervious bowlder clay, in the most intricate, chaotic, and varied manner, and also frequently lying beneath it or above it, there are beds of porous, water-laid sands and gravels which constitute the water-bearing members of the drift. In some places these sand and gravel beds lie between two till sheets of distinctly different age, and represent an interglacial epoch, but the majority of them probably have not this significance. Inspection of the numerous sections of the drift given in this report makes it evident that, although a very large percentage of its material consists of impervious bowlder clay, the interbedded layers of sand and gravel are present in nearly every locality, and are nearly always encountered by wells penetrating the drift to any considerable depth. By comparing the well sections of the same locality, it also becomes evident that most of these porous beds vary widely in thickness, in coarseness of material, and in the depth at which they lie. Only rarely can a bed be traced definitely by means of well sections for more than a few miles. In the terminal and recessional moraines the percentage of sand and gravel is much higher than in the more general ground moraine.

In general the drift has a dark color due to the unoxidized condition of the iron which it contains, but at the surface there is a nearly continuous mantle of yellow, partly oxidized drift, varying in thickness but averaging perhaps not over 15 feet and nowhere attaining any great depth. The water in the drift is almost universally charged with iron in the soluble ferrous condition due to the general dearth of oxygen, but the analyses show that in the surficial yellow zone the water is comparatively free from iron, the obvious explanation being that the iron is here oxidized to the relatively insoluble ferric condition. In many of the undrained depressions peat deposits are forming at the present time from the accumulation of vegetable matter, and in these localities ferric compounds may be absent. Occasionally beds of yellow clay, as well as thin layers of soil and peat, exist between the deposits of dark "blue" clay.

The gray or blue till, which constitutes the bulk of the drift of southern Minnesota, is derived in large part from the Cretaceous shales of this color. Pebbles of crumbly, gray-blue shale are frequently found in well drillings and surface exposures, and this shale is referred without question to the Cretaceous. In certain localities in the eastern part of the State, however, deposits of red drift occur, the material evidently being derived from the red formations of the Lake Superior region. The distinction between northwestern and northeastern drift is frequently very clear and even striking, and the mineral composition of the water can, in a measure, be predicted through a knowledge of the source of the glacial drift from which it is derived.

All but the southeastern portion of southern Minnesota was invaded by one or more ice sheets and (with the exception of a few small rock outcrops) is now covered with glacial drift. As has already been pointed out, the thickness of the drift varies through a wide range, and in some localities is great. The thickness of surface deposits, as shown on Plate II, is based on the large number of well sections assembled in the course of the investigation. In localities where few wells penetrate the underlying rocks and in localities where the formation immediately beneath the drift is so similar in general character to the drift itself that drillers do not differentiate clearly between the two, the map is necessarily more or less inaccurate and the thickness indicated is likely to be too great.

The drift lying at the surface along the eastern margin of the glaciated area, though probably not all of the same age, is distinctly older than the Wisconsin drift which covers most of southern Minnesota. This difference in age is shown chiefly by the differences in the amount of weathering and erosion. In the oldest drift the calcareous matter has been leached out completely to a depth of several feet, but in the Wisconsin drift this leaching has scarcely begun. The upper part of the oldest drift has been oxidized to a deep brown, but in the Wisconsin drift the oxidation of the surficial zone has generally gone only far enough to produce a pale bluish yellow color. The areal distribution of the Wisconsin drift and that of the older drift sheets, as well as the belts of terminal and recessional moraines, are shown in Plate II.

The surficial layer of drift is generally not very compact, and hence allows a slow percolation of water, especially along the more gravelly seams, but also to some extent through the unconsolidated clayey portions. Since the surface is usually poorly drained, this upper layer is in general saturated nearly or quite to the top, and very shallow dug or bored wells receive sufficient seepage for small supplies. However, in periods of prolonged drought the ground-water level is lowered, and these shallow wells are frequently left entirely dry. At greater depths occur the seams of sand and gravel already described, through which the water percolates more freely and in which it is under greater pressure, and hence will be supplied to wells at a much more rapid rate. Drilled wells ending in the best of these sand and gravel horizons yield supplies which are but slightly affected by drought, and which are adequate not only for farm use but for all ordinary industrial and public purposes as well. In the various county reports and in the table of public water supplies (pp. 98–113) will be found a large amount of specific information in regard to the yield of wells ending in the drift.

OUTWASH AND TERRACE DEPOSITS.

Large streams overloaded with rock débris issued from the melting ice sheets of the Pleistocene epoch and flowed over the surface, depositing beds of gravel, sand, and clay, in part quite distinct from the drift proper. Eventually these glacial floods entered preexisting valleys and rapidly filled them with rock débris. More recently the streams have cut into this filling, and now flow at lower levels, leaving the remnants as terraces.

Outwash sands and gravels occur in many portions of southern Minnesota. Nearly the whole of Anoka County is covered by them, as well as large portions of many of the counties to the west. Terraces are found mainly in the valleys of Mississippi River and Minnesota River, but also occur along the smaller tributaries of these streams within the driftless area of southeastern Minnesota. Other elevated valley deposits remote from any present lines of drainage may be mentioned. Among these are the channel leading from Mendota southeastward across Dakota County to Rosemount, that from the northwestern corner of the same county to the Vermilion Valley near Farmington, and the chain of kamelike deposits in northern Kandiyohi County. The terraces along the Mississippi vary in width from a few hundred yards to over 10 miles, as in the "Prairie" south of Hastings. Along the Minnesota the most extensive terraces are found near Shakopee and Belle Plaine, and opposite St. Peter. Of these the first and second have a width of 1½ miles, while the third has a width of about 4 miles.

The outwash sands and gravels, being open and porous, readily absorb the rain falling upon them. Where they are underlain by impervious clay, and where the region remains undissected by stream erosion, they are saturated nearly to the surface with water that contains relatively small amounts of dissolved minerals and is yielded freely to shallow dug or driven wells.

In the terraces most of the water is derived directly from the rain, although some comes from the seepage out of the rocks forming the valley walls. The terrace gravels and sands are open and porous, and although they absorb water quickly, are as ready to give it up where the conditions are favorable as where they are cut by deep valleys. In the narrow terraces, and to some extent in the broader sandy ones, little water exists above the level of the bottom of the adjacent valley, although at many points some distance back from the drainage channels water is found at higher levels, owing to the slope of the ground-water table. Where clayey layers are found, local water pockets may exist in depressions in the impervious bed.

RECENT ALLUVIUM.

This term refers to the gravel, sand, and clay deposited by the streams since the close of the Pleistocene épоch. It is present in greater or less amounts in all the valleys of southern Minnesota, but the thickest accumulations are in portions of the Mississippi and Minnesota valleys, where it locally attains a depth of over 100 feet.

The water of the alluvium is derived in part from the direct downward percolation of the rain falling on the flood plains, in part from seepage from the adjoining hillsides, and in part from the river in its flood stages. When the water level in the stream rises faster than the ground water, the ordinary movement, which is toward the stream, is reversed and the river water penetrates the alluvium on each side. Although the alluvium is usually saturated below the level of the stream, not all of the water is available to wells. Clayey materials, although containing much water, hold it so firmly that little or none is given up, and even sands do not always yield their water freely. Hence it not infrequently happens that wells fail to secure the needed supplies. However, where gravel or coarse sand is encountered the yield is large.

LOESS.

This deposit, locally known as yellow loam or yellow clay, is a fine, nearly structureless silt, with practically no coarse grains of any kind. It is buff in color, and although somewhat plastic when wet is not a true clay. It is found mainly on the upland plateaus of the southeastern counties, where it locally attains a thickness of 25 feet. If it has ever been deposited at lower levels in the valleys, the evidences of its presence have for the most part been removed by the subsequent deepening and widening of the valleys. The loess of this region appears to have been deposited originally by glacial waters in the Mississippi Valley, and later to have been taken up by the wind and distributed over the uplands. The deposits in southern Minnesota are so thin and so high above the general ground-water level of the region that most of the rain which they absorb eventually escapes into the underlying materials. Hence the loess is almost never a source of water, even to open wells, although in other States where it is thicker it is not uncommonly a source of importance.

DUNE SAND.

Dunes are found at several points in southern Anoka County, where the sand derived from the outwash deposits has been blown by the wind into bare rounded hills from 10 to 20 feet high. Because of their exposed position they are of little value as a source of water.

CRETACEOUS SYSTEM.

Cretaceous formations are present throughout most of the western half of the area, and thin scattered remnants appear to be widely distributed in much of the eastern half. But the mantle of drift is so nearly continuous and so little dissected by stream erosion that there are only a few small Cretaceous outcrops, and consequently knowledge in regard to the Cretaceous formations has been very meager until recently, when they have been penetrated by numerous deep wells. In their typical development in Bigstone County and in Lyon and adjacent counties they attain a maximum thickness, as far as known, of about 500 feet, and are composed of thick beds of plastic gray-blue shale, and thinner beds of white sand or sandstone. The shale, which is popularly known as "soapstone," contains pyritiferous layers or concretions, and in some parts includes numerous beautiful crystals of selenite. The sandstone beds, which form only a small portion of the total thickness, occur chiefly near the bottom and top of the series, although the Lyon County sections show a sandy horizon near the middle. While exact correlations are impossible, there is little question that the Cretaceous of southwestern Minnesota is continuous with that of South Dakota and western Iowa and corresponds to the Dakota, Benton, and possibly higher formations. In the vicinity of New Ulm, where plant fossils referred to the Dakota have been described, the deposits have a more littoral aspect, and consist in large part of white sandstone and red clay.

The sandstones are saturated with highly mineralized water under artesian pressure sufficient to bring it to the surface throughout considerable areas (Pl. IV). In a large portion of southwestern Minnesota these sandstones constitute an important source of water supply. Although all the Cretaceous water is rich in certain dissolved minerals, some of it is soft, and hence much better for many purposes than the hard water from other horizons.

PALEOZOIC ROCKS.

Southern Minnesota contains a thick succession of Paleozoic formations comprising various beds of limestone, shale, and sandstones, most of which are of Cambrian or Ordovician age. Rocks of the Devonian period are but meagerly represented, and those of Silurian and Carboniferous age are not known in the area.

DEVONIAN SYSTEM.

The Devonian rocks occur in Mower County with extensions east into Fillmore County and west into Faribault. They are of various character. The lower portions consist of a gray, impure, somewhat granular limestone, interbedded with which are layers of shale of a dirty brown color, due to weathering. Above the limestone lies a division consisting of sandy layers which locally develop into a true sandstone. The total thickness can not be definitely determined, although the well at Austin revealed a section of 51 feet in which there were observed no sandy layers. The beds of sandstone constitute the principal water-bearing portions of the Devonian. Toward the west these become so deeply buried that the water in them is under considerable artesian pressure.

ORDOVICIAN SYSTEM.

MAQUOKETA SHALE.

The Maquoketa shale, like the Devonian representative in this area, is composed of a series of beds of varied character. In the main it consists of light-gray shales, but toward the base it carries more or less magnesian limestone, and the upper layers consist of argillaceous sandstone. The succession of beds is not constant, however, but varies from place to place. Where well developed the formation has a thickness of about 100 feet. More or less water exists in the pores and lamination planes of the shales, in the solution passages or bedding planes of the limestone or dolomite, and in the clayey sandstone at the top, but the amounts are usually small and the formation does not generally afford satisfactory supplies.

GALENA LIMESTONE.

The Galena limestone immediately underlies the Maquoketa shale, and is succeeded downward by the Decorah shale and the Platteville ("Trenton") limestone. It is composed of several distinct members. Its highest layer in the recognized section, designated the *Maclurea* zone, is coarsely stratified, and in weathering passes into a coarse porous rock having almost the water-bearing qualities of a sandstone. It is strongly stained by the alteration of its content of ferrous carbonate and pyrite into oxides of iron. Beneath this lies a stratum 20 feet thick, which is heavily bedded and in places strikingly colored by infiltration bands. It is frequently mistaken for a sandstone. On account of its characteristic fossils it is called the *Lingulasma* zone. Below this, constituting a heavily bedded stratum, is the *Camarella* zone, which is about 30 feet thick and is a somewhat carbonaceous limestone impregnated with iron pyrites and chalcopyrite. It is sharply separated from the shaly fossil-bearing layers of the underlying Decorah shale.

The well-defined bedding planes of the Galena limestone afford rather favorable conditions for the circulation of water, especially after they have been enlarged by solution, and moderate supplies are generally found by wells, except when the formation occurs on knobs and hills or near the edges of valleys where the water has an opportunity to escape to the lower lands. The supplies are most abundant in the basal layers, in which the water is collected along the contact of the impervious Decorah shale.

DECORAH SHALE.

The Decorah shale is known in many localities in Fillmore and Olmsted counties, at St. Charles and Clinton Falls, near Faribault, at Elgin, Cannon Falls and southward to Kenyon, old Concord, and Mendota, in Minneapolis and St. Paul, and at other points along the Mississippi gorge. It occurs persistently beneath the Galena limestone just described, and in many localities where the limestone has been removed by glacial erosion or weathering layers of the Decorah shale of varying thickness are found. It is reached by drilling in a considerable area of southeastern Minnesota. These shales are fissile, crumble easily, and carry few fossils. Their color is green or greenish-gray, weathering always to a dirty brown, due to the amount of iron originally present as a sulphide or carbonate. Interbedded with the shales, and in some localities constituting more than one-half of the thickness of the formation, are layers of crystalline limestone made up of fossil bryozoa, corals, crinoidal forms, and brachiopods. The characteristics of this formation are so unique that it can generally be recognized in well sections. It contains little water, but serves a useful purpose, since it forms an impervious layer which holds a supply of water in the overlying formations, particularly the glacial drift and loess, where these rest upon the Decorah shale.

PLATTEVILLE LIMESTONE.

Lying beneath the Decorah shale is a bed of limestone from 12 to 30 feet in thickness, which is known as the Platteville or "Trenton" limestone. It is somewhat varied in lithologic character, in places being granular and even conglomeratic, while in others it is thoroughly crystalline. It is recognized in Minneapolis and St. Paul as the building-stone layer. In the southern part of the State it is more uniform from top to bottom and shows more distinctly the effects of water percolation along its joints and bedding planes.

ST. PETER SANDSTONE.

This formation is widely distributed and underlies the greater part of the area between Minnesota and Mississippi rivers, and much of Ramsey, Washington, Anoka, and Hennepin counties to the north. It varies from about 80 to 200 feet in thickness and consists of a fine-grained, white or yellow sandstone, with locally a bed of shale about 40 feet above the base.

The greater part of the water of the St. Peter sandstone enters through its outcrop, where it lies immediately below the glacial drift, which serves as an excellent feeder. North of the Mississippi and along its western margin extending through Scott, Lesueur, Waseca, Blue Earth, and Faribault counties, the formation is covered with drift. In Dakota County, however, especially in the southern part, the coating is thin, and the sandstone, except for a few feet of soil, is at the immediate surface and absorbs considerable quantities of water directly from the rainfall. In the counties along the Mississippi it caps the uplands over extensive areas, except for a thin cover of loess which helps to collect the water and feed it to the sandstone. Owing to its position on the uplands throughout the southern portion of the area and to the deep channels cut into it by the Mississippi and its tributaries, its waters are here drained into the valleys, leaving the adjacent portions of the formation with only meager supplies. In the vicinity of St. Paul and Minneapolis the Mississippi cuts deeply into the St. Peter but does not penetrate the shale parting in the lower portion, and therefore the water beneath is confined and when encountered by wells will rise in large quantities nearly or quite to the surface. In the area between the Minnesota and Mississippi margins the St. Peter, in common with other beds, is bent into a broad basin, the center of which is considerably depressed below the rims. In this basin, owing to the comparatively impervious overlying and underlying beds, the waters are confined under artesian pressure sufficient to lift them many feet above the level at which they are encountered, and the amount yielded is consequently large.

PRAIRIE DU CHIEN GROUP.

Shakopee dolomite.—This formation is a fine-grained, granular, yellow, buff, pink, or reddish magnesian limestone, commonly ranging from 25 to 75 feet in thickness. In some localities the rock is oolitic and in others some quartz sand is present. It outcrops at Shakopee and elsewhere near Minnesota River and between St. Paul and Hastings on the Mississippi. To the south it rises to the uplands, underlies the thick drift deposits along the east side of the Minnesota, and outcrops in the bluffs and ravines adjoining the Mississippi. At Shakopee, Inver Grove, and elsewhere a few wells end in this formation, but the supplies which it yields are very small. Most wells either stop in the overlying sandstone or penetrate a lower horizon.

New Richmond sandstone.—This bed is rarely seen in outcrop and is not generally recognized by drillers in the northern counties. In the southern part of the State, however, it becomes better defined and apparently attains a thickness as great as 40 feet in some localities. In exposures it is somewhat iron-stained, but drillings usually show it to be a pure white quartz sand. It is often more or less cemented by lime, which fact makes it difficult to distinguish it in wells from the limestone above and below, especially where, as at points in the north, it appears to be very thin.

The water probably enters chiefly through joints and other openings in the associated limestones. In the more calcareous phases it occurs in what are termed "fissures" by the drillers, but which appear to be local sandy zones from which the cement has been dissolved, leaving layers of nearly pure sand. In some places joints and true solution openings seem to exist. In the sandy phases the water occupies the pores between the grains as in the St. Peter and other sandstones. Notwithstanding its thinness, the New Richmond is a very persistent water-bearing bed, being found throughout nearly the entire area, always yielding more or less water, except where drained by adjacent valleys. In the north, where the formation is especially thin, the supplies are generally small, although nearly always sufficient for domestic or farm demands. In Minneapolis and St. Paul there are, however, many important wells receiving their water from this sandstone.

Oneota dolomite.—This is a buff or reddish magnesian limestone from 75 to 175 feet or more in thickness. In texture it is sometimes granular, apparently being made up of a very fine dolomitic sand, which not infrequently shows distinct stratification and cross-bedding, but as a rule it is seen in heavy uniform layers of a thoroughly crystalline habit. In its upper portion abound small openings and pockets from one-fourth to one-half inch or more in diameter and generally lined with crystals, giving the rock a distinctly porous character. In the southeastern counties, where the limestone is strongly developed in the bluffs of the Mississippi and its tributaries, there are extensive solution passages, some of which reach the dimensions of caves that may be penetrated for some distance. On the west the formation is seldom seen at the surface, but exists beneath the drift and outcrops in a few localities near Minnesota River. In the tract between the Minnesota and the eastern exposures along the Mississippi it lies beneath a thick covering of younger rocks (Pls. IV and V).

In the upper and more porous portion of this formation small quantities of water are found, but the greater part is contained in the larger solution passages representing joints, bedding planes, or other lines of easy circulation, greatly enlarged by streams and sheets of percolating waters. One of these solution passages, known as Tyson's cave, about 4 miles northeast of Wykoff, is said to have an underground stream upon which a boat can penetrate for 200 feet. The flow of this stream is given as 50 cubic feet per minute. Another large stream, 1½ miles south of Lanesboro, flows 360 cubic feet per minute, and has in the past been used as a source of water power Owing to the density of the limestone, it affords little water to wells, except from the solution passages. When these are encountered they generally yield freely, but it is always uncertain when or where they will be penetrated by the drill. On the flat upland bordering the Mississippi, the formation is an important source of domestic and farm supplies, except where drained by adjacent valleys, in which the numerous springs issuing from it are of considerable importance.

CAMBRIAN SYSTEM.

Jordan sandstone.—The Jordan sandstone is a loosely cemented, medium to coarse grained, white sandstone, becoming yellow or brown by oxidation along its outcrops and jointing planes. It ranges from less than 75 to nearly 200 feet thick and is exposed in the valleys of the Minnesota and tributary streams and in the lower part of the bluffs of the Mississippi and its branches from near Hastings southward to the Iowa state line. Elsewhere it is deeply buried beneath younger rocks (Pls. IV and V). Except in the areas adjacent to its outcrops, it is saturated with water, which is under pressure and is yielded freely. When several wells are located close together there is a liability of some interference, but this is not commonly serious. Except perhaps in Minneapolis and St. Paul, and at its outcrop areas, it is believed that the formation will yield all the supplies that it will be called upon to furnish for a long time to come.

St. Lawrence formation.—This formation consists of buff magnesian limestone, alternating with layers of greenish shale, more or less sandy, and in its upper portion with beds of green sand several feet in thickness. It underlies nearly all of southeastern Minnesota, outcropping only in the Minnesota Valley west of Mankato and in that part of the Mississippi Valley near the Iowa line. Its thickness commonly ranges between 100 and 200 feet. The water of the formation is probably obtained almost entirely from the porous overlying and underlying sandstones and from the glacial drift where this rests directly upon it. It is not a water-bearing formation of importance, and is seldom if ever utilized, the yield being small. Its chief value lies in its function as a confining bed.

Dresbach sandstone and underlying shales.—The Dresbach sandstone underlies the St. Lawrence formation. It is seen along St. Croix River in northern Washington County and along Mississippi River in the southeastern part of the State. It also occurs in the Minnesota Valley, and has been reached by deep wells in every part of southeastern Minnesota as far west as Blue Earth and Faribault counties. It consists of an incoherent fine-grained sand of a prevailingly white color in its upper portion, followed downward by more compact layers with associated shaly beds. Throughout southeastern Minnesota, wells which penetrate the formation show a thickness ranging between 50 and 100 feet at the various localities where records are preserved.

The formation is an important bearer of water. The water, which comes largely from the eroded edges lying beneath the glacial drift, is nearly everywhere under artesian pressure, and usually rises above the surface within the gorges of Mississippi and St. Croix rivers and some of their tributaries. The formation seems to consist of two or three somewhat independent water-bearing beds, which differ in their yield and in the height to which the water will rise.

Beneath the Dresbach sandstone lies a series of beds having a persistently shaly habit. In some places the shale assumes a calcareous character and carries layers of limestone several inches in thickness. More rarely pyritiferous beds occur, in which pellets and crystals of iron sulphide constitute a considerable portion of the material. Farther south these beds become less shaly and attain a thickness of several hundred feet, a large part of which consists of water-bearing sandstone. In the Minnesota Valley the beds come to the surface within a few miles of New Ulm, and their catchment basin extends beneath the drift from Brown County in a northeasterly direction to Chisago County and thence into Wisconsin. They hold much water under good artesian pressure, but are seldom penetrated in drilling because satisfactory supplies are usually obtained before they are reached.

ALGONKIAN SYSTEM (?).

Red clastic series.—The red clastic series, being generally deeply buried, is the least known of any rocks in the area. Nevertheless these red beds are revealed by deep drilling everywhere from the gneisses and quartzites of the southwestern counties eastward into Wisconsin and from the Iowa boundary northward beyond Stillwater. They are nowhere exposed within this area, except possibly at Courtland, near New Ulm, in some coarse conglomerates lying upon the Sioux quartzite. In thickness they vary greatly, being many hundreds of feet thick at Minneapolis and Stillwater and gradually thinning out toward the south. In texture they vary from coarse conglomerate, through varying phases of sandstone, to fine shale, which usually forms the upper part. In color they also vary somewhat, being much redder in the north than to the southeast. From their stratigraphic situation and relation to other rock formations it seems probable that these rocks are the sedimentary extension of the Keweenawan series of the Lake Superior basin. This opinion is strengthened by the fact that similar volcanic rocks are characteristic of the Keweenawan, and also by the fact that the diabase which in the Stillwater well is penetrated at a depth of 717 feet is pronounced Keweenawan. Until the age of the whole series is settled beyond question, however, the rocks will be called Algonkian (?). They carry little water, and drilling should always be discontinued when they are encountered. This fact was recognized twenty-five years ago by W. E. Swan, an experienced driller in the region.

ALGONKIAN SYSTEM.

Sioux quartzite.—This formation is exposed in a number of outcrops and has been encountered in many wells in southwestern Minnesota and adjacent parts of South Dakota and Iowa. Its distribution in this State is shown on Plates III and IV. Although it consists essentially of thoroughly indurated red quartzite, it contains a few thin layers of pipestone and also some portions which are but slightly cemented and quite porous. A small amount of water is contained in the less indurated beds and in the joints which break up the rock, and in localities where there is no other available source of water the formation will yield supplies which, though not copious, are adequate for most purposes.

ARCHEAN SYSTEM.

Rocks consisting of dark-colored hornblende or biotite schists, probably belonging to the Keewatin series, have been reached in a number of the deeper wells in the northwestern part of the district under investigation. They are presumed to be a southwestward extension of rocks which appear at the surface in eastern Minnesota along Kettle River and at different places on the north side of the Mesabi iron range. Gneisses and granite gneisses are found in more or less continuous exposures from New Ulm to Ortonville along Minnesota River, and in several outcrops upon the high prairie region to the southwest, in Brown, Lyon, and Yellow Medicine counties. They have been reached in a large number of wells on both sides of the river and no doubt underlie all the other formations. The occurrence of the Archean rocks is shown on Plate III.

In most parts of southwestern Minnesota, where the Archean rocks are covered by Cretaceous deposits, they are profoundly decomposed. The decomposition product, as brought up by the drillers, usually consists of white clay at the top, succeeded downward by decomposed granite of a red, yellow, light-gray, or greenish color. In a number of wells the white clay exceeds 50 feet in thickness, though it is generally much thinner. It is without a doubt a product of the decay of granitic rocks. In some places it contains embedded grains of quartz and is clearly residual, but in others its freedom from grit, its great thickness, or the fact that it includes interbedded layers of sand indicates that it has been transported and redeposited by water. If, as is probable, it was so redeposited when the Cretaceous seas invaded the region, the white clay is in part a basal Cretaceous formation. In this report it is included with the Archean except where it is evidently Cretaceous.

Where the white clay or ordinary granitic residuum is encountered there is little probability of procuring water, though some successful wells stop in these materials. The solid rock is virtually destitute of available water.

ARTESIAN CONDITIONS.

By O. E. Meinzer.

INTRODUCTION.

A flowing well appeals strongly to the imagination, and hence in southern Minnesota, as in other parts of the country, there is a great tendency for the people to be too optimistic in regard to artesian prospects and too ready to involve themselves in heavy expenditures for drilling, with the hope of securing a flow. In nearly every village there are those who believe flowing wells could be obtained if drilling were carried deep enough, but perhaps in a majority of cases such a belief is based upon the most meager and imperfect knowledge of the conditions, and the wish alone is father to the thought. It is important that the people should understand that a flowing well is not an accident, but rather the resultant of a definite combination of structural and topographic conditions, which can to a certain extent be determined by those who have made a study of the subject. It is important for them to realize that random drilling without expert advice is a most costly and unwise method of prospecting for artesian water.

In southern Minnesota flows are obtained from three distinct sources. These are the glacial drift and the Cretaceous and Paleozoic rock systems. Although the same general hydraulic principles are involved in all three, yet their structural and topographic relations are so diverse that the artesian conditions are manifested somewhat differently, and intelligent prospecting requires a knowledge of the peculiarities of each.

These three geologic divisions are widely distributed and the water which they contain is generally under considerable pressure. Nevertheless, it is only in small districts where the conditions are peculiarly favorable that the pressure is great enough to lift the water above the surface. In other words, districts in which flows can be secured are the exception and not the rule. Out of the 28,000 square miles included in this report, the water from some formation will rise above the surface in approximately 700 square miles, or about 2½ per cent of the total area.

GLACIAL DRIFT.

CONDITIONS.

The structure of the drift is unlike that of any other deposit, and the resulting artesian conditions are likewise peculiar. The surficial layer, consisting of clay with an admixture of gravel, is loosely aggregated and absorbs a certain amount of water, which percolates through it slowly. Since most of the drift-covered region is a gently undulating plain with but slight relief and poor drainage, the rain which falls upon it flows off but sluggishly, and therefore has ample opportunity to penetrate the semiporous surface layer. Hence it follows that the ground-water table is normally near the surface, and in swampy districts virtually coincides with the land surface. In the higher morainic belts and in proximity to erosion channels, the depths of water are somewhat greater, but so imperfect is the porosity that the water table follows the topographic irregularities closely.

The greater part of the drift at some distance below the surface layer is quite compact and appears to be entirely impervious, but there are interbedded with it coarse layers of sand and gravel which are nearly always saturated with water under artesian pressure. When a well is sunk into the drift the drill passes through relatively dry and impervious clay until a sand and gravel horizon is encountered. Then the confined water promptly rises through the boring, filling it to a level at which equilibrium is established. The water column in the well then balances the pressure in the water-bearing beds. If water is pumped out this balance is disturbed and a new supply at once flows into the well. If, on the other hand, water should be poured into the tubing, the column in the well would then overbalance the artesian pressure and water would be forced out at the bottom of the tube until the normal level was again reached. The rate at which this adjustment takes place depends upon the porosity of the sand or gravel and is a measure of the rate at which water will be yielded. It follows that a crude estimate of the water that may be procured from a well is obtained by pouring water into it, and this method of testing is occasionally resorted to by drillers.

On the higher belts of glacial moraine the water level in the wells may stand at considerable depths below the land surface, even though it rises above the horizon at which it is tapped, but on the ordinary drift plain it usually stands near the surface of the land, and in small tracts depressed below the general level of the plain it may flow at elevations slightly above the land surface. Nevertheless, the absolute elevation of the water surface in wells is invariably greatest in regions of greatest elevation and is lowest in the depressed areas, even though here it is nearer the land surface or may even rise above it.

It is probable that the most effective catchment areas are the regions of high morainic belts. Because of the large percentage of porous material in these moraines their absorption of the rainfall is more complete than that of the area of true till, which in part forms the surface of the plains. The water that is absorbed by the moraines percolates slowly outward from them beneath the bowlder clay of the drift plains, thereby establishing artesian conditions. Where these artesian conditions exist the ground moraine or till acts as a confining bed and appears to be fairly impervious. Nevertheless, there is doubtless some leakage through it, and this leakage may be one of the reasons why artesian basins within the drift are so moderate in extent. In this connection it is interesting to review a principle stated by Professor Chamberlin in 1885.[a] At points where water from the lower beds rises just to the level of the surface ground-water table the deeper water and the surficial water are in equilibrium, and even though the bed that separates them is not entirely impervious there is no tendency for the water to pass in either direction. In localities where the water from the deeper beds rises to a level below that of the surficial ground-water table the two bodies of water are not in equilibrium, and if the material separating them is at any point not entirely impervious water will pass from the surficial layer into the deeper beds. This relation is the general one throughout southern Minnesota. It exists not only in the morainic belts, but over the greater part of the plains. Where, in contrast to this condition, the waters from the deeper beds tend to rise above the level of the ground-water table, the resultant pressure is upward through the confining layer, and if the latter is not perfectly impervious there will be leakage out of the deeper beds, and as a consequence a diminution of the artesian pressure. The greater the difference between the ground-water level and the level to which the artesian water rises the greater is this pressure, and the more rapidly will leakage take place. This condition is found only in limited areas within the low-lying districts, and the difference in the two levels is rarely great. It is only in exceptional situations where the ground-water table is nearly at the surface, as in specially depressed localities, or where it is suddenly deflected downward, as along the margins of postglacial valleys, that the waters from the deeper beds will rise above the surface. In rare instances the drift gives rise to great pressure, but this is due to unusual features and need not be considered in discussing general conditions.

Confining layers of till are not sufficiently impenetrable to prevent the escape of waters upward from the confined beds when the pressure is outward. Neither can they prevent the passage of water downward into these beds in localities where the balance of pressure favors movement in this direction. It is therefore proper to regard the entire region in which the water from confined beds fails to rise to the surficial ground-water level as a catchment or intake area. The material of the moraines and their relations to the flowing districts indicate that they play a most important part in supplying the deeper beds, but the remaining portions of the intake area, as just defined, probably also exert an appreciable influence.

[a] Chamberlin, T. C., Requisite and qualifying conditions of artesian wells: Fifth Annual Report U. S. Geol. Survey, 1885, pp. 139-140.

In order to maintain artesian conditions it is probably not essential that the confining layer should be absolutely impervious, but only that it should be less pervious than the water-bearing body below. Leakage upward and outward does not preclude the maintenance of artesian pressure, provided the supply to the bed that acts as a reservoir be more rapid than the leakage outward from the bed.

PRACTICAL APPLICATIONS.

An understanding of the conditions that have been discussed should assist in judging of the prospects of securing flows in any given locality. If the till does not form an ideal confining stratum because leakage may take place through it, it is evident that general elevation of surface will have less to do with the occurrence of flowing-well areas than local topography, because the till sheet is probably not capable of resisting high pressures and transmitting them for long distances. Hence a large area of relatively low land, even though it is probable that ground waters percolate toward it from an adjacent area of relatively high land, is not likely to be a general flowing-well area. On the other hand, a valley or other limited local depression, especially if its borders are rather abrupt, is a favorable locality for securing flowing wells, because pressures do not have to be transmitted great distances to such an area, and hence are not likely to be lost through leakage. If, in addition to this favorable local topographic condition, the till contains an abundance of the lenticular masses of sand and gravel which form the most favorable deep-seated reservoirs for the storage of water under pressure, the combination of conditions is ideal, and exploration is likely to develop flowing wells.

Illustrations of favorable topographic conditions will be found on Plate IV. It is evident that the water is likely to rise near to the surface at the foot of a relatively abrupt slope. If this slope occurs at the base of a steep morainic belt, the conditions may be regarded as exceptionally favorable. Exactly this situation gives rise to the flowing wells in the northeastern corner of Nobles County. There a high area of moraine rises toward the west, while the general surface descends gently toward the east. Into this gently sloping surface the valley of Jack Creek has been incised, and here a flowing-well area has been developed. Farther east the prairie, by a gentle grade, is brought to a level considerably below that of the valley of Jack Creek, but the water, nevertheless, will not rise to the prairie surface. It is probable that the pressure is dissipated by leakage before it reaches these points more distant from its source.

Although postglacial valleys cut a short distance into the drift are the most favorable topographic features for the production of flows, yet if these valleys are cut through the confining beds artesian conditions are thereby destroyed and flows will not be secured.

A number of small tracts in which flows may be found in the drift are indicated on Plate IV. In general, no attempt has been made to show the localities that are regarded as favorable for flowing wells except where developments have proved that these conditions actually obtain. Hence there can be little doubt that water will rise above the surface in small districts not indicated upon the map. Although sufficiently complete data do not exist for an accurate estimate of the area over which flows from the drift may be secured, such crude estimates as are possible appear to indicate that the flowing-well areas constitute less than 1 per cent of the total drift-covered surface.

CRETACEOUS SYSTEM.

The Cretaceous formations present a structure and resulting artesian system that are in sharp contrast to those of the drift. The water-bearing members are without doubt far more continuous over wide areas and are better adapted to transmit water for long distances, while the confining beds are very much more competent. The former consist of sandstone strata; the latter of a great thickness of shale which is so fine-grained and homogeneous that it is highly impermeable, so soft and plastic that all fissures are sealed even under moderate pressure, and so widespread and continuous, except near its margins, that there are few interruptions where water might escape. The Cretaceous, in its typical development, fulfills more nearly the ideal conditions than do most artesian systems.

There are two areas in southern Minnesota in which this system gives rise to flows (1) in the valley occupied by Bigstone Lake and (2) along the foot of the coteau in Lyon and Redwood counties. The first is not extensive; the second covers approximately 200 square miles and contains a large number of flowing wells. The first shows no unusual features, but the second presents several problems, which will be briefly discussed. Both of the areas are shown in Plate IV, and they are described in detail in the reports on Bigstone, Lyon, and Redwood counties. In the Red River valley, directly north of the region included in this paper, flows are obtained over a wide territory.

The Cretaceous formations extend from the western mountains, across the Dakotas, into Minnesota. In the high altitudes of the mountains the sandstones outcrop, thus forming ideal catchment areas. Eastward they pass beneath thick shale beds, and as they reach lower altitudes their water comes to be confined under great artesian pressure. The so-called James River valley is a broad belt in the eastern part of North and South Dakota, sufficiently depressed so that the Cretaceous water will rise far above the surface, and is an artesian basin of unusual interest, made possible only by the great efficiency of the shale beds in preventing leakage. The artesian supply is there being squandered on a grand scale. East of the James River valley lies the Coteau des Prairies with an elevation too high for flowing wells. There, indeed, as far as present knowledge is concerned, the entire Cretaceous system is virtually lost; but it reappears beneath a thin coating of drift under the low plain on the east side of the coteau, where it again gives rise to flows.

But in one respect the artesian conditions are here essentially different from those on the west side of the coteau, for the flowing area is only 6 or 8 miles in width, and is bounded on the east not by higher ground but by a gently descending plain. The topographic features are similar to those just described for the drift artesian area in northeastern Nobles County. The structure is, however, believed to be entirely different. The principal sandstone strata, and with them the artesian conditions, are here terminated by the impervious Archean rocks, against which they abut (fig. 3), and in addition to this the confining beds become less perfect at the margin and a certain

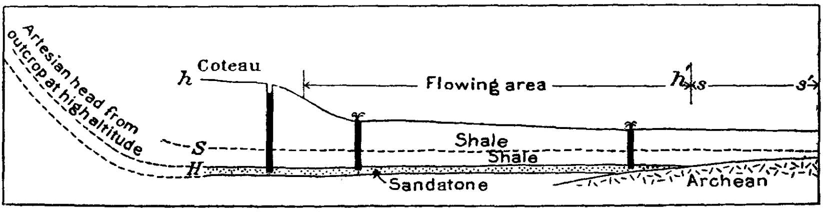


FIGURE 3.—Diagrammatic section of the Cretaceous, showing (1) the conditions that limit the flowing area and (2) the supposed relations of hard and soft waters. *H*, Main artesian hard-water zone; *S*, principal soft-water zone; *hh'*, area in which hard water predominates; *ss'*, area in which soft water predominates.

amount of leakage and consequent lowering of the head results. In the report on Lyon County are presented some of the data upon which these conclusions are based.

When the first deep wells were drilled in the city of Marshall, the artesian pressure was found to be great, in some instances sufficient to lift the water 200 feet above the surface. Since that time (about 15 years) it has quite steadily diminished. (See specific data in the report on Lyon County.) Some of this decrease may be attributed to local interference, but apparently the explanation lies in part in the general lowering of the head. Although there are now many flowing wells, the total draft on the artesian beds is not large, and if this draft is the cause of the change in pressure, either the capacity of the water-bearing beds is very small or their conductivity is poor. Whatever may be the ulterior factors involved, it would certainly be prudent for the people of Lyon and Redwood counties to conserve their artesian supply more carefully in the future by preventing the waste that has heretofore been permitted.

PALEOZOIC ROCKS.

The Paleozoic rocks form an artesian system which differs from each of the other two. They consist of a succession of beds of sandstone, shale, and limestone, lying in a sort of pre-Paleozoic basin, and dipping gently from the periphery toward the interior of this basin. The sandstones form the principal water-bearing members and the shales constitute the most competent confining layers, while the limestones and overlying drift perform both functions to some extent. The alternation of relatively porous with relatively impervious beds gives a succession of more or less independent artesian horizons, but the confining layers are far less competent than those of the Cretaceous, and the intake areas are less definitely limited. In these respects the Paleozoic artesian system therefore stands intermediate between the other two.

It is, however, in its topographic relations that the Paleozoic is most distinctive. It lies in southeastern Minnesota, and hence the surface consists essentially of a plateau dissected by deep-stream valleys, which in very large measure control the head. If the plateau were not dissected, the water from all horizons would come relatively near the surface, but would probably nowhere be lifted above it. But the deep valleys, which cut through successive formations, allow leakage from the water-bearing beds at many points, giving rise to countless springs, but destroying artesian conditions and greatly lowering the head of the water on the uplands. At the same time they locally bring the surface below the level to which the water beneath the undissected confining beds will rise, thus making possible the flowing wells obtained along the principal streams.

The total area in southern Minnesota in which the water from Paleozoic formations will rise above the surface has been roughly estimated at 300 square miles. This area is outlined on the map (Pl. IV). It will be seen that the flowing wells are confined to the valleys, and the general fact needs to be here emphasized that flows can not be obtained on the uplands.

The relations of the head to the depth are similar to those in the drift. On the uplands the water from the shallow sources rises nearest the surface, and the head is generally progressively lower as deeper horizons are reached. On the other hand, in the valleys where artesian prospects exist there is a tendency for the pressure to increase slightly with the depth.

Wherever the Paleozoic beds have been drawn upon to any large extent, the pressure, which in most places was originally not great, has gradually diminished, owing perhaps chiefly to interference and local depletion. To obtain the greatest benefit from the prevailing artesian conditions it is necessary here, as in the Cretaceous basin, to stop the waste that has hitherto been tolerated.

SIOUX QUARTZITE AND GLACIAL DRIFT.

Small flowing areas may result where bodies of Sioux quartzite rise above the general level of a region. In such a place the catchment area is furnished by the quartzite ridge or plateau, and the confining bed is the impervious bowlder clay that laps up on the quartzite and extends as a continuous sheet to an altitude considerably higher than the surrounding surface. A part of the water that falls as rain sinks into the joints and less firmly cemented portions of the rock, through which it is transmitted to sandy beds of the drift that are in contact with the quartzite but lie below the confining layer of clay. A part of the water may also find its way to the deeper portions of the drift through sandy deposits between the quartzite and the bowlder clay without entering the former. Beneath the confining layer the water accumulates head, and on the low ground near

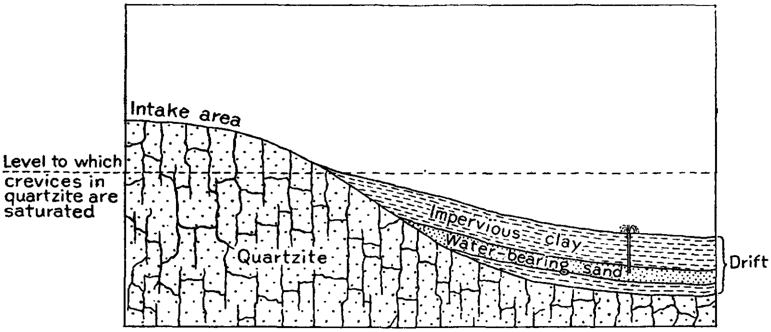


FIGURE 4.—Ideal section showing the structure which gives rise to flowing wells near the margins of quartzite plateaus.

the quartzite plateau it may be under sufficient pressure to rise to the surface when the confining layer is punctured. These relations are illustrated in figure 4. One of the most interesting flowing areas of this type is the one east of Hardwick (see the report on Rock County), but others are found in similar locations.

MINERAL QUALITY OF THE UNDERGROUND WATERS.

By O. E. MEINZER.

SOURCES OF THE DATA.

In all 484 mineral analyses of water from the various geologic formations in southern Minnesota appear in this paper, those from each county being arranged according to formations in a table at the end of the corresponding county report. In connection with the tables are given the depth and diameter and the owner and location of the well or other source from which each sample was taken, also the date, analysts, etc. Generally the date refers to the time the sample was collected, but in some cases it is the date of the completion of the analysis.

The analyses were obtained from various sources: (1) For some years past Prof. C. W. Hall has collected chemical data from railway companies, water-softening companies, chemists, etc., and the analyses thus secured constitute a large proportion of those given in this report. Acknowledgment is due to the following companies and individuals for furnishing data: Chicago, Milwaukee and St. Paul Railway Company, G. N. Prentiss, chemist; Chicago and Northwestern Railway Company, G. M. Davidson, engineer of tests; Minneapolis and St. Louis Railroad Company; Dearborn Drug and Chemical Works of Chicago; Dr. C. W. Drew, chemist, Minneapolis; A. D. Meeds, chemist, Minneapolis Board of Health; Prof. C. F. Sidener, University of Minnesota; Prof. E. E. Nicholson, University of Minnesota; St. Paul Board of Water Commissioners; and others. (2) During the field work conducted by M. L. Fuller in 1906 a number of samples were collected from the southeastern part of Minnesota, some of which were analyzed by H. S. Spaulding and some by W. S. Hendrixson, Iowa College, Grinnell, Iowa. (3) In 1907 the Minnesota State Board of Health cooperated with the United States Geological Survey, and mineral analyses were made in their laboratories by their chemist, H. A. Whittaker, of 100 samples collected by O. E. Meinzer.

Nearly all the analyses collected by Professor Hall were reported as hypothetical combinations and were given in grains per gallon. In order to have them agree in form with those made for the Survey, they were recalculated so that the amount of each element or radicle is shown, and the quantities are expressed in parts per million parts of water. All carbonates were recalculated as bicarbonates (HCO_3). It may be well to call attention to the circumstance that the total solids are in every case less than the sum of the constitutents given, which results from the fact that the bicarbonates, if they exist in solution, break down in whole or in part to form normal carbonates, and hence are only in part converted into solid matter. This can be made clearer by the following illustration, in which two bicarbonate radicles and an atom of calcium come out of solution:

Calcium	+	Bicarbonate radicle	→	Calcium carbonate	+	Water	+	Carbon dioxide.
Ca	+	$2HCO_3$	→	$CaCO_3$	+	H_2O	+	CO_2
		Solution	→	Solid	+	Liquid	+	Gas
Relative weights:		162	→	100	+	18	+	44

INTERPRETATION OF THE ANALYSES.

Underground water dissolves mineral substances from the rocks through which it percolates; and the different ingredients thus held in dilute solution produce noteworthy chemical and physical effects in industrial and domestic processes and in the human body. It is therefore of great moment to know the amounts and relative proportions of these ingredients. It is not feasible to discuss here this entire subject, with its numerous ramifications, but a few of the most important effects of the substances commonly found in solution will be briefly outlined. In what is said about the interpretation of the analyses, a recent article by Herman Stabler[a] is closely followed.

SOAP-CONSUMING POWER.

For toilet and laundry purposes it is desirable to have water that will readily form a lather when soap is used. Calcium, magnesium, iron, and aluminum in solution have the capacity of combining with soap and thereby destroying its power to produce a lather. As iron and aluminum are usually present only in small amounts, the soap-consuming power can be judged approximately by considering merely the content of calcium and magnesium. The smaller the quantity of these two elements the better is the water for toilet and laundry purposes. It must be remembered, however, that one part of magnesium consumes as much soap as 1.6 parts of calcium. Soft water is water that lathers readily, and hard water is water that has the power of consuming much soap before it will form a lather. The amount of soap necessary to produce a lather in a given quantity of water is a measure of the hardness. Boiling the water decreases its soap-consuming capacity by causing the precipitation of part of the calcium, magnesium, iron, and aluminum.

FORMATION OF SCALE.

When water is heated and concentrated in boilers, much of the dissolved substance is precipitated, forming scale and sludge, which diminish the heating power of the fuel and may eventually ruin the boiler. Suspended matter, silica, and compounds of calcium, magnesium, iron, and aluminum are scale-forming materials; and among these calcium and magnesium are usually present in much the largest quantities. Generally the calcium occurs in the scale as either carbonate or sulphate, and the magnesium, iron, and aluminum as oxides. Since there is some uncertainty as to the compounds that will be formed, it is not possible to calculate, from a given analysis, the exact amount of scale that will be deposited, but the following formulas, computed by Stabler, will give approximately the amount and character of it.

[a] The mineral analysis of water for industrial purposes and its interpretation by the engineer: Eng. News, vol. 60, 1908, p. 355.

$$A = 0.0246\ Ca + 0.0138\ Mg + 0.0107\ Fe + 0.0157\ Al + 0.00833\ Cm + 0.00833\ Sm.$$

$$B = 0.00833\ SiO_2 + 0.0138\ Mg + (0.016\ Cl + 0.0118\ SO_4 - 0.0246\ Na - 0.0145\ K).$$

The symbols in these formulas represent amounts as follows: In pounds per 1,000 gallons of water—A, the amount of scale; B, the amount of the hard-scale forming ingredients in the scale. In parts per million—Sm, the amount of suspended matter; Cm, the amount of colloidal matter (silica plus oxides of iron and aluminum); SiO_2, silica; Fe, iron; Al, aluminum; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; SO_4, sulphates; Cl, chlorides.

It is sometimes uncertain whether iron and aluminum are in solution or in colloidal state, but little error will be introduced by assuming that Sm equals silica only. In applying the first formula to the analyses in this report, the results will not be greatly in error if only the calcium and magnesium terms are computed. Boiler scale varies in hardness with the composition of the water. The principal precipitates that make the scale hard are calcium sulphate and magnesium oxide. Silica also increases the hardness. The greater the value of B in comparison with the value of A, therefore, the harder will be the scale.

When water is heated nearly to boiling under atmospheric pressure, as in an open feed-water heater, much of the calcium and other substances that form soft scale are precipitated, but the hard-scale forming ingredients are left in solution. The result of such preliminary treatment, therefore, is to reduce the total amount of scale formed in boilers, but to increase its hardness.

FOAMING.

Foaming in boilers is the forming of bubbles that do not readily break, and hence are liable to carry water out with the steam, thus interfering with the proper action of the engine. Dissolved substances increase the tendency to foam; but as sodium and potassium compounds are much more soluble than those of the other bases, and therefore remain in solution in the boiler water after the other bases have been precipitated, the proportion of sodium and potassium in solution is enormously increased. Therefore, the length of time a boiler can be used without blowing off the concentrated water can be measured by the amount of sodium and potassium in the boiler feed. The greater the amount of these two elements the greater will be the tendency for the water to foam.

CORROSION.

Water that will corrode iron is, of course, deleterious wherever that metal is used. Under the high temperatures in boilers the magnesium, iron, and aluminum may be precipitated as hydrates and the acid radicles thus left in solution may cause corrosion. The carbonate and bicarbonate radicles to some extent counteract this tendency, while the danger of corrosion increases with the amounts of the sulphate radicle and chlorine.

SURFACE DEPOSITS.

ALLUVIUM AND DRIFT WATERS COMPARED.

The surface deposits vary widely in composition, porosity, etc., and there are correspondingly great differences in the chemical character of the waters. The alluvium water is generally less mineralized than that from the glacial drift, as is shown by the following table compiled by M. L. Fuller. All the samples whose analyses appear in this table were collected in the eastern portion of the State, but similar results would be shown if waters of these two sources were compared in other parts of the area under consideration.

Relative mineralization of waters from glacial drift and alluvium.

[Parts per million.]

Depth and formation.	Number of analyses.	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.
0 to 25 feet:								
Drift	17	90	32	23	348	64	26	444
Alluvium	9	81	25	21	341	44	14	406
25 to 50 feet:								
Drift	17	102	35	22	399	99	12	500
Alluvium	13	69	27	7	314	29	63	312
50 to 100 feet:								
Drift	9	112	40	14	509	65	6	514
Alluvium	3	71	25	6	279	23	4	299

It will be seen that the two groups do not differ greatly in the relative proportions of the different constituents, but for virtually each constituent and for each range of depth given, the average amount in the alluvium waters is somewhat less than that in the drift waters. This difference is especially noticeable in the deeper wells.

DECREASE IN MINERALIZATION FROM WEST TO EAST.

A marked difference exists between the mineralization of the waters from the surface deposits (glacial drift, alluvium, etc.) in the western and eastern parts of southern Minnesota. This is shown by the following table, in which all the analyses available were averaged for each county, except that in a few cases where the number was small several counties were taken together. A total of 229 analyses enter into the tabulation.

Mineral content of waters from the glacial drift and other surface deposits in southern Minnesota, by counties, showing decrease from west to east.

[Parts per million.]

NORTHERNMOST TIER OF COUNTIES.

Counties.	Number of analyses.	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.
Bigstone	9	196	113	178	483	873	27	1,646
Chippewa and Swift	9	135	45	80	506	125	92	747
Kandiyohi	3	126	49	26	418	108	96	632
Meeker	6	100	29	18	371	83	14	467
Wright	4	73	29	33	415	29	2	401
Hennepin and Anoka	8	53	18	10	246	16	7	252
Ramsey and Washington	16	74	28	8	358	15	5	345
SECOND TIER OF COUNTIES FROM THE NORTH.								
Yellow Medicine	4	257	108	83	496	541	212	1,526
Renville	14	99	49	87	499	157	37	706
McLeod	18	96	38	48	516	52	16	522
Carver, Scott, and Dakota	10	98	33	10	375	74	10	428
THIRD TIER OF COUNTIES FROM THE NORTH.								
Lincoln	9	220	67	103	575	543	12	1,264
Lyon	5	199	83	163	617	628	15	1,419
Redwood	6	189	68	76	582	411	6	1,067
Brown	3	174	69	63	638	307	7	964
Nicollet and Lesueur	5	71	30	84	368	135	6	575
Rice	7	106	44	24	410	44	35	547
Goodhue	2	86	23	19	338	33	9	366
Wabasha	5	82	29	12	359	32	9	354
FOURTH TIER OF COUNTIES FROM THE NORTH.								
Pipestone	2	110	25	13	395	45	18	444
Murray	12	203	67	77	452	523	23	1,145
Cottonwood	5	223	77	87	522	600	8	1,280
Watonwan	8	167	53	60	559	291	4	902
Blue Earth	0	....	....	....	....	....	....	....
Waseca	3	107	41	28	478	75	12	507
Steele	7	98	34	59	486	105	8	659
Dodge	0	....	....	....	....	....	....	....
Olmsted and Winona	9	64	25	7	298	27	8	298
FIFTH TIER OF COUNTIES FROM THE NORTH.								
Rock	2	124	29	46	515	88	8	584
Nobles	6	221	77	64	421	575	35	1,245
Jackson	7	135	47	50	417	270	11	742
Martin	10	156	48	76	459	371	10	901
Faribault	4	96	34	44	480	76	3	496
Freeborn	3	122	34	23	412	105	30	520
Mower	4	77	17	11	263	63	11	329
Fillmore	4	80	25	11	365	35	18	343
Houston	2	80	32	15	358	33	23	370

The above table shows that in each tier of counties, from the western margin of the State eastward to the Mississippi, there is a gradual but decided decrease in the total mineralization of the water from the glacial drift and other surface deposits, and that this is due to a decrease in the amounts of most of the important constituents. Thus, excluding Pipestone and Rock counties, the average content of calcium and magnesium is only a little over one-third as great in the eastern as in the western part, the average content of sodium and potassium is only about one-tenth as great, and in the content of sulphates the difference is still wider.

The cause of this condition is not difficult to find. The glacial drift of the western counties is derived from the Cretaceous sediments which underlie the western portion of this State, as well as the region beyond, while the drift of the eastern counties was abraded chiefly from the Paleozoic formations. The marked difference between the Cretaceous and the Paleozoic rocks, in the amount of soluble matter which they contribute to the underground water, is shown later in this chapter.

ANALYSES CONSIDERED ACCORDING TO PROVINCES.

For the present purpose, southern Minnesota will be separated into three general provinces—southeastern, southwestern, and north-central. Although this is a somewhat arbitrary division of the region, it makes it possible to bring out important relations that can not otherwise be shown. Broadly speaking, it may be said that in the first province the glacial drift is underlain by Paleozoic formations and in the second by Cretaceous. The third, which lies entirely north of Minnesota River, is in a sense intermediate.

The southeastern province includes the following counties: Anoka, Hennepin, Ramsey, Washington, Carver, Scott, Dakota, Lesueur, Rice, Goodhue, Wabasha, Blue Earth, Waseca, Steele, Dodge, Olmsted, Winona, Faribault, Freeborn, Mower, Fillmore, and Houston. The ensuing table gives the composition of waters from different depths in the glacial drift and other surface deposits of this area. It was compiled by averaging all the available analyses within the assigned limits of depth.

Mineral content of waters from different depths of glacial drift and other surface deposits of the southeastern province, southern Minnesota.

[Parts per million.]

Depth.	Number of analyses.	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4)	Chlorine (Cl).	Total solids.
0 to 25 feet	26	87	30	22	346	57	22	431
25 to 50 feet	30	88	32	14	361	69	34	418
50 to 100 feet	12	102	36	12	452	55	6	460
Over 100 feet	18	81	30	46	375	78	31	463

The table shows that the waters of this group are moderately mineralized, and that the principal constituents are calcium and magnesium in equilibrium with the bicarbonate radicle, the quantities of chlorine and sulphates and of sodium and potassium being comparatively small. The normal amounts of chlorine are probably less than those in the table, because the averages are raised by including a number of samples believed to be polluted by sewage. The average water of this group consumes considerable soap, but can be appreciably softened by heating. In boilers it is not corrosive, has little tendency to foam, and forms scale that is only moderately hard.

The following counties are included in the southwestern province: Bigstone, Lac qui Parle, Yellow Medicine, Lincoln, Lyon, Redwood, Brown, Pipestone, Murray, Cottonwood, Watonwan, Rock, Nobles, Jackson, and Martin. The table here given was compiled, like the previous one, by averaging all available analyses within the prescribed limits of depth from which the samples were taken:

Mineral content of waters from different depths of glacial drift and other surface deposits of the southwestern province, southern Minnesota.

[Parts per million.]

Depth.	Number of analyses.	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.
0 to 50 feet	37	157	57	51	448	301	38	868
50 to 100 feet	18	213	85	95	530	598	13	1,293
100 to 200 feet	20	198	72	136	550	874	14	1,300
Over 200 feet	13	235	78	125	523	674	17	1,417

In this province the waters from all depths are highly mineralized, each of the common ingredients being present in quantity. Since there are large amounts of calcium and magnesium, the waters are very hard; and since the sulphate radicle is much in excess of the sodium and potassium they will form hard scale in boilers.

The following counties are included in the north-central province: Swift, Kandiyohi, Meeker, Wright, Chippewa, Renville, McLeod, Sibley, and Nicollet. The next table shows the average composition of the waters from different depths in the surface deposits of this region:

Mineral content of waters from different depths of glacial drift and other surface deposits of the north-central province, southern Minnesota.

[Parts per million.]

Depth.	Number of analyses.	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.
0 to 50 feet	19	135	47	26	416	144	58	621
50 to 100 feet	6	137	49	99	541	183	77	837
100 to 200 feet	11	78	37	42	498	44	7	489
Over 200 feet	18	71	35	79	513	55	12	527

A casual comparison of the three tables makes it evident that this group is in general intermediate in composition between the first two.

VARIATIONS WITH DEPTH.

The table for the southeastern province shows no important variation with depth in any of the dissolved constituents.

In the tabulation for the southwestern province the waters within 50 feet of the surface are on an average somewhat less highly mineralized than those at greater depths, there being smaller quantities of calcium, magnesium, sodium and potassium, bicarbonates, and sulphates. Inspection of the 27 analyses of waters less than 50 feet deep shows that this difference is due chiefly to the samples derived from the alluvial and outwash sands and gravels at the surface. If only analyses from the glacial drift proper were considered, the waters from a depth of less than 50 feet would be shown to have virtually the same mineralization as those from deeper sources. With the exception just noted, the composition does not appear to vary with the depth, the differences shown in the table being small and probably accidental. Thus the average composition of the 18 samples secured from between 50 and 100 feet is essentially the same as that of the 13 samples from a depth of more than 200 feet.

In the waters of the north-central province a distinct variation with depth is discernible. The samples from less than 100 feet below the surface are somewhat richer in total solids than the deeper waters, owing to their decidedly greater content of calcium and magnesium and of the sulphates. The amount of bicarbonates is practically the same for different depths, and, since the analyses which were averaged together differ widely in the amounts of sodium and potassium, it is probable that the variations shown in respect to these elements should be regarded as accidental. Because of the difference in the quantity of the alkaline-earth bases (calcium and magnesium), the soap-consuming power and the amount of scale deposited in boilers are greater in the shallow than in the deep waters; and because of the much larger amount of sulphates, with no corresponding differences in the alkalis and bicarbonates, the soap-consuming power after heating the water is much greater, while the scale formed is much harder. The deep water is superior to the shallow for boiler, laundry, and toilet purposes.

CHLORINE CONTENT.

The tables show the average chlorine content to be highest in the waters near the surface, but this is believed to be due to the more frequent contamination of shallow wells. The sources of many of the samples included in the tables for the southwestern and north-central provinces were examined from a sanitary point of view, and bacteriological analyses were made of the waters. If all samples are rejected that were thrown under suspicion of pollution either by inspection of the source or by the fact that they contained *Bacillus coli*, or both, those that remain show the following content of chlorine:

Chlorine content of unpolluted waters from the glacial drift and other surface deposits.

	Number of analyses.
Southwestern province:	
1 part per million	1
2 parts per million	2
3 parts per million	4
4 parts per million	4
5 parts per million	4
6 parts per million	3
7 parts per million	4
8 parts per million	0
9 parts per million	2
10 parts per million	0
Total less than 10 parts per million	24
More than 10 parts per million	3
North-central province:	
1 part per million	3
2 parts per million	6
3 parts per million	2
4 parts per million	2
5 parts per million	2
6 parts per million	2
7 parts per million	1
8 parts per million	0
9 parts per million	1
10 parts per million	1
Total 10 parts or less per million	20
More than 10 parts per million	5

In the first group, of the three analyses with more than 10 parts per million, one represents water from the shallow open well that furnishes the public supply at Mountain Lake and shows only 11 parts; the other two represent waters from the village wells at Canby and Clinton. By referring to the proper county reports (Yellow Medicine and Big stone), it will be seen that in both of the last-named wells the water is drawn from the base of the drift, from horizons especially close to the Cretaceous waters in the region where they contain the largest quantities of chlorine. In the second group two of the five analyses with more than 10 parts per million represent the waters from the village wells at Olivia and Renville and show, respectively, 13 and 14 parts. These are rather deep wells and extend virtually to the underlying Cretaceous or altered Archean, from which the excess of chlorine may be derived. The other three analyses represent waters from the city wells at Litchfield, a private well at Litchfield, and the village wells at Atwater and show, respectively, 17, 35, and 35 parts per million. All three are shallow wells driven into surficial deposits of sand. While there is no indication of pollution, it seems possible that the extra amount of chlorine comes originally from sewage. The evidence of the reliable analyses available seems to be that the waters from the glacial drift and other surface deposits in these two provinces tend to contain not over 10 parts per million of chlorine unless (1) they are mingled with water from another formation which bears more chlorine or (2) they receive chlorine through human agencies. However, the number of analyses is too small to allow generalization, and more extended investigation may develop different results.

CONTENT OF IRON AND FIXED NITROGEN.

Most of the iron in solution in the water is in the ferrous state, but whenever it comes in contact with oxygen the greater part is converted to the ferric state, in which condition it is so nearly insoluble that most of it is precipitated. In order to ascertain the true condition of the iron in the underground waters, it is therefore necessary to take the samples directly from the wells before the water has been aerated. Moreover, it must be derived from a drilled or driven well rather than from an open well of large diameter in which the water is reservoired and comes in contact with the atmosphere before it is pumped. The following table contains such samples from drilled and driven wells and springs as were collected with the precautions above prescribed, and, for purposes of comparison, the samples that were taken from open (bored and dug) wells. The table shows not only the content of iron, but also that of free ammonia and nitrates, in the same samples.

Content of iron, free ammonia, and nitrates in waters from the glacial drift and other surface deposits.

[Parts per million.]

	Number of analyses.	Total iron (Fe).	Free ammonia (NH_3).	Nitrate radicle (NO_3).
Drilled and driven wells and springs: [a]				
Depth less than 50 feet	9	0.9	0.3	7.8
Depth 50 to 100 feet	6	3.1	.6	1.0
Depth 100 to 200 feet	7	2.5	1.4	.0
Depth over 200 feet	17	2.3	1.8	.1
Bored and dug wells:				
Depth less than 50 feet	17	.7	.1	23.6
Depth over 50 feet	5	1.6	.7	4.3
Driven wells—all shallow	4	.1	.1	5.2

[a] Springs are included with wells less than 50 feet deep, although some of them would more properly be classified with the deep wells.

The table shows that the waters from drilled and driven wells of all depths over 50 feet contain considerable iron, but those from the shallow wells contain relatively little. This condition apparently results from the fact that in the bulk of the drift the iron and other substances capable of oxidation exist in a partly reduced or deoxidized state (as is shown by the dark color of the clay and sand), and the water is consequently robbed of virtually all dissolved oxygen which it may once have possessed; while, on the other hand, the deposits near the surface are generally oxidized (as is proved by their yellow color), and hence have not the power of divesting the water of its load of atmospheric oxygen. The deeper waters therefore have abundant opportunity to take into solution iron in a soluble ferrous condition, while near the surface this element is kept in the insoluble ferric state by the excess of oxygen. The driven wells represent more strictly surficial conditions than do springs and drilled wells less than 50 feet deep, and accordingly they show a still lower content of iron. The smaller average amounts of iron in the water from the bored and dug wells of equivalent depths should probably be attributed, at least in part, to aeration of the water after the latter enters the well and before it is pumped to the surface.

Analogous to ferrous and ferric iron are the two combinations in which most of the fixed nitrogen in the water is found. Where there is a deficiency of oxygen, ammonia predominates, but in waters containing an abundance of oxygen the prevailing nitrogenous compounds are the nitrates. This condition is shown in the above table, in which in general the ammonia varies directly and the nitrate radicle inversely with the iron. It is possible that in water containing ferrous iron some of the ammonia is formed by the reduction of nitrates after the water is pumped. The large amount of nitrates in the shallow bored and dug wells is probably in part caused by the direct introduction of decomposed organic material.

CRETACEOUS FORMATIONS.

TWO GROUPS OF WATER.

The following table includes all the available analyses of waters derived from Cretaceous formations in southern Minnesota. They are arranged according to their calcium content.

Analyses of waters from Cretaceous formations in southern Minnesota.

[Parts per million.]

County.	No.[a]	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.
Lyon	11	329	97	339	676	1,279	51	2,449
Watonwan	9	327	118	83	512	1,026	4	1,853
Do	10	324	116	146	503	1,121	10	1,994
Lyon	14	324	99	422	387	1,679	47	2,774
Cottonwood	9	287	99	129	713	759	19	1,677
Lyon	12	261	75	203	420	934	40	1,789
Cottonwood	7	219	75	150	539	705	6	1,545
Lyon	13	209	139	415	716	1,317	30	2,473
Cottonwood	10	159	46	348	385	971	12	1,797
Jackson	8	158	57	43	459	346	3	845

[a] The numbers are those under which the analyses are given in the tables accompanying the corresponding county reports.

Analyses of waters from Cretaceous formations in southern Minnesota—Continued.

County.	No.	Calcium (Ca.)	Magnesium (Mg.)	Sodium and potassium (Na+K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.
Lyon	16	139	33	182	231	630	18	1,150
Do	15	138	36	214	283	645	39	1,244
Do	17	130	33	242	296	689	18	1,271
Brown	5	77	33	163	288	223	131	789
Do	6	71	36	144	270	257	104	756
Lyon	8	59	20	524	325	950	49	1,793
Redwood	11	57	12	508	371	912	29	1,816
Lyon	7	40	13	269	268	291	92	854
Cottonwood	8	37	9	512	283	933	13	1,710
Redwood	12	32	7	457	701	450	40	1,339
Lyon	6	31	16	258	242	378	52	836
Bigstone	14	25	10	951	478	871	535	2,662
Yellow Medicine	5	23	10	251	229	137	215	759
Lyon	10	22	16	536	361	819	63	1,663
Bigstone	10	18	10	351	527	284	78	1,044
Do	11	17	9	321	493	248	65	931
Do	12	17	11	337	566	252	67	977
Do	13	17	10	341	562	256	68	978
Do	15	17	8	1,021	400	1,167	490	2,946
Do	16	17	8	1,029	400	1,161	505	2,959
Redwood	10	17	12	423	263	709	23	1,345
Lac qui Parle	....	10	7	248	483	136	27	697

If all the Cretaceous analyses tabulated above are divided into two arbitrary groups, those showing less than 80 parts per million of calcium and magnesium being placed in the "soft water" group, and those showing a greater content of these elements being included in the "hard water" group, the average results will be as follows:

Average content of soft and hard Cretaceous waters.

[Parts per million.]

Group.	Number of analyses.	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.
Soft water	17	26	10	500	414	584	146	1,486
Hard water	15	210	74	215	445	837	35	1,625

The data thus presented bring out a number of very interesting facts. In the first place they show that the Cretaceous waters differ radically in their content of calcium and magnesium, the elements which give hardness to the waters. The range of calcium, as shown in the large table, is between 10 and 329 parts per million, and the range in magnesium between 7 and 97 parts. Although there are some analyses that show intermediate amounts of these elements, there appears to be a tendency for the Cretaceous waters to be either rather soft or very hard.

It will be observed that the total amount of solids dissolved in all the Cretaceous waters is great. Of the 32 analyses given above, the range is between 697 and 2,959 parts per million, and the average is 1,560 parts. It will further be noted that the average of total solids is nearly the same for the two groups (that is, the hard and the soft), but that the substances which make up the totals occur in very different proportions.

All the Cretaceous waters are rich in the alkalies (sodium and potassium), but the soft waters are much richer than the hard, the average content in the former group being 500 parts per million, while in the latter it is only 215. It should here be explained that among the latter, No. 9 in Watonwan County and No. 8 in Jackson County, which show less sodium and potassium than the others, probably represent Cretaceous water diluted by water from the drift.

All Cretaceous waters contain an abundance of sulphates, and in many the quantity is excessive; but the average amount is greater in the hard waters than in the soft, being 837 parts per million in the former and 584 in the latter. While the large table shows that there is a wide range in the sulphate content within each of the two groups, it also seems to show that the averages are not entirely accidental, but that there is a tendency for the waters with much calcium and magnesium to have especially large amounts of sulphates.

Virtually all the Cretaceous waters are rich in chlorine. Only four analyses in the above tables show 10 or less parts per million, and these represent waters which, from their known geologic relations, may well be derived in part from the glacial drift. Nearly all the waters whose analyses are given above come from deep drilled wells, and in very few of them is it probable that the chlorine content has been appreciably augmented by pollution. The average chlorine for the soft waters is much greater than that for the hard, and although there are great variations in both groups it appears evident that these averages represent real tendencies. Indeed, all the distinctly saline waters are soft.

The average content of combined carbonic acid (represented by the bicarbonate radicle) is only moderate, and it is nearly the same in the two groups; furthermore, the range among the individual analyses is relatively small.

In general, two distinct waters of different chemical composition seem to occur; calcium, magnesium, and the sulphate radicle predominate in one water over the alkalies and chlorine; sodium, potassium, and sulphates, with moderately large amounts of chlorine, predominate in the other over the alkaline-earth bases. The differences are presented graphically by the continuous lines in figure 5. The first water is extremely hard and forms a great amount of hard scale in boilers; moreover it is corrosive and readily causes foaming. The second is distinctly softer and much better for laundry and toilet purposes, but it is likely to cause serious foaming, especially in locomotive boilers. The first type is better for irrigation than the second.

The amounts of iron and nitrogen and their relations to each other are indicated by the following table. Only such samples are included as were collected with the precautions prescribed for the waters from the surface deposits.

Content of iron, free ammonia, and nitrates in the Cretaceous waters, southern Minnesota.

[Parts per million.]

Group.	Number of analyses.	Total iron (Fe).	Free ammonia (NH_3).	Nitrate radicle (NO_3).
Hard water	4	2.5	2.1	0.1
Soft water	14	.5	2.0	.0

The hard Cretaceous water, like the deep drift water, is rich in iron and ammonia and is virtually devoid of nitrates. As in the case of the drift, this is probably to be explained by the deficiency of oxygen. The soft water is like the hard in containing much ammonia and essentially no nitrates, but it stands in sharp contrast

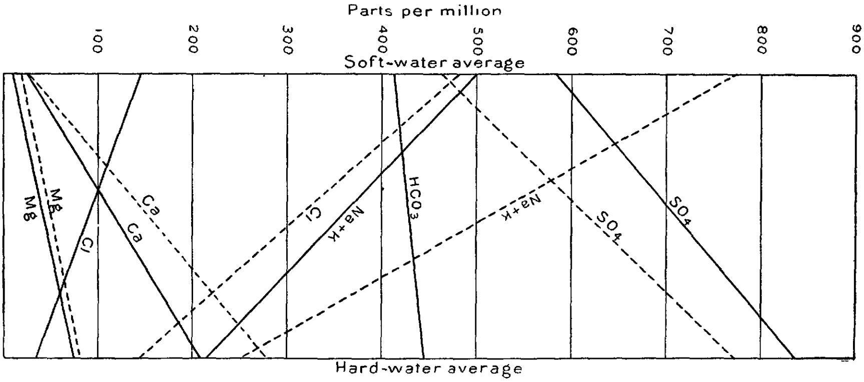


FIGURE 5.—Diagram showing the relations of hard and soft Cretaceous waters.

to the hard water in containing only small quantities of iron. In view of the geologic relations and the evidence given by the nitrogen, it can not be inferred that the slight amount of iron is here due to the greater abundance of oxygen. Whatever may be the explanation, it is evident that the iron content varies directly with that of calcium and magnesium. Although only four analyses of hard water enter into the above table, these are known to be typical of the group so far as iron is concerned.

Some samples of soft water are charged with a gas, the character of which was not investigated. When the water is brought to the surface it effervesces slightly.

GEOGRAPHIC AND STRATIGRAPHIC RELATIONS OF THE TWO GROUPS.

The soft water predominates in the northern part of the Cretaceous area and the hard water in the southern. This is shown on the map (Pl. IV). The facts presented in the reports on Lyon and adjoining counties and the sections given in Plate XII make it evident also that in the same locality certain strata yield hard water and others soft. At Marshall the principal soft-water zone is about 250 feet below the surface, and the principal hard-water zone about 400 feet, and this stratigraphic relation appears to exist at a number of other points. By reference to Plate IV it will be seen that in the region in question the area in which Cretaceous deposits are thin and the area in which soft Cretaceous water predominates are roughly coextensive; and, likewise, the area in which the Cretaceous deposits are thick and contain reliable water-bearing beds and the area in which hard water predominates are roughly coextensive. It was explained in the chapter on artesian conditions that the lowest water-bearing beds of the Cretaceous (those which give rise to most of the flows) are terminated toward the northeast by the impervious granitic rocks which rise nearer the surface in this region. Apparently the hard-water zones are thus chiefly cut off, while the higher and much weaker soft-water zones extend northward and eastward above the granite. These supposed relations are shown diagrammatically in figure 3 (p. 55), in which H and S represent, respectively, the principal hard and soft water zones, while *hh'* and *ss'* represent, respectively, the areas in which hard and soft waters are predominant.

While various lines of evidence indicate that the principal soft-water zone lies at a higher level than the principal hard-water zone, yet some of the data presented in the county reports show that the complete stratigraphic relations of these two types of water can not be stated so simply.

A few analyses of Cretaceous waters from the region north and west of the area under consideration are given in the following table:

Analyses of Cretaceous waters in the region north and west of southern Minnesota.

[Parts per million.]

No.	Description of source.	Date.	Depth of source.	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.
1	Northwest city well, Wahpeton, N. Dak.	Sept. 28, 1907	*Feet.* 430	8	3	372	586	189	90	1,004
2	Well of John Lockman in Breckenridge, Minn.	....do....	260	12	4	346	473	220	110	949
3	"Workman's well," Aberdeen, S. Dak.	Oct. 31, 1907	945	13	3	839	519	730	463	2,318
4	"Artesian well," Aberdeen, S. Dak.	....do....	1,000	10	3	929	600	416	791	2,445
5	Andover, S. Dak.	Nov. 18, 1904	1,100	10	3	788	378	1,098	208	2,295
6	Bristol, S. Dak.[a]	May 20, 1907	368	173	60	289	401	897	26	1,642
7	City artesian well, Webster, S. Dak.	June 30, 1905	1,700	114	51	262	393	623	64	1,332

[a] It is not certain that this water comes from the Cretaceous.

Analyses 1 and 2 were made for this survey by H. A. Whittaker, chemist, Minnesota state board of health. Analyses 3, 4, 5, 6, and 7 were furnished by G. N. Prentiss, chemist, Chicago, Milwaukee and St. Paul Railway Company.

It is significant that the analyses here given can also be divided into two groups, one containing hard and the other soft water, and that all of the main generalizations made above with respect to the Cretaceous waters of southern Minnesota will hold in regard to these analyses. As far as known, the Cretaceous water of the Red River region belongs to the soft group.

In an investigation conducted by J. H. Shepard [a] of the South Dakota Agricultural College, it was found that two types of Cretaceous water exist in South Dakota. The water of one type is rich in calcium and magnesium, and is therefore hard; that of the other type is poor in these elements, and is consequently soft. As in Minnesota, the soft water contains more sodium and chlorine, but somewhat smaller amounts of sulphates than the hard, and it holds very little iron, while the hard water holds relatively much. Moreover, according to Shepard, the soft water comes from a higher horizon than the hard. The former he designates "first flow" water, and the latter "second flow" water. In the following table the averages of the analyses of each group are given, and in figure 5 the relations of the two groups are shown by means of the dotted lines. This figure shows that the two South Dakota types correspond to the two types found in Minnesota. It would be hazardous, from the data here considered, to correlate the 250-foot zone at Marshall with the "first flow" stratum of South Dakota, and the 400-foot zone at Marshall with the "second flow" stratum of South Dakota; but the fact should not be overlooked that these groups of analyses bear important and reliable evidence of the general correlation of the Minnesota Cretaceous with the Cretaceous of South Dakota.

Average content of the two groups of Cretaceous waters in South Dakota.

[Parts per million.]

Group.	Number of analyses.	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.
"First flow"	10	27	20	773	465	480	2,261
"Second flow"	10	279	79	249	770	145	2,019

ARCHEAN-CRETACEOUS CONTACT ZONE.

Two samples were analyzed, one of water which comes from near the contact of the Cretaceous and the decomposed upper portion of

[a] Shepard, J. H., The artesian waters of South Dakota: South Dakota Agr. Coll. and Exper. Sta. Bull. No. 41, 1895.

the granite, and the other from the white kaolin that lies between these two rock systems. In both places the yield was extremely small. The analyses are given in the following table:

Two analyses of waters from the Archean-Cretaceous contact zone in Lyon County.

[Parts per million.]

No.[a]	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.
18	38	32	934	85	258	1,340	2,669
19	89	69	611	254	778	580	2,274

The two samples are somewhat similar, and they are most closely allied to the soft Cretaceous waters. Their most distinctive characteristic is the quantity of sodium chloride (common salt) which they contain. The mineralization is probably derived from the Cretaceous sediments and not from the Archean residuum.

PALEOZOIC FORMATIONS.

The following table, compiled by M. L. Fuller, shows the average composition of the waters from the various Paleozoic formations, based on a large number of reliable analyses:

Average composition of waters from the various Paleozoic formations.

[Parts per million.]

Formation.	Number of analyses.	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.
Devonian sandstone	1	66	12	6.7	276	18	9	269
Galena limestone	10	94	25	41	366	95	9.5	482
St. Peter sandstone	14	84	30	20	372	61	8	430
New Richmond sandstone	14	74	25	14	346	25	4.1	336
Shakopee and Oneota dolomites	11	92	37	23	433	52	8.4	409
Jordan sandstone	35	80	30	31	359	75	13	445
St. Lawrence formation	3	87	31	15	316	85	22	430
Dresbach sandstone	8	88	27	37	319	36	38	345
Lower sandstone	5	61	22	36	258	59	45	400
St. Peter, New Richmond, and Jordan sandstones	6	134	20	98	328	347	29	739
St. Peter, New Richmond, Jordan, Dresbach, and lower sandstones	2	86	53	16	349	40	6.1	363
New Richmond, Jordan, Dresbach, and lower sandstones	1	99	30	9.4	431	38	1.2	391
Jordan and Dresbach sandstones	2	92	17	75	466	57	15.7	509
Jordan, Dresbach, and lower sandstones	4	93	34	95	422	44	109	483
Dresbach and lower sandstones	21	77	28	36	342	60	36	418

The above table shows (1) that the average waters from all the Paleozoic formations are moderately mineralized; (2) that calcium,

[a] The number is that under which the analysis is given in the table accompanying the Lyon County report (p. 251).

magnesium, and the bicarbonate radicle are the principal ingredients; and (3) that only minor quantities of chlorine and the alkalies are usually present. The tables accompanying the various county reports, however, show that some of the Paleozoic waters are highly mineralized, similar to the Cretaceous and drift waters of the southwestern part of the State; and this is perhaps generally true in the southwestern province, where the Paleozoic strata extend beneath beds of Cretaceous from which they probably derive much of their water.

The average water of this group has considerable temporary hardness but less permanent hardness. It deposits scale that is only moderately hard, and it will not readily foam nor will it corrode the boilers in which it is used.

The table reveals no important differences in the total solids nor in the chemical composition of the waters from the various Paleozoic formations, except that the waters from the sandstones are perhaps not quite as hard as those from the limestones, and the waters from the lowest beds are distinctly richer in chlorine than those from higher horizons.

SIOUX QUARTZITE.

The following table gives analyses of waters from the Sioux quartzite:

Analyses of waters from the Sioux quartzite.

[Parts per million.]

County.	No.[a]	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.
Jackson	10	277	82	134	489	877	8	1,807
Pipestone	4	160	68	33	620	41	98	845
Jackson	9	130	149	276	692	886	33	1,855
Pipestone	7	104	49	110	372	368	8	833
Do	5	85	41	20	351	89	31	442
Rock	4	81	36	7	310	45	45	393
Pipestone	6	72	28	38	317	59	36	425
Do	3	48	19	16	261	16	11	269
Watonwan	13	27	10	532	199	389	532	1,618
Rock	3	15	9	2	58	24	5	106
Highest	....	277	149	532	692	886	532	1,855
Lowest	....	15	9	2	58	16	5	106
Average	....	100	49	117	367	279	81	859

There is an enormous range in the total solids and in all of the constituents contained in the various quartzite waters. The explanation of this is evident. The quartzite itself contributes very little to the water, and thus in an area where it occurs at the surface the rain enters the rock at once and remains virtually free of dissolved substances. Analysis 3 in Rock County shows a remarkably soft and slightly mineralized water. It comes from a spring at the margin of a quartzite plateau which is here covered with only

[a] The number is that under which the analysis is given in the table accompanying the corresponding county report.

a few feet of drift. The rain soaks at once into the crevices of the rock and emerges at a lower level, having dissolved very little of any mineral constituent.

In a district deeply covered with drift, the water falling as rain has a long history previous to its entrance into the quartzite, and its mineralization is similar to that of other waters in the drift. Analysis 10 in Jackson County is characteristic of this type. This water comes from a well that passes through more than 100 feet of drift before entering the rock. It is extremely hard and is comparable to some of the most highly mineralized drift waters in the same region.

Again, the quartzite no doubt comes in contact with Cretaceous and other stratified formations, and from these may receive waters that are characteristic of the source from which they come. Analysis 13 in Watonwan County probably belongs to this class.

Many of the quartzite waters are nearly free from iron, and the few analyses at hand show an absence of ammonia. The quartzite contains essentially no available iron, nor anything that will consume oxygen; hence it may be assumed that in localities where it lies near the surface, its water will retain its atmospheric oxygen and will be poor in both iron and ammonia. The water pumped from this formation is quite free from the fine suspended matter which is frequently present in water drawn from the incoherent sediments of the drift and Cretaceous. Where it is also free of iron, it retains, after reaching the air, a perfect absence of turbidity perhaps never found in drift and Cretaceous waters.

SUMMARY.

The following table shows the average composition of the principal groups of water discussed in this chapter (see also Pl. V):

Average composition of the principal groups of underground waters.

[Parts per million.]

Formations.	Number of analyses.	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.
Glacial drift and other surface deposits:								
Southeastern province	86	88	31	23	372	62	24	438
Southwestern province	88	191	58	88	499	542	21	1,132
North-central province—								
Depth less than 100 feet	25	135	47	44	446	154	53	673
Depth more than 100 feet	29	74	35	65	507	48	10	513
Cretaceous:								
Soft water	17	26	10	500	414	584	146	1,486
Hard water	15	210	74	215	445	837	35	1,625
Paleozoic	137	84	29	34	358	74	21	432
Sioux quartzite	10	100	49	117	367	279	81	859

In conclusion, the following general facts can be pointed out:

1. The average composition of the waters from the glacial drift and other surface deposits in the southeastern province is essentially the same as that from the underlying Paleozoic formations in the same region.

2. The average composition of the waters from the glacial drift and other surface deposits in the southwestern province is similar to that of the hard waters from the Cretaceous strata in the same district, except that the content of sodium, potassium, and sulphates is much less.

3. In average composition the waters from the glacial drift and other surface deposits of the north-central province are intermediate in nearly every respect between those from the same deposits in the other two provinces, the water from shallow sources in general resembling that in the southwestern province, and the deeper water resembling more nearly that in the southeastern.

4. The least mineralized waters are those from the Paleozoic formations and from the drift and other surface deposits in the same area; the most highly mineralized are the Cretaceous waters, while next in rank are those from the drift in the southwestern (Cretaceous) province. The waters from the Sioux quartzite range from very low to very high.

5. The softest waters are those of the soft-water group of the Cretaceous, while the Paleozoic waters, those from the drift and other surface deposits in the southeastern province, and those from the lower portions of the drift in the north-central province are only moderately hard. The hardest waters are those belonging to the hard-water group of the Cretaceous and those from the drift in the southwestern province. The waters from the Sioux quartzite range from very soft to very hard.

6. The Paleozoic waters and those from the surface deposits in the southeastern province contain the smallest amounts of alkali, while the Cretaceous waters, and especially the soft Cretaceous waters, contain the greatest quantities. The quartzite waters range from very low to very high in their alkali content.

7. The range in the amount of combined carbonic acid (bicarbonates) is much less than that of any other constituent. This is true of every group of water in southern Minnesota and of all the groups taken together. The waters in the eastern part of the State average somewhat lower in this respect than those in the western, but the difference is not great. None of the analyses made for the Survey showed the presence of normal carbonates.

8. The Cretaceous waters and the waters from the surface deposits in the southwestern province contain notable quantities of sulphates. The Paleozoic waters and those from the surface deposits in the

eastern part of the State have a considerable range in the quantity of sulphates they contain, though usually only moderate amounts are present. In the upper portion of the drift in the north-central province the sulphate content is generally high, while in the lower portion it is usually very low. In the quartzite waters the range is great.

9. In chlorine the soft Cretaceous waters rank highest, some being distinctly salty to the taste. The hard Cretaceous waters and the deepest Paleozoic waters also contain considerable quantities of this element, but the normal waters from the glacial drift and other surface deposits throughout southern Minnesota and from the upper formations of the Paleozoic generally contain only small amounts.

10. The deeper drift waters and the hard Cretaceous waters are usually relatively rich in iron and free ammonia and poor in nitrates, while the very shallow drift and alluvium waters and other waters containing free oxygen average lower in iron and ammonia and higher in nitrates. The soft Cretaceous waters are relatively low in iron and nitrates, but relatively high in ammonia. The relations of these three constituents to each other are shown by the following summary table, which is based chiefly upon analyses of samples from the surface deposits and Cretaceous:

Relations of iron, free ammonia, and nitrates to each other in underground waters of southern Minnesota.

[Parts per million.]

Iron (Fe).	All groups except soft Cretaceous water.			Soft Cretaceous water.		
	Number of analyses.	Free ammonia (NH_3).	Nitrate radicle (NO_3).	Number of analyses.	Free ammonia (NH_3).	Nitrate radicle (NO_3).
Trace	8	0.02	19.2	3	2.46	0.0
0.1	3	.01	31.7	3		.0
0.2	7	.02	22.6	3	1.17	.0
0.3 to 1	13	.78	.5	3	3.38	.0
1 to 2	13	1.11	.1	1	1.01	.0
2 to 3	16	1.26	.3	1	1.69	.0
3 to 5	9	1.67	.1	0		
Over 5	2	1.16	.0	0		

PROBLEMS RELATING TO WELLS.

By M. L. Fuller and O. E. Meinzer.

To explain the advantages and disadvantages of the different types of wells for the various conditions found in southern Minnesota, and to discuss the multitude of problems that are confronted in constructing and finishing these wells, would require an extensive treatise. In the following pages only a few subjects pertaining to wells are considered—subjects which are especially important for the area under consideration.

TYPES OF WELLS.

IN THE SURFACE DEPOSITS.

A majority of the wells of southern Minnesota draw their water from the glacial drift. Since the drift sheet, which is spread over most of the region, is but slightly eroded and poorly drained, and since much of the loosely aggregated material near the surface is more or less porous, small supplies of water are generally found near the surface except in periods of prolonged drought. It was a simple matter for the pioneer to dig down to water, and the shallow dug well was therefore at first the prevailing type wherever the drift was sufficiently deep and undissected. Later well augers or boring machines were introduced, with which it was possible to penetrate the incoherent deposits more readily. By the use of these machines wells were constructed that have a somewhat smaller diameter and greater depth than those dug by hand, but which resemble the latter in principle. In both types it is difficult to sink deeper after a saturated sand bed is reached, and hence weak surficial water horizons are utilized and reliance for obtaining a sufficient supply is placed chiefly in the large diameter and the pervious casing (commonly consisting of boards), by means of which the seepage is received from an extensive surface. Because of its large diameter, such a well also serves as a reservoir, gradually filling up to the ground-water level, and thus accumulating a store of water during the intervals that it is not pumped.

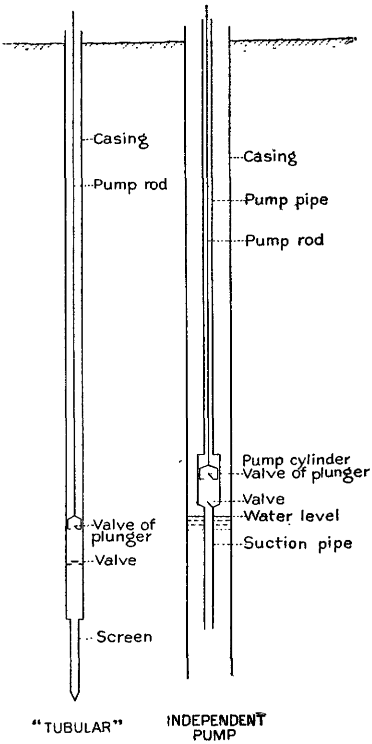


FIGURE 6.—Diagram showing the two most common types of deep-well pumps.

A bored or dug well is unsatisfactory in several respects. The constant fluctuation of the level of the water causes the wooden casing to decay rapidly, with the result that the clay and gravel on the sides cave and fall into the bottom of the well, soon filling it above the ground-water table. When the casing is partly rotted the well becomes a veritable trap for mice, rats, rabbits, and other small animals, which decompose in the water, producing conditions notoriously filthy. Furthermore, in seasons of protracted drought the yield, which in most instances is normally small, becomes much reduced, or the well may dry up entirely, thus subjecting the farmer to great inconvenience. As the herds of live stock grow in size the difficulties attending an uncertain water supply increase in seriousness, and as the farmers become prosperous many of them are ready to abandon their unsatisfactory shallow wells and to employ a driller to sink to stronger and more reliable beds at greater depths.

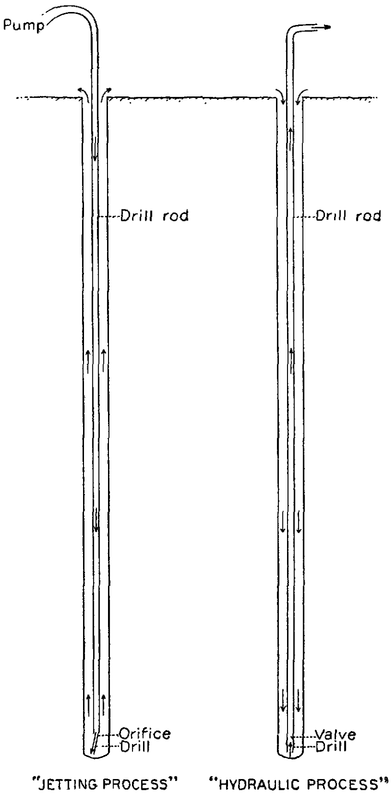


FIGURE 7.—Diagram showing two methods of drilling "tubular" wells.

The most common type of drilled wells ending in the drift is the so-called "tubular," which is cased with 2-inch iron pipe and terminates with a sand screen or strainer, through which the water is admitted. In this type the plunger and valve are inserted in the casing and there is no independent pump pipe (fig. 6). The wells are usually drilled by the "jetting" process, in which water constantly forced down through a hollow drill rod by means of a pump, is ejected with some force through a small orifice at the bottom and returns to the surface on the outside of the drill rod, carrying up the material that has been loosened by the drill or by its own impact. Another method, less frequently employed, is locally known as the "hydraulic" process. In this case water poured down the hole is forced up into the hollow drill rod with every downward stroke of the latter, and is prevented from returning by means of a valve. Thus the water is brought up carrying the drillings with it. Both methods are shown diagrammatically in figure 7. One of the principal difficulties met in drilling in the drift is presented by the glacial bowlders, which block effectually the progress of all drills of frail construction. These obstacles can best be removed by the use of explosives.

There are now numerous drilled drift wells of larger diameter, owned by municipalities, railway companies, and various manufacturing concerns, and not infrequently by farmers. A well more than 3 or 4 inches in diameter is usually made with a "standard rig," in which a heavy percussion drill is suspended by means of a cable and is withdrawn at regular intervals in order that the drillings may be removed by lowering a bailer or "sand bucket." Virtually all drilled wells ending in the drift are provided with iron casing from top to bottom.

While on a large proportion of farms the bored wells have been replaced by drilled ones, in most of the villages they are still in general use for furnishing domestic supplies. Dug wells of great diameter, sunk into alluvial or outwash gravels, are frequently used for public and locomotive supplies.

In the areas where sand or gravel lies at the surface, shallow, inexpensive driven wells are the prevailing type and for the most part furnish very satisfactory supplies. Such a well consists merely of a perforated "sand point" attached to an iron pipe and driven into the sandy deposits either by means of mallets wielded by hand or by some contrivance similar to a pile driver.

IN THE CRETACEOUS.

The Cretaceous rocks consist essentially of soft shale and sandstone that can be penetrated quite as readily as the drift. Hard material, perhaps chiefly concretionary in character, is frequently encountered, but there are no erratic bowlders such as cause trouble in the drift. Most of the wells that draw from this system are of the small "tubular" type, and although generally several hundred feet in depth, are for the most part drilled with very light rigs, by the "jetting" process above described. Wells passing through the Cretaceous, like those in the drift, are cased throughout with iron pipes.

IN THE PALEOZOIC.

In the southeastern part of the State, where there is considerable relief and the rock lies near the surface, the drift does not always supply enough water even for farm use, and consequently numerous wells have been drilled into the Paleozoic formations. Since in many places on the uplands the distance to water is great, many of these wells are deep. For penetrating the indurated limestones, shales, and sandstones of the Paleozoic, relatively heavy percussion drills are necessary, and it is not found advantageous to have the hole less than 5 or 6 inches in diameter. In most instances casing is inserted only to the unweathered rock, below which the well is open.

IN THE SIOUX QUARTZITE.

In the southwestern part of the State there are localities in which the Sioux quartzite (locally known as "the red rock") is so near the surface that little or no water is obtained from the overlying deposits.

In these areas the problem of water supplies was at one time acute, but wells are now sunk into the rock and adequate quantities of water are secured there from. The quartzite is very hard, hence drilling into it is a slow and expensive process. Moreover, the mechanical difficulties prove quite insurmountable to anyone not skilled in this kind of work. Most of the wells are 6 inches in diameter and are made with heavy percussion drills. They require no casing nor screens, and when once constructed are permanent.

IN THE ARCHEAN.

Although the Archean crystalline rocks are essentially not water bearing, much money has been expended in drilling into them, frequently to considerable depths. The admonition is here repeated that when unweathered granite or allied igneous rock is reached drilling should in all cases be discontinued.

FINISHING WELLS IN SAND.

THE PROBLEM.

Throughout the southwestern part of Minnesota and adjacent parts of Iowa and South Dakota the majority of drilled wells end in sand belonging either to the glacial drift or the Cretaceous system. The successful finishing of these wells is perhaps the most important problem in connection with water supplies in this area. Most of them have 2-inch iron casing which serves also as the pump pipe (fig. 6.). The sand rises with the water so persistently that it is found necessary to put a screen or strainer at the bottom of the casing to shut out the sand while admitting the water. Various types of screens are in use, but the common type for wells of small diameter consists of a perforated iron pipe surrounded by a brass gauze of fine mesh, and the whole inclosed in a perforated jacket to protect the gauze. The screen is small enough so that it can be let down inside the casing.

Wells finished in this manner prove satisfactory for a time, but in the course of a few years the yield diminishes and eventually almost no water can be obtained. When the screens are removed they are found to be effectually sealed by a coating of silt, etc., firmly cemented into a hard impervious mass. The cost of a screen is not great, and the substitution of a new one for the old every few years would be no serious matter were it not that the removal of a screen is attended by great difficulties. In many instances the coating of cemented silt becomes so thick that the screen can not be withdrawn on the inside, and it is then necessary to pull up the entire casing in order to remove it. The labor and difficulty involved in this process are considered by many drillers to be equivalent to those of sinking a new well.

Moreover, the rusted casing is liable to break, or the hole may cave in, and the well is then usually lost.

The clogging of the screen has been found to be so great a nuisance that in many localities the drilled wells have nearly all been abandoned and shallow sources are again resorted to. Especially has this been done in the recent years of abundant rainfall, following a series of dry years in which many of the drilled wells were sunk. The aggregate cost of the wells that have thus been abandoned in this region amounts to hundreds of thousands of dollars, and, furthermore, the return to shallow wells is not a solution of the problem. In recognition of the magnitude of the difficulty the entire matter was investigated with a view to finding a practical remedy.

CHEMISTRY OF THE INCRUSTING PROCESS.

In order to ascertain the composition of the incrustant and the chemical changes involved in the incrusting process, a typical 2-inch well was selected from which had recently been removed a screen of the ordinary construction, coated with the usual hard, dirty-gray substance. The water from this well and the incrusting material were both analyzed.

The well is owned by George Clynick and is located in the SW. ¼ sec. 33, T. 104 N., R. 29 W., in Martin County, Minn. It was drilled in 1899 and is 70 feet deep and 2 inches in diameter. It yields all that the windmill can pump. The head is 13 feet below the surface. In drilling the material penetrated was (1) blue clay; (2) bluish-white sand, at first very fine but changing to coarse grit, in which the well ends. The well has an iron casing, with a screen at the bottom. The screen is a perforated galvanized iron pipe surrounded by brass gauze, the whole inclosed in a perforated brass sheath. It is 3 feet long and about 1 inch in diameter. The length of time required for it to become effectually clogged is reported to be about five years.

Analysis of water in clogged well.

[Date, July 25, 1907. Analyst, H. A. Whittaker, chemist, Minnesota state board of health.]

	Parts per million.
Silica (SiO_2)	24
Iron (Fe)	2.6
Calcium (Ca)	140
Magnesium (Mg)	54
Sodium and potassium (Na+K)	22
Carbonate radicle (CO_3)	0
Bicarbonate radicle (HCO_3)	259
Sulphate radicle (SO_4)	389
Chlorine (Cl)	4
Nitrate radicle (NO_3)	1.5
Free ammonia	2.0
Carbon dioxide (CO_2)	54
Total solids	772

Analysis of material that incrusted screen in clogged well.

[Date, Sept. 26, 1907. Analyst, R. B. Dole, U. S. Geological Survey.]

Clay, sand, silica, etc	56.0
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	2.8
Calcium (Ca)	13.0
Magnesium (Mg)	1.3
Alkalies (Na+K)	.7
Carbonate radicle (CO_3)	20.6
Sulphate radicle (SO_4)	.4
Chlorine (Cl)	.1
Phosphate radicle (PO)	.0
Organic and volatile matter	5.3
	100.2

To the above analysis the following note was added:

Of the 56 per cent comprising the silica and insoluble silicates, only 31 per cent is volatilized by hydrofluoric acid, showing that there is probably considerable clay present. Indeed, clay, sand, and carbonates of calcium and magnesium comprise 90 per cent of the deposit. The probable presence of sand particles is indicated by the fact that the substance was gritty when first pulverized and required two days' grinding to reduce it to a powder fine enough for analysis.

The principal cementing substance is probably calcium carbonate precipitated from the water. The sand, silt, and clay are packed about the screen by the inflow of the water, and the interstices are then filled with calcium carbonate and other materials. Thus the whole becomes a nearly impervious sheath which shuts out the water.

Whenever in any well the pump is operated the weight of the water column is decreased by the removal of water, and it is this diminution in pressure that causes a new supply of water to flow through the screen into the well. The reduction of the pressure may allow a portion of the carbon dioxide to pass out of solution, disturbing the equilibrium between the free carbon dioxide and the bicarbonate radicle and effecting partial decomposition of the latter substance. As a result of this reaction, calcium carbonate is probably precipitated and is incorporated in the incrusting material. Only minute quantities of calcium carbonate need be deposited in order to effect the sealing of the screen in the course of several years. Possibly precipitated iron also adds to the cementing material. Electrolysis may occur between the brass and iron portions of the screen, but does not seem to be an adequate cause. City and village wells are usually provided with large brass screens, and these do not appear to cause as much trouble as the ordinary screens in the 2-inch farm wells, but brass screens in the 2-inch farm wells become incrusted as readily as the ordinary brass and iron ones, and the incrustant appears to be of the same character. If the diagnosis given is correct, the process does not depend chiefly upon the nature of the screen, but upon changes that unavoidably accompany the withdrawal of water from the well, and hence the remedy must be sought along mechanical rather than chemical lines.

REMEDIES.

A study of the mechanical aspects of the problem makes it possible to put forth some suggestions, which, if followed, should prove of value, diminishing the annoyance and expense connected with wells finished in sand.

A well of large diameter and open end.—Two-inch wells should not be drilled in regions where the screens become incrusted. For farm purposes wells from 4 to 6 inches in diameter can generally be finished successfully with open ends, whereas it is invariably necessary to put screens into those which are only 2 inches in diameter. The explanation is simple. With a given rate of pumping the upward velocity of the water in a well varies inversely as the square of the diameter; while the capacity of a current to move solid particles has been proved to vary as the sixth power of the velocity. Consequently sand that will cause no trouble in a large well will be driven rapidly into a small one if it is not screened. Practically the effect is probably even greater than the above ratio indicates, because in the wells of large diameter the inflow and upward velocity are nearly constant as long as the rate of pumping is kept constant, while in a well of small diameter the casing usually serves also as the pump pipe, and hence the upward current is not uniform, being zero during the downward stroke and varying from zero to a maximum and back to zero during the upward stroke. This can be better understood by reference to figure 6. In general it will be found more satisfactory and ultimately more economical to drill wells at least 4 inches in diameter than to put down the small 2-inch "tubulars."

It is important, however, to understand that the finishing of sand wells with open ends should be attempted only where the rate of pumping is to be slow, for example, in farm wells where windmills are used. As a rule wells furnishing water for public supplies and all others pumped by steam or gasoline engines should be provided with screens. A number of sand wells used for public supplies in southern Minnesota were finished without screens and nearly all of these have given trouble. The sand rises with the water, cutting out the pump valves, clogging the mains, and filling the wells to such an extent that the supply is greatly diminished or the wells are totally ruined.

A well of large diameter finished with a screen.—Drilled sand wells of large diameter invariably require screens if the rate of pumping is to be rapid, and some require them even though the rate of pumping is slow. Whenever there is danger that the sand will rise it is the part of discretion to put in a screen. It should be remembered, however, that a 5-inch well with a screen is much better than a 2-inch well similarly finished. In the latter the screen must of necessity fit snugly into the casing, and when it becomes incrusted it is liable to refuse to come up, thus causing much trouble and frequently making it necessary to pull the entire casing. In a 5-inch well, on the other hand, a small enough screen can be used so that there will be no difficulty in removing it. Experience shows that it is poor economy to drill 2-inch wells.

Finding a coarse layer.—The glacial deposits, in which many of the wells under consideration end, are irregular and may alternate rapidly from fine sand to coarse gravel. It is a matter of great importance to finish a well where the material is coarsest. Drillers understand the significance of this but are not always successful in practice. As a rule, the coarsest part of a sand and gravel bed is at the bottom, but this is not invariably so.

Driving the casing to the proper depth.—Commonly a thin layer of "hardpan" lies at the contact between a bed of clay and a deposit of water-bearing sand and gravel. Frequently there is difficulty in driving the casing through the "hardpan," and hence it is often allowed to stop above this hard layer or to fit only loosely into it. If a screen is inserted it is somewhat smaller than the casing and can easily be projected through the hole in the "hardpan" and into the water-bearing sand. This is a careless method of finishing a well. The clay is liable to be washed down and to come in contact with the screen, thus greatly hastening the clogging process; or if the well has an open end the caving of the clay may obstruct the entrance. Not infrequently wells are ruined by neglect of the driller in this respect. Whether they are to be finished with or without a screen, it is important to have the casing driven completely through the cap of "hardpan" and down into the coarsest part of the sand or gravel.

Developing a natural screen.—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.

Making an artificial gravel screen.—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.

An independent pump.—As has already been explained, in 2-inch wells the casing usually serves also as the pump pipe; a device that produces more or less unsatisfactory results. The water must enter as rapidly as it is drawn up by the pump. This gives an intermittent and irregular current into the well and increases greatly the danger of drawing up sand. Even where a screen is used it is liable to force fine silt through the meshes or to break holes in the screen, and the great reduction of pressure in the well on the upstroke probably increases the precipitation of calcium carbonate. When the yield is small or when the inflow of the water is obstructed by the incrusting of the screen, pumping becomes difficult and the wear and tear become great. An independent pump hung in a well of adequate diameter involves some additional cost, but is much more satisfactory.

Removing the screen frequently.—Much of the difficulty with the screens could be avoided if they were renewed more frequently. A screen which is left in the well until it has become so completely sealed that its removal is absolutely necessary not only is an aggravation for a long time before its removal, but also is likely to have become so thickly coated that it can not easily be withdrawn.

Summary.—Only wells of large diameter should be drilled (that is, 4 inches or more). Care should be taken to drive the casing through the cap of "hardpan" and through any beds of quicksand which may exist, to the coarsest portion of the deposit. The fine sand should then be removed by protracted pumping and a natural screen of coarser sand or gravel developed. Gravel of the proper coarseness may also be introduced into the well to be added to the natural strainer. If the water is to be drawn at a slow rate and an independent pump is used, it is not usually necessary to put in a metal screen. If, however, the water will not become clear and the sand persists in rising, a screen should be inserted and tightly attached to the bottom of the casing. It should be considerably smaller than the latter in order that it can easily be removed when it has become incrusted. As soon as the yield of the well shows distinct signs of reduction, the screen should be drawn up and cleaned or else replaced by a new one.

DRILLING IN QUARTZITE.

The Sioux quartzite ("red rock") presents a group of difficulties which are exceedingly troublesome to any driller not accustomed to penetrating this formation, but if these difficulties are foreseen and properly guarded against they become much less serious. The following are some of the principal points that must be observed:

(1) The machine must be strong and heavy. Many of the rigs that are satisfactory for sinking into the drift and Cretaceous are entirely inadequate for hard rock drilling. (2) The well must be large enough to admit heavy drill rods. A hole 6 inches in diameter can perhaps be drilled more advantageously than any larger or smaller size. (3) The drill must be kept properly sharpened and tempered. It is customary to have the outfit include a forge and to be equipped with two drills in order that one can be sharpened while the other is in service. The length of time a drill can be used advantageously before it is exchanged for a newly sharpened one varies with the hardness of the rock, the average period being about forty minutes. (4) The drill must be kept up to the standard diameter. As the hard rock abrades its sides, it gradually becomes smaller and makes a hole of diminished diameter. When once the size of the hole has been reduced, it is well-nigh impossible to enlarge it. Thus it happened, before this contingency was vigilantly guarded against, that the well would persistently shrink in diameter as the work progressed, until it was no longer feasible to continue drilling. It is now the practice to restore the drill to its standard diameter each time it is removed and sharpened. (5) The well must be kept straight. Its obstinate tendency to become crooked was perhaps the greatest difficulty encountered by the pioneer rock drillers. This may be caused by the presence of "crevices" which the drill persists in following, instead of cutting straight downward into the hard rock.

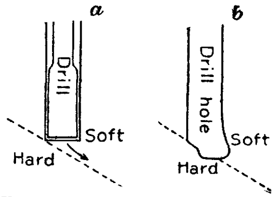


FIGURE 8.—Diagram showing the deflection of the drill in Sioux quartzite.

More commonly perhaps it is due to the fact that there are great differences in the degree of induration. Thus when the drill passes from a relatively soft portion into harder rock (the contact plane between the two being oblique), instead of going directly downward into the hard rock it tends to follow the contact plane and to remain in the soft portion (fig. 8). It is about as difficult to straighten a hole that is out of alignment as it is to enlarge a contracted one, and the experienced workman is therefore watchful to prevent any departure from the plumb line. The principal precaution to be taken is to work with a taut cable when the drill shows a tendency to be deflected.

PHENOMENA DUE TO VARIATIONS IN ATMOSPHERIC PRESSURE.

FLUCTUATION OF HEAD.

The fluctuations in the level to which water rises in wells are controlled by a number of factors, most of which (such as rainfall, melting of snow, and freezing and thawing of the ground) relate to the supply contributed to the underground reservoirs. But attention is here directed to a class of fluctuations more limited in their range and less frequently observed, but no doubt occurring very generally. They are the variations in water level resulting from the changes in the pressure of the atmosphere. An example is afforded in the vicinity of Winnebago, where it is reported that some of the wells show slight daily variations of level, the water frequently standing lowest at about 10 a. m., when the barometric pressure is usually greatest, and highest at about 4 p. m., when the pressure is likely to be least; while still greater fluctuations mark the passage of storms, the water rising materially with the decrease in pressure on their approach, and subsiding on the return of fair weather and a high barometer.

VARIATIONS IN THE YIELD OF FLOWING WELLS.

It follows as a corollary of what has just been said that the discharge from flowing wells is greater when the barometer is low than when it is high. Although this is perhaps a universal phenomenon, the difference in discharge is usually so small that it is quite unobserved. However, where the artesian pressure is slight, as in many of the drift and Paleozoic wells of the region under consideration, the effect of the fluctuations in atmospheric pressure is frequently apparent, and it sometimes happens that a well will flow during storms but will cease flowing when the weather clears up. The well of the Red Wing Malting Company, 470 feet deep and ending in sandstone, is said to flow 25 per cent more when the wind is northeast (during storms) than ordinarily.

ROILINESS OF THE WATER DURING STORMS.

Most wells, except when first sunk, yield clear water. In isolated cases, however, the water, which is ordinarily clear, becomes cloudy or milky on the approach of storms, and more rarely it turns to a bright yellow or deep red color under the same conditions. Among the instances of milkiness before storms may be mentioned certain wells near Lakeville in Scott County, while of discoloration the most pronounced examples are in the vicinity of Waterville in Lesueur County. Examination shows the milkiness to be due to the presence of a slight amount of suspended silt or clay, and the yellow and red colors to fine particles of iron oxide held in suspension.

Since this phenomenon is closely associated with the changes in the weather, it is altogether probable that in some way it results from fluctuations in atmospheric pressure. In the case of flowing wells it could perhaps be explained by the increased discharge during low barometer, the water at these times having a greater velocity and hence being able to bring up sediment that usually remains undisturbed. But the fact that the phenomenon occurs also in wells that do not flow seems to discredit such a hypothesis and leaves the precise explanation obscure.

"BLOWING" AND "BREATHING" WELLS.

"Blowing" and "sucking" are common phenomena in southern Minnesota, not only in drilled wells, but also in those of the dug and bored types. In the latter the air passes in and out through openings in the curbs, in some instances with considerable force. Often the whistling of the escaping air is loud enough to be heard for several rods. In some wells in other sections of the country the current is strong enough to operate a whistle that can be heard at a distance of a mile or more. The indraft is usually less rapid and less conspicuous than the outward current, and in warm climates it is often overlooked, but its presence is abundantly demonstrated by freezing wells. In the majority of instances, however, the "blowing" is observed to be intermittent and to alternate with periods of "sucking." In this case the well is commonly known as a "breathing" well, or it may be aptly called a "barometer" or "weather" well.

Since the "blowing" is commonly associated with a falling barometer and the "sucking" with a rising barometer, it seems certain that they are caused by the variations of atmospheric pressure. The essential condition is that the well must be in connection with underground cavities not filled with water and not in free communication with the atmosphere. This condition is common in the Paleozoic area, where formations of limestone are traversed by solution passages forming a cavernous network, where these formations are now covered by drift or other relatively impervious material, where the ground-water level is often low, leaving the passages filled with air instead of water, and where the wells are generally not cased below the point at which they enter indurated rock. Porous gravels of the drift will serve the same function as the solution passages of the limestone, provided they lie above the ground-water level and are not shut out by the casing. When, on the approach of a storm, the pressure at the surface is reduced, the air confined in the earth rushes out until equilibrium is reestablished; but when, upon the return of fair weather, the pressure again increases air is forced back through the well into the earth. In the few wells from which water is spouted during the period of "blowing," the casing probably extends virtually to the water, but not far below it.

Some of the "blowing" wells of southern Minnesota will be briefly described. (1) In a number of the valleys between Wabasha and Reads Landing and elsewhere in the same vicinity, a dozen or more wells are known which exhibit the phenomenon of "blowing," the air coming in strongly at depths of about 60 feet from openings in the limestone into which the wells are mainly drilled. (2) In the region of Waseca, under a layer of clayey hardpan at about 100 feet below the plateau surface, there appears to be a bed of coarse gravel which yields "blowing" wells whenever encountered, but which does not afford water. In one well of the group it is known that the "blowing" alternates with a "sucking" of the air. (3) On the prairies in the vicinity of Roberds and Cannon lakes, near Faribault, many "blowing" wells are reported. According to the local drillers the phenomenon is confined to uncased wells, the air being found in gravel beneath beds of clay, never in gravel near the surface. According to their statements, when the wind is from the south air is expelled with a whistling sound; when from the north it is drawn in. Poisonous gas is sometimes given off with the expelled air, occasionally producing fatal results. In winter, during periods of north wind, freezing occurs to a depth of 80 feet, notwithstanding the attempts to prevent it by coverings. (4) In Lac qui Parle County there are a number of "barometer" wells ending in gravel. In one of them water is forcibly ejected when a storm is approaching.

FREEZING OF WELLS.

At certain points in southern Minnesota much trouble is experienced from the freezing of the water in wells, and it is often only with the greatest difficulty that the wells are kept in use during the winter. It is known that the freezing takes place in the clear weather following a storm, when the barometer stands unusually high, while the wells thaw during storms or periods of low barometer. It is further noted in some wells that the freezing takes place when there is an inward current, while the thawing is associated with a discharge of air. These facts show that barometric fluctuation is the general cause of the difficulty.

The freezing occurs in dug and drilled wells, but is not manifested in double-tube wells when both casings are carried below the water level, although where the outer extends only to the rock or stops at some other point before the water is reached there is danger of freezing. In some wells the mischief seems to be caused not by the air passing down on the inside of the casing, but by its penetrating on the outside or through natural passages intersecting the well.

In the treatment of freezing wells the aim is either to warm the air passing in or to prevent its entrance. The most common method of accomplishing the first of these purposes is to pack manure about the top of the well, the heat generated by its decomposition tending to warm the air to some extent. This method should be condemned, since it involves the danger of polluting the water.

A better remedy is to prevent the entrance of the air. If possible this should be done by carrying air-tight casings to a sufficient depth, but air currents can also be stopped by filling the space between the two tubes with some impervious material. A filling of cement resting on an improvised plug is very effective, as is the use of rubber packers, where these can be secured. The homemade rag packing is unsatisfactory, as it is generally sufficiently porous to permit the air to get in. Where the air does not enter through the well, but passes down on the outside or circulates in underground passages intersecting the drill hole, it may be advisable to fill the space between the outer and inner tubes from top to bottom with cement.

In dug wells the remedy lies not in housing the well, a method that has been found unsuccessful, but rather in making an air-tight curb of cement or other material tightly fitted to the well curb, which should also be lined with cement for some feet below the surface to prevent the entrance of air through the soil.

DRAINAGE BY WELLS.

THE PROBLEM.

Over much of the drift-covered uplands of southern Minnesota the ground-water level is near the surface, and numerous undrained depressions exist as swamps or lakes. The soils of such depressions are usually rich, and when reclaimed yield splendid crops, tracts originally almost worthless being converted to valuable farming lands that add materially to the productiveness of the region. Artificial drainage, therefore, is a problem of great importance.

Cooperative drainage by ditching is undoubtedly the best general method, and is the one commonly employed where the relief is sufficient to make it possible and where the wet lands are not separated from the drainage line by ridges of too great height. But where the topographic conditions are such that it is not feasible to conduct the water to a natural drainage channel, small tracts can in some cases be reclaimed by drainage wells.

NECESSARY CONDITIONS.

The efficiency of wells for drainage purposes depends upon the difference in head of the surface and underground water, and upon the texture of the deposits into which the water is introduced. The texture is important in determining the water-bearing capacity, the rate at which the water is conducted away, and the liability of the passages to become filled by sediment unavoidably carried down by the water.

Of the various materials encountered in drilling, gravels are among the best for drainage by wells, since they not only have a high degree of porosity, averaging 30 to 35 per cent of their volume, but the openings are so large that they conduct water readily and do not easily become clogged by foreign matter. Sand, though fully as porous as gravel, offers more resistance to the passage of the water and has a greater tendency to become clogged. This latter difficulty is a serious obstacle to draining into sand, especially into the finer varieties. Of the consolidated materials in southern Minnesota, sandstones and limestones only need to be considered. The former are rather porous, but present the same difficulties as unconsolidated sand. The limestone in itself is virtually impervious, but its bedding planes, joints, and solution passages afford ideal conditions for drainage by wells.

REMOVAL OF DÉBRIS AND SEDIMENT FROM THE WATER.

One of the principal precautions to be taken in connection with drainage into wells is to prevent the entrance of solid matter, which will in time partly choke up the pores of the formation into which the water is poured, and will thus greatly reduce the capacity of the well. This foreign material consists of two kinds—(1) floating vegetable matter in the form of leaves, twigs, grass, slime, etc., and (2) suspended particles of clay and silt. The floating matter can readily be strained out by allowing the water to pass through a screen. The particles of clay and silt are less easily removed. Perhaps the most feasible method is to have a settling reservoir, but it is possible that, under conditions otherwise favorable, some method of filtration could profitably be employed. If the wet land is drained through a subsurface system of tiles, the water conducted to the well will be less burdened by sediment than if it flows upon the surface.

EXTENT OF AREAS THAT CAN BE RECLAIMED.

The number of acres that can be reclaimed with a well of a given diameter depends upon the factors already mentioned as governing the capacity of the well, and upon the quantity of water that must be removed per acre. In many cases not only the visible water but also the tributary ground water must be disposed of. Where the conditions are favorable, a single 4-inch well will sometimes remove ponds 2 or 3 acres in extent and drain land areas of 10 to 60 acres between the thawing in the spring and the time of planting.[a] At a few places in southern Minnesota wells have been used for the drainage of wet lands. Six miles south of Blooming Prairie, Steele County, a well successfully drained several acres, while 3 miles south of Albert Lea a 3-inch well drained 5 acres. Similar results are said to have been obtained in other localities. If reservoirs were

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[a] Horton, R. E., The drainage of ponds into drilled wells: Water-Supply Paper U. S. Geol. Survey No. 145, 1905, pp. 30–39.

Crider, A. F., Drainage of wet lands in Arkansas by wells: Water-Supply Paper U. S. Geol. Survey No. 160, 1906, pp. 54–58.

excavated they would not only serve to free the water of sediment, but, by receiving the water at times of heavy rainfall, would keep the wells more constantly employed and would thereby increase their effective capacity.

HYDRAULIC RAMS.

The benefits resulting from the use of hydraulic rams have seldom been brought to the attention of the spring owners and the owners of flowing wells. The statement is often made by a property holder that he would give a considerable sum of money for a flowing well at his house like that of some more fortunate neighbor on lower ground, or for a spring like those in an adjacent valley. Of course the conditions may make it impracticable for a farmer to obtain such water at his home, but in many localities the same advantages may be secured by installing a hydraulic ram. Given a flowing well or spring with a few feet of head and a moderate yield, this appliance can frequently be successfully used to lift an adequate supply of water to a house and barn at a considerably higher level. With 5 feet of head at the ram, the water may be conveniently raised to about 30 feet, while with large rams and favorable conditions of head and volume, water can be carried as much as half a mile and lifted 200 feet. The length of the supply pipe should be at least 30 or 40 feet to give the most efficient results. An actual test on a small ram costing $9, with 70 feet of supply pipe and 12 feet of fall, showed that with 2.1 gallons per minute furnished to the ram, 0.3 gallon was delivered through 100 feet of pipe at a height of 50 feet above the ram. The only cost of operating is that of repairs.

Although not in common use in southern Minnesota, rams have, nevertheless, been employed in a number of instances. At Hokah one has been used to pump the water from a 544-foot well with a head of about 18 feet, to the village 30 or 40 feet above it. At Sterling Center several of the flowing wells are connected with rams and the water lifted to the houses on the higher lands. The same is true of the flowing-well district about the head of Straight River in southern Steele County and near Geneva in northern Freeborn County. The heads are usually from 10 to 15 feet, the lift 25 or 30 feet, and the distance carried often several hundred feet.

Rams are seldom used for pumping the water of springs, although in a number of instances this might readily be done. The largest springs, however, are often in deep valleys, such as those of the streams entering the Mississippi near the southeastern corner of the State. Here it would be necessary to lift the water greater distances than is practicable with rams.

SCIENTIFIC PROSPECTING FOR WATER.

In southern Minnesota, as in other sections of the country, prospecting for water has been conducted in a desultory manner, and but little attention has been given to securing or preserving definite information in regard to the water horizons penetrated in deep drilling. Many of the deepest wells have been sunk by the municipalities, at considerable cost; with only slight additional expenditure data in regard to the underground waters could have been obtained which would be of great permanent value to the communities concerned. Random methods are just as extravagant in securing water supplies as in any other line of work, and precise information is of equally great value. It is desired here to make a plea for more intelligent action in the future.

Whenever a community goes to the expense of sinking a deep well it should at the same time secure a record of its underground water resources to the depth drilled, and the contract made with the driller should provide for it. Approximately the following procedure should be observed:

1. Samples should be kept of all material penetrated and full descriptive notes made of everything found by the drill and of all difficulties or unusual conditions met in drilling. The record should include the exact thickness of each stratum and its depth beneath the surface. The drillings should be submitted for examination to a competent geologist.

2. All water-bearing strata should be described in special detail. If the material consists of sand, gravel, or sandstone, it is important to note the porosity, induration, and size of grain, as well as variations with depth in any of these.

3. The height to which the water will naturally rise should be ascertained for each water-bearing stratum. The notes should state whether the water at higher levels was shut out by casing when the head was measured.

4. At each depth at which a new supply is encountered the yield should be tested. The record must show not only the rate at which the well was pumped, but also the distance that the water level was lowered thereby, and the length of time that the pumping was continued. The best method is to insert the suction pipe a definite depth into the water and then determine the rate of pumping required to lower the water level this distance. By raising and lowering the pump very precise results can be obtained. Where the formation consists of incoherent sand that persists in coming into the well it may not be feasible to make accurate determinations of the yield, but in this case the general conditions should be described. In all instances it is necessary to note whether the water comes from

only the lowest bed, the higher ones being shut out by casing, or whether water from different levels contributed to the yield.

5. The quality of the water from each horizon should be ascertained, as important results may thus be produced. Great effort should be put forth to obtain samples from each source unadulterated by the water from other levels. It may not be feasible to have a complete analysis made of the water from each depth, but the temporary and permanent hardness can at least be determined, and a few other simple tests made, which will throw much light upon the character of the water.

6. In the well as finally completed, the length and diameter of the casing and the description of the screen (if one is required) should be noted in detail. The method of finishing the well, the difficulties encountered, and indeed the entire history of the process should be described.

If the method above outlined is faithfully pursued, the community will have in its possession a reliable record of its water resources and underground conditions which will be of great intrinsic value. If a competent engineer or other person with expert knowledge is employed to superintend the prospecting and to make and record the various tests, the data will of course be so much the more reliable and complete. In the future when new supplies are required for public waterworks, for industrial concerns, or for any other purpose, trustworthy information will be at hand, and this will make intelligent action possible and may show the way to a better supply than would otherwise be secured. Indeed, it may prove a distinct asset to the community, as far as industrial development is concerned. When, later, other deep wells are drilled, similar records should be kept, and these can then be compared and contrasted with the original and with each other, thus giving a body of information that will be far more comprehensive and reliable than the record of any single well.

One of the greatest difficulties experienced, especially in the smaller settlements, is to retain such data as have been secured. With the frequent changes in the official personnel, well records which were at first preserved are almost invariably lost sooner or later, and even the depth of the hole may become a matter of uncertainty. It is therefore important that special care be taken to preserve the record. Several copies should be made and deposited in different places for safe-keeping. It would be well to have one copy registered in a county office in which permanent records are filed.

If the drilling project ends unsuccessfully it should not be assumed that the record is, therefore, of no value. Negative facts are frequently worth as much as positive ones. Moreover, a knowledge of the difficulties that are to be expected may aid in a future drilling enterprise to overcome these obstacles and to achieve success.

PUBLIC WATER SUPPLIES.

By O. E. Meinzer.

GENERAL STATEMENT AND TABLE.

In connection with the field work upon which this report is based the public supplies in the cities and villages of southern Minnesota were thoroughly examined, especial attention being given to the geologic and sanitary aspects of the source of the water. The investigations in 1907 were conducted in cooperation with the Minnesota state board of health, and mineral, sanitary-chemical, and bacteriological analyses of most of the supplies were made in their laboratories. Later, through correspondence with the superintendents of the various waterworks, the statistical data were verified and corrected for January 1, 1908. This revised body of information forms the basis upon which the following table of public water supplies was constructed. For the most part, the sanitary data do not appear in this paper, but are in possession of the state board of health, to be used as occasion demands. The present chapter is little more than a summarized statement of the information presented in the table.

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Public water supplies in southern Minnesota.

[For other half of table see page 107.]

City or village.	County.	Population.a	Water supply.									Plant.				
			Source.	Geologic source.	Diameter of wells.	Depth of wells.	Elevation of surface.	Head relative to surface.	Head of water above sea level.	Test of wells.b	Effect of test.c	Method of lifting water to the surface.d	Capacity of pumps (or other device) for lifting water.e	Power.f	Reservoirs.g	Capacity of reservoirs.
					In.	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Galls. per min.*			*Galls. per min.*			*M galls.*
Adams	Mower	575	Well	Devonian limestone.	8	291	1,298	−18	1,280	75	L. w. about 30′.	D.-w. p.	75	G	El. tank	55
Adrian	Nobles	1,184	do	Drift	120	47	1,550	−30	1,520	500	L. w	Suc. p.	1,000	S	do.h	i 50
Albert Lea	Freeborn	5,657	2 wells j	Galena, etc. St. Peter	12 8	448 660		0		1,000	N. e	Nat. flow	1,000	S	Sur. res. and el. tank.	i96
Alden	do	635	Well	Maquoketa and Galena.	6	215	1,278	−50	1,228	60	N. e.	D.-w. p.	60	G	El. tank	60
Alpha	Jackson	241	do	Drift	8	96	1,392			100	N. e.	D.-w. p.	150	G	Comp. ch.	15
Amboy	Blue Earth	490	do	Jordan	6	486	1,045	−40	1,005			D.-w. p.		G	El. tank	60
Anoka	Anoka	4,053	River										1,000	S	St. pipe	275
Appleton	Swift	1,321	River and well.	Outwash sand	240	40	990	−30	960	500	E. w. in 30 min.	Suc. p.	500	S	El. tank	65
Atwater	Kandiyohi	689	4 wells	do	3	35	1,211	−20	1,191	75	N. e.	Suc. p.	75	G	do	45
Austin	Mower	6,489	River and 6 wells.	St. Peter and New Richmond.	6–12	Up to 710	1,195	−10	1,185			Nat. flow		S	2 res	110
Avoca	Murray	251	Well	Drift	36	20	1,540	−4	1,536	Small.		Suc. p.		G	El. tank	10
Balaton	Lyon	350	do	Outwash gravel	96	27	1,532	−13	1,519	45	N. e.	Suc. p.	45	G	do	14
Beardsley	Bigstone	441	do	do	72	40	1,099	−32	1,067	65	L. w. 2′	Suc. p.	65	G	do	30
Belle Plaine	Scott	1,301	do		8	213	880	−100	780	50	L. w. 6″ in 7 hrs.	D.-w. p.	50	G	do	50
Bellingham	Lac qui Parle	406	do	Drift (?)	6	120	1,070	−30	1,040	35	N. e.	D.-w. p.	35	G. e.	do	45
Benson	Swift	1,766	2 wells	Drift	6 8	167	1,049	−13	1,036	k 160	L. w. 25′	2 suc. ps	560	S. and e. m.	do	75
Bird Island	Renville	907	Well	do	8	l 298	1,081	−30	1,051	100	N. e.	D.-w. p.	140	G	do	40
Blooming Prairie.	Steele	900	do	Galena		245									do	
Blue Earth	Faribault	2,364	2 wells	Jordan m	8 8	1,243 672	1,085 1,085	−32 −32	1,053 1,053	240 350	N. e.	Suc. ps. Air lift	240 350	S S	Sur. res. and el. tank.	96

Boyd	Lac qui Parle	420	Well	Drift	8	62	1,055	− 8	1,047	80	L. w. 4″	Air lift	70	G.	Sur. res. Comp. ch.	42.5 13.5
Bricelyn	Faribault	335	do.		6	107	1,177	− 19	1,158	80	N. e.	D.-w. p.	50	G. e.	do.	14
Brown Valley (main supply).	Traverse	902	Springs	Drift							Nat. flow	Nat. flow	125	G.	Sur. res. at spring. Sur. res. at station. El. tank	 15 70
Brown Valley (soft water supply). [n]	do.	902	2 wells	Cretaceous		500± 500±	981 1,014	(+)	1,014+	Small.		Nat. flow		Nat. flow	2 res	Small.
Brownton	McLeod	484	Well	Drift	6	304	1,021	− 24	997	95		Air-lift	95	G.	Sur. res. Comp. ch.	3 17
Buffalo Lake	Renville	474	2 wells	Drift and Archean.	6 10	[o] 370 400	1,067 1,067	− 10 − 10	1,057 1,057			D.-w. ps.		G. S.	El. tank	80
Caledonia	Houston	1,405	Well	Jordan	8	320		−250				D.-w. p.			St. pipe	
Canby	Yellow Medicine.	1,505	do.	Drift	8	[p] 100	1,240	− 18	1,222	125	Not great	Suc. p.	125	G.	El. tank	60
Cannon Falls	Goodhue	1,460	do.	Jordan	8	270	794	(+)	794	300	N. e.	Nat. flow	250	G.	do.	100
Ceylon	Martin	341	do.	Drift (?)	8	300		− 60		100	N. e.	D.-w. p.	100	G.	Comp. ch.	13.5
Chaska	Carver	2,085	do.	Dresbach, etc.	8	640	748	+ 30	778	500	Nat. flow	Nat. flow		Nat. flow	None	
Chatfield	Fillmore	925	do.	Jordan	8	200	1,435	−125(?)	1,310(?)		N. e.	D.-w. p.		S.	Res.	423
Clarkfield	Yellow Medicine.	614	do.	Drift	6	[q] 197	1,095	− 40	1,055	13	(r)	D.-w. p.	100	G.	El. tank	55
Clinton	Bigstone	400	do.	do.	8	344		−120		80	N. e.	D.-w. p.	80	G.	do.	48
Cokato	Wright	721	do.	do.	3	125	1,065	− 45	1,020			D.-w. p.		G.	El. tank 3 cist.	50 14
Comfrey	Brown	299	do.		8	140		− 20		60	N. e.	D.-w. p.	60	G.	El. tank	50
Cottonwood	Lyon	883	do. [s]	Archean	8 and 6	375	1,082	− 40	1,042	Small.		D.-w. p.	30	G.	do.	50

[a] Population according to the state census of 1905.
[b] The most severe test reported.
[c] Abbreviations: N. e., no noticeable effect. L. w., lowered water. E. w., emptied well. Nat. flow, natural flow. St. flow, stopped flow.
[d] Abbreviations: D.-w. p., deep-water pump. Suc. p., suction pump. Nat. flow, natural flow. Air l., air lift.
[e] The reference here is only to the lifting of the water to the surface. No data are given in regard to other pumps.
[f] Abbreviations: G., gasoline. S., steam. G. e., gas engine. E. m., electric motor. W. m., windmill. W. p., water power. H. r., hydraulic ram.
[g] Abbreviations: El. tank, elevated tank; that is, one set upon a tower. St. pipe, standpipe. Comp. ch., compression chamber. Sur. res., surface reservoir. Cist., cistern.
[h] Large surface reservoir for fire reserve.
[i] Elevated tank only.
[j] Fountain Lake for fire reserve.
[k] From the two wells combined.
[l] Water comes from depth of about 190 feet.
[m] Dresbach is not used.
[n] No system. Supply used by all for bath and laundry purposes.
[o] Main supply comes from a depth of 100 feet.
[p] Drilled to depth of 426 feet.
[q] Water comes from depths of 120 to 140 feet.
[r] Sand is lifted if well is pumped more rapidly.
[s] Well was to be abandoned and water from lake used after Apr. 1, 1908.

Public water supplies in southern Minnesota—Continued.

City or village.	County.	Population	Water supply.									Plant.				
			Source.	Geologic source.	Diameter of wells.	Depth of wells.	Elevation of surface.	Head relative to surface.	Head of water above sea level.	Test of wells.	Effect of test.	Method of lifting water to the surface.	Capacity of pumps (or other device) for lifting water.	Power.	Reservoirs.	Capacity of reservoirs.
					In.	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Galls. per min.*			*Galls. per min.*			*M galls.*
Currie	Murray	311	Well	Drift	6	120	1,511	− 20	1,491	60	N. e.	D.-w. p.	70	G.	Comp. ch.	13.5
Dassel	Meeker	592	do	do	8	180	1,089	− 55	1,034	45	N. e.	D.-w. p.	45	G.	El. tank	50
Dawson [a]	Lac qui Parle	1,056	2 wells	Cretaceous	6 or 8	148	1,065	− 15	1,040	160	N. e.	D.-w. ps.		E. m.	do	60
De Graff	Swift	222	Well	Drift	6	80		− 20				D.-w. p.		W. m.	3 res.	30
Delano	Wright	1,023	14 wells	Drift or alluvium	3	46	912	− 1	911	250	N. e.	Suc. p.	400	S.	El. tank	50
Delavan	Faribault	281	Well	Jordan	8	473		− 15							do	
Easton	do	328	do		6 and 4	110	1,050	− 6	1,044	110	N. e.	Suc. p.	110	G.	do	50
Echo	Yellow Medicine.	600	do	Drift	144	53	1,090	− 35	1,055	Small.		D.-w. p.		G.	do	55
Eden Valley	Meeker	709	8 wells 1 well	Outwash sand do	2½ 2½	44 28	1,123	− 15	1,108	75	N. e.	Suc. p.	40	G.	do 2 sur. res.	60 23
Edgerton	Pipestone	380	Well	do	192	24	1,574	− 13	1,561	265	L. w. [b]	Suc. p.	265	G.	El. tank	30
Elgin	Wabasha	358	do	Jordan	10	275										
Ellendale	Steele	252	do	Galena (?)	6	212	1,280	− 80	1,200	112	N. e.	D.-w. p.		G.	Sur. res. Comp. ch.	25 15
Ellsworth	Nobles	537	do	Drift	144	33		− 15				D.-w. p.	240	G. e.	do	15
Elmore	Faribault	742	do		6	110		− 8							El. tank	
Elysian	Lesueur	384	do	St. Peter	8	287	1,087	− 87	1,000	35±	N. e.	D.-w. p.	35±	G.	do	50
Emmons	Freeborn	235	do	Devonian limestone.	4	160	1,287	− 32	1,255	45	N. e.	D.-w. p.	45	G.	Sur. res.	14
Excelsior	Hennepin	850	Lake											G.	El. tank	18
Eyota [c]	Olmsted	400	Well		10	203		− 17							Comp. ch.	
Fairfax	Renville	775	do	Drift	6	185	1,040	− 80	960	20	N. e.	D.-w. p.	20	G.	El. tank 4 cist.	80
Fairmont	Martin	2,955	Lake											S.	2 sur. res.	
Faribault	Rice	8,279	2 wells [d]	Jordan, Dresbach, etc.	10 10	800 1,000		− 7				Suc. ps.		S.	Sur. res. [e]	1,000
Fort Snelling	Hennepin		Well	St. Peter, New Richmond, Dresbach, etc.	10	638		+ 20		1,000	Nat. flow	Nat. flow and suc. ps.	700	S.	2 el. tanks.	390

Fountain	Fillmore	364	Well	Jordan	10 and 6	608	1,320	−340	980	85	N. e.	D.-w. p.	65	G.	Comp. ch.	15
Franklin	Renville	524	do.	Drift	72	108	1,020	− 50	970	50	L. w. 14″	D.-w. p.	50	G.	El. tank	35
Fulda	Murray	701	do.	Sioux quartzite	8 and 6	225	1,507	− 40	1,467	30	N. e.	D.-w. p.		S. and w. m.	Sur. res. and el. tank.	72
Gibbon	Sibley	528	do.		2½	210	1,044	− 80	964			D.-w. p.		G.	El. tank; 3 cist	
Glencoe	McLeod	1,805	do.	Dresbach, etc.	8-6	1,640	995	− 90	905	175	N. e.	D.-w. p.	175	E. m.	Sur. Res.; El. tank	165; 245
Goodhue	Goodhue	410	do.	New Richmond or Jordan.	10	275	1,120			300	N. e.	D.-p. w.	300	G.	El. tank(?)	80
Good Thunder.	Blue Earth	448	do.		6	374	1,000	− 65	935	50	N. e.	D.-w. p.	50	G.	El. tank	60
Graceville	Bigstone	1,032	2 wells	Cretaceous	8	520	1,110	−100	1,010	f 60	N. e.	D.-w. p.		S.	do.	60
Grand Meadow.	Mower	459	Well	Devonian sandstone (?).	8	125		− 35		75	N. e.	D.-w. p.	75	G.	do.	52
Granite Falls.	Yellow Medicine.	1,340	River											W. p.	Sur. res; do.[e]	6; 125
Grove City	Meeker.	339	Well	Drift	8	g 700	1,207	− 57	1,150	75	N. e.	D.-w. p.	35	G.	El. tank	60
Hanley Falls.	Yellow Medicine.	309	do.	Cretaceous	5	247	1,050	− 40	1,010	40	N. e.	D.-w. p.	40	G.	do.	50
Hardwick	Rock	269	do.	Sioux quartzite	6	420	1,628	− 36	1,592	25	N. e.	D.-w. p.	25	G.	do.	17
Harmony	Fillmore	689	do.	St. Peter	8	220		−130		45	N. e.	D.-w. p.	45	G.	Sur. res. and comp. ch.	
Hartland	Freeborn	299	do.	Galena, etc.	6	311		− 50				D.-w. p.			El. tank	
Hastings	Dakota	3,810	do.													
Hayfield	Dodge	516	do.	Galena, etc	8	377									El. tank	
Hector	Renville	774	2 wells	Drift	144 and 8	380	1,073	− 12	1,061			D.-w. p.	45	G.	do.	70
					8	400	1,073	− 12	1,061	60	N. e.	D.-w. p.	45	G.		
Henderson	Sibley	820	Well	Dresbach, etc.	8	764	750	+ 60	810	300	Nat. flow	Nat. flow		S.	do.; 12 cist.	60
Hendricks	Lincoln	380	do.	Drift	192	16		− 10				Suc. p.		G.	El. tank	56.7
Hokah	Houston	522	do.	Dresbach, etc.	6	544	674	+ 18	692	86	Nat. flow(?)	Nat. flow		G. and h. r.	Sur. res.[e]	150
Houston	do.	639	do.	do.	6	302	684	+ 12	696	130	St. flow	Nat. flow and suc. p.	130	G.	Comp. ch.	11
Howard Lake	Wright	763	Lake											S.	El. tank	53
Hutchinson	McLeod	2,489	Well	Drift	10	180	1,030	+ 28	1,058	800	St. flow	Nat. flow and suc. ps.	800	S.	do.	100
Iona	Murray	288	do.	do.	6	204	1,630	− 35	1,595	32	N. e.	D.-w. p.	32	G.	do.	38
Ivanhoe	Lincoln	451	do.	do.	10	315		−100							do.	
Jackson	Jackson	1,776	do.	Alluvium	312	20	1,335	− 10	1,325	300	(h)	Suc. p.	300	S.	do.	68

a Installed in 1908.
b Nearly to bottom.
c Recently installed.
d Also two shallow wells for emergencies.
e On high ground.
f One well alone tested at this rate.
g Water comes from depth of 220 to 260 feet.
h Depends on the season.

Public water supplies in southern Minnesota—Continued.

City or village.	County.	Population.	Water supply.									Plant.				
			Source.	Geologic source.	Diameter of wells.	Depth of wells.	Elevation of surface.	Head relative to surface.	Head of water above sea level.	Test of wells.	Effect of test.	Method of lifting water to the surface.	Capacity of pumps (or other device) for lifting water.	Power.	Reservoirs.	Capacity of reservoirs.
					In.	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Galls. per min.*			*Galls. per min.*			*M galls.*
Jasper	Pipestone	619	Spring	Sioux quartzite			1,560			50+	Nat. flow	Nat. flow		G	Sur. res. El. tank	12 60
Kasson	Dodge	1,049	Well	St. Peter	8	275	1,256	− 25	1,231			Suc. p.	300	S	do	50
Kenyon	Goodhue	1,252	do	Galena, etc	240	18		− 15							do	
Kilkenny	Lesueur	239	do	St. Peter		250		− 0								
Kiester	Faribault	211	do		8	400						D.-w. p.		G	El. tank	50
Lake Benton	Lincoln	848	do	Drift	144	16	1,755	− 2		400	N. e.	Suc. p.	500	S	Sur. res.[a]	81
Lake City	Wabasha	2,877	Wells[b]	Alluvium		40		− 15		Large		Suc. ps.	2,000	S		
Lake Crystal	Blue Earth	1,231	Well or lake.	Dresbach, etc		719		− 70						S	Sur. res.	90
Lakefield	Jackson	916	Well	Drift	10	190	1,490	−100	1,390	175	N. e.	D.-w. p.	175	S	do	46
Lamberton	Redwood	657	do	do	8	64	1,450	− 30	1,420	60	N. e.	D.-w. p.	35	G	El. tank	70
Lanesboro	Fillmore	1,041	Spring	Oneota											Res.	
Leroy	Mower	788	Well		8	422	1,289	− 28	1,261	85	N. e.	D.-w. p.	85	G	El. tank	60
Lester Prairie	McLeod	454	do	Alluvium	240	22	982	− 8	974	200	E.w. in 1 hr.	Suc. p.	400	S	do	60
Lesueur	Lesueur	1,842	do	Dresbach, etc	8	668	770	+ 18	788	415	L. w. 33′	Nat. flow. Suc. p.	415	S	St. pipe	142
Lesueur Center.	do	698	do		8	340		−180				D.-w. p.		S	El. tank	30
Lewiston	Winona	388	2 wells	Jordan	6	350 290	1,230	−260	970	40	N. e.	D.-w. p.		G	do	60
Litchfield	Meeker	2,415	28 wells	Outwash sand	2	42	1,134	− 20	1,114	600	N. e.	Suc. ps.	600	S	do	70
Lonsdale	Rice	172	Well	St. Peter		332									do	
Luverne	Rock	2,272	2 wells	Alluvium	156 240	19	1,432	− 10	1,422	750	L. w., 3′	Suc. ps.	1,000	S	St. pipe	140
Lyle	Mower	451	Well	Devonian sandstone (?).	8	240	1,203	− 12	1,191	35	N. e.	D.-w. p.	35	G	El. tank	55
Mabel	Fillmore	546	do	New Richmond (?).	6	140		− 40		50	N. e.	D.-w. p.	50	S	do	84
Madelia	Watonwan	1,290	2 wells	Drift (?)	6 8	216 249(?)	1,027	− 30	997	75 75	L.w.greatly	D.-w. ps.		S	do	60

Mankato	Blue Earth	10,996	4 wells	Dresbach, etc.	8-10	650	790	+ 30	820			D.-w. p. Nat. flow		S	Res	870
Mapleton	do.	938	Well	St. Peter	4	224		− 30		50	N. e.	Suc. p.	50	G	El. tank	60
Marshall	Lyon	2,243	3 wells	Cretaceous	(c) 8 8	90 410 250	1,174 1,174 1,174	− 8 + 25 −120	1,166 1,200 1,054	35 20 Small.	 Nat. flow	Suc p. Nat. flow D.-w. p.	100	S S	Sur. res.	150
Maynard	Chippewa	445	Well	Drift		80		− 4				Nat. flow.		G	Comp. ch.	
Mazeppa	Wabasha	556	do.	Oneota (?)	12	90		− 25							El. tank	60
Milan	Chippewa	488	do.	Drift	108	25	990	− 14	976	25	N. e.	Suc. p.	25	G	do.	36
Minneapolis	Hennepin	261,974	River											S	2 sur. res.[a]	96,000
Minneiska	Wabasha	338	do.													
Minneota	Lyon	954	Well	Cretaceous	6	111	1,184	− 20	1,164	30	N. e.	D.-w. p.	30	G	El. tank	60
Minnesota Lake.	Faribault	482	do.	Drift	8	185	1,049	− 15	1,034			D.-w.p.		G	do.	50
Montevideo	Chippewa	2,595	Spring	do.						350	Nat. flow	Nat. flow		G., e. m.	Sur. res. and el. tank.	200
Montgomery	Lesueur	1,281	Well		10	213		−150				D.-w. p.	100	G	El. tank	
Monticello	Wright	973	do.	Alluvium (?)	8	237	923	− 5	918	275	L. w. 2′	Suc. p.	300	G	Comp. ch.	14
Morton	Renville	755	Spring	Drift			905					Nat. flow		G	Sur. res.[a]	105
Mountain Lake.	Cottonwood	1,063	Well	do.	144	40	1,305	− 20	1,285	50	(d)	Suc. p.	50	G	El. tank	45
New London	Kandiyohi	392	Mill pond											G., w. p.	None	
New Prague	Scott and Lesueur.	1,419	Well	Jordan (?)	8	289		−116		25-50		Air lift	25-50	S	El. tank	66
New Richland.	Waseca	697	do.	Galena, etc.		150		− 34							do.	
New Ulm	Brown	5,720	2 wells 1 well	Cretaceous do.	6 8	195	842	− 75	767	350	N. e.	D.-w. ps.	350	S	Sur. res. St. pipe.	100 31
Nicollet	Nicollet	341	2 wells		3 2	175	1,000	−145	855			D.-w. p.		G. and w. m.	El. tank	55
Northfield	Rice	3,438	Well	Jordan	8	[e] 647	905	+ 20	925	1,000	Nat. flow	Nat. flow		S	Sur. res.[a]	240
North St. Paul.	Ramsey	1,400	Well and lake.		8	400		− 82		100	N. e.	D.-w. p.	40	S	El. tank	56
Olivia	Renville	1,019	Well	Drift	6	320	1,079	− 14	1,065	60	N. e.	D.-w. p.	45	G	do.	74
Ortonville	Bigstone	1,612	do.	do.	240 and 6	60	998	− 12	986			Suc. p.	300	S	do.	100
Owatonna	Steele	5,651	5 wells 1 well	St. Peter Jordan (?)		95 640		− 13							St. pipe	
Pine Island	Goodhue	760	Well	New Richmond(?)	8	156		− 10		100	N. e.	Suc. p.	100	S	Sur. res.[a]	55
Pipestone	Pipestone	2,885	2 wells	Sioux quartzite	6 8	200 350	1,726	− 96	1,630	140	N. e.	Air lift	140	S	Sur. res. St. pipe	165 90
Plainview	Wabasha	1,140	do.	Jordan Dresbach		325 692		− 6							El. tank	
Preston	Fillmore	1,320	Spring	New Richmond						250		Nat. flow		S	Sur. res.[a]	
Red Wing	Goodhue	8,149	River													

[a] On high ground.
[b] Twenty 4-inch driven wells, discharging into a dug well 16 feet in diameter. Water from the lake can be used in case of fire.
[c] Dug and drilled.
[d] Varies with season.
[e] Water from a depth of 300 feet.

Public water supplies in southern Minnesota—Continued.

City or village.	County.	Population.	Water supply.									Plant.				
			Source.	Geologic source.	Diameter of wells.	Depth of wells.	Elevation of surface.	Head relative to surface.	Head of water above sea level.	Test of wells.	Effect of test.	Method of lifting water to the surface.	Capacity of pumps (or other device) for lifting water.	Power.	Reservoirs.	Capacity of reservoirs.
					In.	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Galls. per min.*			*Galls. per min.*			*M galls.*
Redwood Falls.	Redwood	1,806	Springs	Drift								Nat. flow		E.m and S.	Sur. res.	30
															El. tank	100
Renville	Renville	1,229	Well	do	6	236	1,053	− 50	1,003	50	N. e.	D.-w. p.	50	G	do	60
Rochester	Olmsted	7,233	Several wells.[a]	Alluvium	204–240	32	968	− 12	956			Suc. p.	1,000	S	St. pipe	240
Rolling Stone	Winona	192	Well		6	340		− 60		50	N. e.	D.-w. p.	50	E. m.	Sur. res.[b]	120
Rose Creek	Mower	194	do	Devonian sandstone(?).	8	175	1,295	−130	1,165	100	N. e.	D.-w. p.		G		
Rushford	Fillmore	1,133	do	St. Lawrence	6	180		−140							Res	
				Dresbach, etc	8	553		+ 3								
Ruthton	Pipestone	323	do	Drift	6	260	1,740	− 60	1,680	35	N. e.	D.-w. p.	35	G	El. tank	25
Sacred Heart	Renville	639	do	do	168	40	1,060	− 18	1,042	50	L. w. 4′ in 4 hrs.	Suc. p.	50	G	do	20
St. Charles	Winona	1,238	do	Jordan and Dresbach.	10	942		−150							Sur. res.[b]	
St. James	Watonwan	2,320	2 wells	Various sandstones.	8	541	1,085	− 32	1,053	200	N. e.	D.-w. ps.	600	S	St. pipe	145
					10	480				400	N. e.					
St. Paul	Ramsey	197,023	Lakes and many wells.[b]	St. Peter, Jordan, Dresbach, etc.		100–685						Suc. ps.		S	Res	20,000
St. Peter	Nicollet	4,514	Well	Dresbach, etc	8	362		+ 0				Nat. flow			Sur. res., St. pipe.	
Sherburn	Martin	871	do	Drift	8	248	1,307	− 96	1,211	160	N. e.	D.-w. p.	80	G	Sur. res.	30
															El. tank	68
Silver Lake	McLeod	390	Lake											S	Res	30
Slayton	Murray	839	Well	Drift	8	205	1,611	− 50	1,561	45	N. e.	D.-w. p.	45	G	Sur. res. and el. tank.	168
Sleepy Eye	Brown	2,312	2 wells	do	4½	180	1,034	− 60	974	40		D.-w. p.	110	S	El. tank	66
					4	222	1,034	− 45	989	100		Air lift		S		

South St. Paul.	Dakota	3,458	Well	Dresbach, etc	8	880		+ 7				Nat. flow. Suc. p.		S	St. pipe	150
South Stillwater.	Washington	1,572	Well and creek.		216	20	686	+ 0	686			Nat. flow		S		
Springfield	Brown	1,546	2 wells and springs.	Alluvium	4	36	1,030					Suc. p.	250	S	Sur. res. and el. tank.	45
Spring Grove	Houston	627	Well	St. Peter, New Richmond.	5	396		−300							El. tank	
Spring Valley	Fillmore	1,573	Spring and well.	Galena, etc	480	18										
Stewart	McLeod	460	Well	Drift	8	320	1,060	− 13	1,047	60	N. e.	D.-w. p.	60	G	El. tank	70
Stewartville	Olmsted	851	do [c]	Drift (?)	6	63		− 33							do	
Stillwater	Washington	12,435	Lake Well Spring	 Dresbach, etc Jordan (?)	8	3,447		− 30							3 st. pipes.	300
Tracy	Lyon	2,015	Well	Cretaceous	10, 8 and 6	600	1,408	−180	1,228	50	N. e.	D.-w. p.	50	G. and s.	Sur. res. El. tank	87 98
Truman	Martin	450	do	Drift	8	104	1,100	− 6	1,094					G	Comp. ch.	13.5
Tyler	Lincoln	699	do	do	8 and 6	230	1,750	− 70	1,680	35	N. e.	D.-w. p.	35	G	El. tank	73
Vernon Center.	Blue Earth	313	do		8	147	1,035	− 90	945	80	N. e.	D.-w. p.	80	G	do	40
Walnut Grove.	Redwood	392	do	Cretaceous	6	312	1,228	− 12	1,216	37	N. e.	D.-w. p.	37	G	do	64
Waseca	Waseca	2,838	2 wells	St. Peter Jordan	10 10	600 1,157	1,153	−125	1,028	100	N. e.	Air lift	50	S	Res. and el. tank.	600
Waterville	Lesueur	1,383	Well	Drift	8	185	1,007	− 10	997			Suc. p.		S	El. tank	
Waverly	Wright	582	Lake											G	Comp. ch.	10
Welcome	Martin	500	Well	Drift	60	150	1,251	−100	1,151	60	E. w. in 1 hr.	D.-w. p.		G	do	13.5
Wells	Faribault	1,814	2 wells	Galena, etc. St. Peter (?)	8 12	216 265		− 10		100		Suc. p.	500	S	Sur. res. El. tank	90 75
Westbrook	Cottonwood	460	Well	Drift	36	64	1,425	− 25	1,400	25	E. w. in 1 hr.	D.-w. p.		G	do	41
West Concord	Dodge	616	do		8	150	1,230	− 3	1,227	Large.		Suc. p.		G	None	
West Minneapolis	Hennepin	2,530	do	St. Peter New Richmond Dresbach	8	600									El. tank	
White Bear Lake.	Ramsey	1,724	do	St. Peter	10	112		− 34		85	N. e.	D.-w. p.	85	G	do	75
Willmar	Kandiyohi	4,040	do	Drift	8	273	1,133	− 4	1,129	500	N. e.	Suc. ps.	500+	S	do	72
Wilmont	Nobles	279	do	do	8	345	1,745	−120	1,625	100	N. e.	D.-w. p.	100	G	do	42
Windom	Cottonwood	1,884	2 wells	Drift and Cretaceous	168 and 3 8	65 280	1,358 1,358	− 10 −100	1,348 1,258	 120	 N. e.	Suc. p. D.-w. p.	300 120	S S	do	129
Winnebago	Faribault	1,553	Well		8	266		− 6								
Winona	Winona	20,334	2 wells [d]	Alluvium Dresbach, etc	720 8	28 and 38 500									St.-pipe	
Winsted	McLeod	314	Lake													

[a] River for reserve in case of fire. [b] See p. 304. [c] A new well is being installed. [d] Also river.

Public water supplies in southern Minnesota—Continued.

City or village.	County.	Population.	Water supply.										Plant.				
			Source.	Geologic source.	Diameter of wells.	Depth of wells.	Elevation of surface.	Head relative to surface.	Head of water above sea level.	Test of wells.	Effect of test.	Method of lifting water to the surface.	Capacity of pumps (or other device) for lifting water.	Power.	Reservoirs.	Capacity of reservoirs.
					In.	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Galls. per min.*			*Galls. per min.*			*M galls.*
Winthrop	Sibley	1,031	Well	Drift	10	239				75	N. e.	D.-w. p.		S.	El. tank	55
Wood Lake	Yellow Medicine.	347	do	do	6	186	1,069	− 45	1,024	25	N. e.	D.-w. p.	25	G.	do	50
Worthington	Nobles	2,276	2 wells[a]	do	12	77	1,585	− 7	1,578			Suc. ps.	1,000	S.	None	
Wykoff	Fillmore	488	Well	Jordan	8	600		−300		180	N. e.	D.-w. p.	40	S.	{El. tank {5 cist.	50 150
Zumbrota	Goodhue	1,129	do	St. Peter, New Richmond (?)	10	210		− 30				D.-w. p.	50	G.	Sur. res.[b]	150

[a] Also two shallow wells and the lake for reserve in case of fire.

[b] On high ground.

Public water supplies in southern Minnesota—Continued.

City or village.	Plant—Continued.				System.			Consumption.					
	Domestic pressure[a] per square inch.	Method of applying domestic pressure.[b]	Fire pressure[c] per square inch.	Method of applying fire pressure.[b]	Length of mains.	Number of fire hydrants.	Number of taps.[d]	Average daily consumption.[e]	Maximum daily capacity of source.[f]	Number of people supplied.[g]	Percentage of total population.[h]	Is water used for drinking in public schools?	Price charged.[i]
	Pounds.		*Pounds.*		*Miles.*			*Gallons.*	*Gallons.*				
Adams	40	Gravity	40	Gravity	1	11	60	9,000	100,000 (?)	400	65	Yes	Flat, $3.
Adrian	40–45	...do	80–100	Direct	Several.	20	64	40,000	.....	700	50	No	Flat, meter, 50 to 40 c.
Albert Lea	50	...do	100	...do	6	75	650	200,000	1,500,000 (?)	3,250	50	Yes	Flat, $5; meter, 20 to 8 c.
Alden	44	...do	44	Gravity	1	15	25	19,000	80,000	150	25	Yes	Flat, $5.
Alpha	55–70	Comp. air.	70	Comp. air.	$\frac{1}{2}$	5	0	Small.	150,000	0	0	No	
Amboy	43	Gravity	43	Gravity	$\frac{3}{4}$	10	20	10,000	Large.	200	30	Yes	Flat, $5.
Anoka	45	...do	100–120	Direct	$7\frac{1}{2}$	65	Many.	300,000	.....	Many.	.....	.....	Meter, 45 c. and less (min. $9 a yr.).
Appleton	45	...do	90	...do	4	16	87	20,000	.....	400	30	No	Meter, 15 c.
Atwater	43	...do	43	Gravity[j]	1	8	16	15,000	100,000	40	5	No	Meter, 25 c.
Austin	60	Direct	115	Direct	12	96	650	500,000	[k] 1,000,000	2,700	40	Yes	Meter, 20 to 15 c.
Avoca	40	Gravity	40	Gravity	$\frac{1}{5}$	3	0	Small.	2,250	0	0	No	
Balaton	40	...do	40	...do	$\frac{4}{5}$	10	30	10,000	.....	200	50	.....	Meter, 25 c. (min. $3 per yr.).
Beardsley	43	...do	43	...do	$\frac{1}{2}$	8	20	6,000	90,000	350	$66\frac{2}{3}$	Yes	Flat, $6.
Belle Plaine	50	...do	60	Gravity and direct.	$\frac{4}{5}$	10	[l] 10	([l])	100,000	([l])	([l k])	Yes	Meter, 40 c.
Bellingham	45	...do	45	Gravity	$\frac{1}{5}$	3	3	Small.	50,000	.....	.....	No	
Benson	50	...do	50+	Gravity or direct.[j]	Several.	21	130	25,000	225,000	800	40	.....	Flat; meter, 27 to 19 c.
Bird Island	45	...do	45	Gravity	$\frac{1}{2}$	9	16	16,000	150,000	100	10	Yes	Meter, 10 to 8 c.
Blooming Prairie.	65	...do	65	...do	1	15	100	20,000	.....	.....	.....	.....	

[a] The pressure given is generally the average for the business section.
[b] The term "direct" indicates that the pressure is applied by the pumps discharging directly into the mains.
[c] The pressure here recorded is commonly the maximum that is applied.
[d] This column gives the number of dwellings, places of business, factories, etc., supplied.
[e] Nearly all the figures given are estimated.
[f] This column shows the extent to which the source has been tested. For many towns the actual maximum capacity is greater.
[g] Estimated.
[h] The percentage is based on the approximate population Jan. 1, 1908, and not on that given in the column headed "Population."
[i] Flat: Minimum for one year. Meter: Maximum and minimum for 1,000 gallons.
[j] Portable fire engine.
[k] From the wells.
[l] Installed in 1908. More taps, etc., will be added.

Public water supplies in southern Minnesota—Continued.

City or village.	Plant—Continued.				System.			Consumption.					
	Domestic pressure per square inch.	Method of applying domestic pressure.	Fire pressure per square inch.	Method of applying fire pressure.	Length of mains.	Number of fire hydrants.	Number of taps.	Average daily consumption.	Maximum daily capacity of source.	Number of people supplied.	Percentage of total population.	Is water used for drinking in public schools?	Price charged.
	Pounds.		*Pounds.*		*Miles.*			*Gallons.*	*Gallons.*				
Blue Earth	33	do	85	Direct	5½	60	225	60,000	500,000	1,200	50	Yes	Flat, $4.
Boyd	65	Comp. air	80	Comp. air	2/5	11	1	50		5	1	No	Flat, $12.
Bricelyn	65	do	65	do	1½	12	60	5,000	125,000	300	75	Yes	Flat, $5.
Brown Valley (main supply).	43	Gravity	43	Gravity	1	11	21	18,000	25,000	450	50	Yes	Flat, $4; meter, 25 to 20 c.
Brown Valley (soft-water supply).[a]	Small.	do											
Brownton	65	Comp. air	65	Comp. air	3/4	10	90	4,000	125,000	450	92		Flat, $5; meter, 30 c.
Buffalo Lake	45	Gravity	45	Gravity	2/5	7	12	3,000	Not great.	25	5	Yes	Flat.
Caledonia	47	do	120	Direct	2	20	100	25,000					
Canby	45	do	45	Gravity	1 3/5	18		10,000	[b] 195,000			Yes	Meter, 14 c.
Cannon Falls	65	do	85	Gravity and direct.	1 3/5	15	39	4,000	500,000	200	12½	Yes	Meter, 40 to 10 c.
Ceylon	40–50	Comp. air	70–75	Comp. air	1/6	3	4	1,500	150,000	15	3	No	Free.
Chaska	15	Direct from well.		(c)	1/4	4	5	Small.	750,000	Small.	Small.	No	
Chatfield	60	Gravity	60	Gravity			200	30,000		600(?)	60(?)	Yes	Flat, $5.
Clarkfield	45	do	45	do	1/5	4	0	Small.	20,000	None.	0		
Clinton	37	do	37	do	1½	9	15	14,000	120,000	400	80	Yes	Flat, $5.
Cokato	50	do	50	do	Short.	1	0	Small.		Few.		No	
Comfrey	45	do	45	do	1/4	4	0	Small.	86,000	None.	0	No	
Cottonwood	40	do	40	Gravity and direct.[d]	2/7	6	0	Small.	1,200	None.		No	
Currie	60–80	Comp. air	60–80	Comp. air	1/4	4	5	1,200	75,000	80	20	No	Flat, $4.
Dassel	40	Gravity	40	Gravity	3/4	12	30	7,000	65,000	100	15		Flat and meters.
Dawson[e]	50	do	50–150	Gravity and direct.	1½	9	42		200,000(?)	210	20	No	Flat, $12; meters.
De Graff	None.	None		Direct[d]	0	0	0	Small.				No	

Delano	45	Gravity	45	Gravity and direct.	5/6	13	52	30,000	350,000	250	25	No	Meter, 20 to 10 c.
Delavan		do				9	8	5,000					
Easton	36	do	36	Gravity	3/4	9	19	7,000	165,000	150	45	Yes	Free.
Echo	40	do	40	do	1/6	5	2	Small.		None.	0	No	
Eden Valley		do		Gravity and direct.[d]	1/3	4	10	4,500	60,000			No	
Edgerton	44	do	44	Gravity	3/4	8	32	7,000	250,000	100	25	No	Flat, $6.
Elgin	40		40										
Ellendale	55–65	Comp. air.	65	Comp. air and direct.	1/2	9	23			150	60	No	Flat, $5.
Ellsworth	70–95	do	70–95	Comp. air.	1 1/4	7	12	200		12	2		Flat, $8.
Elmore		Gravity				19	1						
Elysian	75	do	75	Gravity	3/4	8	15	5,000	55,000	100	20	Yes	Flat, $5.
Emmons	None.		80	Direct	0	1	0	Small.	60,000	None.	0	No	
Excelsior	25	Gravity	(f)	(f)	3/4	0	30	3,500		100	10	No	Flat, $18.
Eyota[g]	65	Comp. air.	100	Comp. air.	1	10	0						
Fairfax	40	Gravity	40	Gravity and direct.[d]	1/2	8	12	2,500	30,000	Few.	Small.	No	Meter, 50 c.
Fairmont	50	Direct	150	Direct	2 1/2	39	175	120,000		1,500	50	In part.	Flat, $4; meter, 35 c.
Faribault	100	Gravity	100	Gravity	15	105	500	450,000	1,500,000	3,000	33 1/3	Yes	Meter, 40 and 10 c.
Fort Snelling	55	Gravity and direct	100	Direct[h]	4	47	200	240,000	1,500,000		100		Free.
Fountain	60	Comp. air.	100	Comp. air.	1 1/2	10	25	15,000	95,000	425	99	Yes	Flat, $6; meter, 40 c.
Franklin	45	Gravity	45	Gravity	3/4	9	42	10,000	70,000	500	90	Yes	Flat, $4; meter, 40 c.
Fulda	50	do	50–100	Gravity[e]	1 1/4	14	45		45,000	225(?)		Yes	Flat, $5.
Gibbon		do		Gravity and direct.[d]	1/6	3	2	Small.		None.	0	No	
Glencoe	65	do	125	Direct	4 1/4	37	200	125,000	300,000	1,000	50	Yes	Flat, $4; meter, 20 to 10 c.
Goodhue		do		Gravity	2	15	100	10,000	432,000	400	95	Yes	Flat, $4; meter, 47 c.
Good Thunder.	60	do	60	do	1/2	8	27	9,400	75,000	126	25	No	Flat, $3.
Graceville	47	do	47	do	2	21	212	10,000	100,000	1,032	100	Yes	Meter, 80 to 40 c.
Grand Meadow.	44	do	44	do	3/4	10	14	2,350	110,000	60	10	Yes	Flat, $5.
Granite Falls	70–80	do	70–80	do	2	16		40,000	Large.		Large.		Meter, 27 to 11 c.
Grove City	40–50	do	40–50	do	4/5	11	33	6,000	100,000	80	20	Yes	Flat, $2.
Hanley Falls.	45	do	45	do	3/5	6	20	12,000	60,000	400	100	Yes	Free.
Hardwick	23	do	23	do	0	0	0	Small.	35,000	None.	0	No	

[a] No system. Supply used by all for bath and laundry purposes.
[b] Less in dry years.
[c] Portable fire engine.
[d] Fire engine.
[e] Water can be used direct from lake in case of fire.
[f] Fire engine pumps direct from lake.
[g] Recently installed.
[h] Fire engine is also used.

Public water supplies in southern Minnesota—Continued.

City or village.	Plant—Continued.				System.			Consumption.					
	Domestic pressure per square inch.	Method of applying domestic pressure.	Fire pressure per square inch.	Method of applying fire pressure.	Length of mains.	Number of fire hydrants.	Number of taps.	Average daily consumption.	Maximum daily capacity of source.	Number of people supplied.	Percentage of total population.	Is water used for drinking in public schools?	Price charged.
	Pounds.		*Pounds.*		*Miles.*			*Gallons.*	*Gallons.*				
Harmony	65	Comp. air	65–100	Comp. air and direct.	1¼	14	100	10,000	65,000		Large.	Yes	Flat, $5; meter, $1.
Hartland	59	Gravity	59	Gravity	½	6	8	1,800					
Hastings													
Hayfield					1¼	12		2,000					
Hector	45	Gravity	45	Gravity	¾	10	16	12,000		80	10	Yes	Meter, 50 c.
Henderson	80–85	do	85–135	Gravity and direct.	1½	13	1	Small.	450,000	None.	0	Yes	
Hendricks	55	do	55	Gravity		10	25	3,000		75	20	No	Flat, $3.
Hokah	65	do	65	do	1	9	45	5,000	125,000	250	50	Yes	Flat, $4.
Houston	70	Comp. air	70	Comp. air	½	7	None.	Small.	185,000	None.	0	No	
Howard Lake	64	Gravity	64+	Gravity and direct.	1¼	13		25,000		480	60		Flat, $5.
Hutchinson	60	do	125	Direct	3¼	36		33,000	1,000,000(?)			Yes	Flat, $5; meter, 25 c. (min., $5).
Iona	40	do	40	Gravity	¼	4	17	7,680	46,000	150	50	No	Flat, $6.
Ivanhoe	45	do	45	do		8	16						
Jackson	65	do	65	do	1½	18	100	50,000		600	33⅓	Yes	Flat, $6.
Jasper	30–60	do	80	Gravity and direct.	1¼	16	40	10,000	75,000	200	33⅓		Flat, $5.
Kasson	55	do	100	Direct	2½	38	96	30,000	Large.	500	50	Yes	Flat, $4.50.
Kenyon	100	do	100	Gravity	1	20	60	10,000					
Kilkenny													
Kiester	35–40	Gravity	35–40	Gravity	½	6	23			85	35	No	Flat, $6.
Lake Benton	80	do	110	Direct	1⅓	11	50	7,500		250	30	Yes	Meter, 25 c.; (min., $5.40.)
Lake City	60	Direct	100	do	5¼	36	315	100,000		2,800	90	Yes	Meter, 33⅓ to 13⅓ c.
Lake Crystal	0		100	Direct *a*	½	9	0	Fire only.		None.	0	No	
Lakefield	40	Direct	140	Direct	1½	12	45	25,000	250,000	200	20	Yes	Flat, $6.
Lamberton	48	Gravity	48	Gravity	1	13	27	10,00	40,000	125	20	Yes	Do.
Lanesboro	60	do	100	Direct	1½	15	40	27,000					
Leroy	40	do	40	Gravity	2	16	75	8,000	120,000	300	33⅓	No	Flat, $5.
Lester Prairie	45	do	45	do	⅖	8	22	6,000		100	15		Flat, $4.

Lesueur	70	do	70	Gravity and direct.	3¼	42	200	40,000	500,000	1,000	50	Yes	Flat, $5; meter, 20 c.
Lesueur Center.	42	do	100	Direct	¾	7	13	10,000		18	3	No	Meter, 20 c.
Lewiston	42	do	42	Gravity	1¾	14	60	2,000	60,000	350	75	Yes	Flat, $3.
Litchfield	43	do	165	Direct	6	28	100	60,000	800,000	500	20	Yes	Meter, 20 c.
Lonsdale		do		Gravity	⅓	5	20						
Luverne	45	do	80	Direct	6	44	480	100,000	Great.	2,000	70	Yes	Meter, 56 to 8 c.
Lyle	40	do	40	Gravity	½	12	19	8,000	50,000	150	20	No	Flat, $5.
Mabel	55	do	55	do	1½	14	50	1,900	95,000	175	25	Yes	Flat, $3.75.
Madelia	40	do	40	do	2	36	125	12,000	100,000	700	45	Yes	Meter, 40 to 25 c.
Mankato	100	do	100	Gravity and direct.	17	162	1,125	783,000	1,500,000	8,000	66⅔	Yes	Meter, 12 to 10 c. (min., $6).
Mapleton	55	do	55	Gravity	1½	14	78	10,000	70,000			Yes	Meter, 25 to 15 c.
Marshall	45	Direct	100–120	Direct	3½	30	112	40,000	80,000	600	25		Meter, 27 to 20 c.
Maynard		Comp. air		Comp. air.	½	10	0	Small.		None.	0	No	
Mazeppa	40	Gravity	40	Gravity	½	6	29	1,000					
Milan	52	do	52	do	½	6	10		36,000			No	
Minneapolis	90	do	(b)	(b)	349	4,015		c17,591,854	(c)			No	Flat, $2; meter, 8 c.
Minneiska								Fire only.					
Minneota	40	Gravity	40	Gravity	1⅗	20	40	7,000	45,000	280	25		Flat, $5; meter, 25 c.
Minnesota Lake.	35	do	35	do	1½	16	20	1,000		100	20	No	Flat, $5.
Montevideo	80	do	80	do	2½	35	143	100,000	500,000	900	33⅓	Yes	Meter, 40 to 12 c.
Montgomery	52	do	52	do	1¾	18	75	25,000		750	60	No	Flat, $4.
Monticello	40–80	Comp. air.	40–80	Comp. air.	1½	19	48	25,000	800,000	250	25	Yes	Flat, $4; meter, 30 to 20 c.
Morton	20	Direct	60	Gravity	1½	16	80	20,000		650	80	Yes	Flat, $5.
Mountain Lake.	40	Gravity	40	do	2	19	60	20,000	60,000	400	33⅓	Yes	Do.
New London			150	Direct	¼	3	0	None.		None.	0	No	
New Prague	50	Gravity	50	Gravity	1	18	40	45,000		750	75 (?)	Yes	Flat; meter, 50 to 20 c.
New Richland.	53	do	53	do		22	28	1,750 (?)					
New Ulm		do		Direct	11	8	450	80,000	400,000	3,400	60		Meter, 25 c. (more or less).
Nicollet	50	do	50	Gravity	½	6	6	1,600	32,000	35	10	Yes	Meter, 50 c. (min., $5).
Northfield	80	do	80–150	Gravity and direct.	8	81	377	236,000	1,500,000		33⅓	Yes	Meter, 20 to 8 c. (min., $6).
North St. Paul.	20	do	60–80	Direct	2	27	10	6,000	d150,000			No	Meter, 20 c.
Olivia	50	do	50	Gravity	2	20	58	17,000	90,000	250	25	Yes	Flat, $5; meter, 40 c.
Ortonville	70	do	70	do	1⅔	19	125	65,000	200,000	500	25		Meter, 53 to 13 c. (min., $6).
Owatonna	50	do	100	Direct	14	105	800	400,000					
Pine Island	50	do	50	Gravity	1½	18	75	40,000	150,000	500	66⅔	No	Flat, $3.
Pipestone	20–40	do	140	Direct	6	42	375	60,000	216,000	2,300	90	Yes	Flat, $6; meter, 30 c.
Plainview	40	do	40	Gravity	4	10	220	25,000					
Preston	95	do	95	do		29	167	30,000				Yes	Flat, $5.
Redwing													

a Capacity of pump 500 gallons per minute.
b Portable fire engines.
c Daily capacity of plant 80,000,000 gallons.
d From well alone.

Public water supplies in southern Minnesota—Continued.

City or village.	Plant—Continued.				System.			Consumption.					
	Domestic pressure per square inch.	Method of applying domestic pressure.	Fire pressure per square inch.	Method of applying fire pressure.	Length of mains.	Number of fire hydrants.	Number of taps.	Average daily consumption.	Maximum daily capacity of source.	Number of people supplied.	Percentage of total population.	Is water used for drinking in public schools?	Price charged.
	Pounds.		*Pounds.*		*Miles.*			*Gallons.*	*Gallons.*				
Redwood Falls.	45	...do......	80	Direct.....	6	....	210	30,000	100,000	980	50	Yes.....	Meter, 40 to 15 c.
Renville.....	45	...do......	45	Gravity...	1⅘	23	60	10,000	65,000	300	25	Yes.....	Flat, $4.80.
Rochester....	80	Gravity and direct.	80–110	Gravity and direct.	12	165	900	400,000	1,000,000	4,000	50	Yes.....	Flat, $5; meter, 30 to 10 c.
Rolling Stone	78	Gravity...	78	Gravity...	1½	12	30	....	75,000	200	90	Yes.....	Flat, $3.
Rose Creek...	....	....	60	Direct.....	½	6	11	3,000	150,000	20	10	No......	Flat, $5.
Rushford.....	....	....	....	....	2½	35	75	15,000	....	....	....	....	
Ruthton.....	40	Gravity...	40	Gravity...	⅐	3	0	Small.	50,000	None.	0	No......	
Sacred Heart.	40	...do......	40	...do......	⅗	8	28	4,000	75,000	125	20	Yes.....	Flat, $6.
St. Charles...	50	...do......	50	...do......	3	40	200	10,000	....	....	....	....	
St. James....	40	...do......	80–120	Direct.....	3½	43	135	30,000	800,000	....	....	....	Flat; meter, 50 c. and less.
St. Paul......	10–75	...do......	(*a*)	(*a*)	300	2,773	24,773	*b*10,781,044	(*b*)	....	....	Yes.....	Flat, $3; meter, 13 to 7 c.
St. Peter.....	85	...do......	85	Gravity...	4⅕	41	225	20,000	....	1,050	28	Yes.....	Meter, 30 c. (min., $3).
Sherburn.....	50	...do......	50	...do......	Several.	38	50	13,000	240,000	250	25	Yes.....	Flat, $3; meter, 25 c.
Silver Lake..	....	....	....	Direct.....	1½	9	....	....	....	....	....	No......	
Slayton......	40	Gravity...	60	Gravity and direct.	1½	23	72	15,000	65,000	600	66⅔	Yes.....	Flat, $5.
Sleepy Eye...	45	...do......	100	Direct.....	2	25	65	28,800	150,000	400	20	Yes.....	Flat, $4.80; meter, 40 to 20 c.
South St. Paul.	100	...do......	100	Gravity...	6	34	190	22,500	2,000,000	3,000	50	Yes.....	Meter, 40 to 20 c.
South Stillwater.	....		150	Direct.....	2	21	20	....	....	....	....	No......	
Springfield...	68	Gravity...	68	Gravity...	3	36	25	30,000	180,000	....	....	Yes.....	Flat, $5.
Spring Grove	....	...do......	....	...do......	1	14	40	8,000	....	....	....	....	
Spring Valley	40	Direct.....	100	Direct.....	3	45	150	65,000	....	....	....	....	
Stewart......	43	Gravity...	43	Gravity...	⅗	9	23	20,000	80,000	50	10	....	Do.
Stewartville..	50	...do......	50	...do......	1¼	7	40	8,000	....	....	....	....	
Stillwater....	65–100	...do......	65–100	Direct.....	14	130	750	1,250,000	3,000,000	....	75	Yes.....	Flat, $6.
Tracy........	45	...do......	100–150	...do......	3½	28	250	50,000	75,000	1.800	85	....	Do.
Truman......	50–60	Comp. air.	50–60	Comp. air.	¼	4	3	Small.	....	Few.	Small.	No......	Do.
Tyler........	45	Gravity...	45	Gravity...	½	9	25	....	45,000	....	....	Yes.....	Flat, $5.40; meter, 40 c.

Vernon Center.	44	...do......	44	Gravity and direct.	$\frac{1}{3}$	5	15	....	120,000	40	10	No......	
Walnut Grove.	44	...do......	44	Gravity...	$\frac{4}{5}$	10	50	3,000	50,000	300	75	Yes.....	Flat, $4.
Waseca......	45	...do......	150	Direct.....	$6\frac{1}{2}$	46	....	50,000	150,000	2,000	$66\frac{2}{3}$	Yes.....	Flat, $6; meter, 30 c. (min. meter, $5.)
Waterville...	45	...do......	45	Gravity...	$\frac{3}{4}$	9	22	10,000	....	....	....	No......	Flat, $6; meter, 80 to 30 c.
Waverly.....	50	Comp. air.	75	Comp. air and direct.	1	13	30	3,500	....	....	....	No......	Flat, $4.
Welcome.....	60–65	...do......	60–65	Comp. air.	$\frac{3}{4}$	7	10	2,000	20,000	25	5	Yes.....	Flat, $6.
Wells........	45	Gravity...	100	Direct.....	$2\frac{1}{2}$	23	125	100,000	150,000	1,250	65	Yes.....	Flat, $5; meter, 25 c.
Westbrook...	45	...do......	45	Gravity...	$\frac{1}{3}$	5	0	500	5,000	0	0	No......	
West Concord	None.	....	80	Direct.....	1	7	0	Small.	Great.	0	0	No......	
West Minneapolis.	50	Gravity...	50	Gravity...	....	....	....	....	....	....	....	....	
White Bear Lake.	50	...do......	50	...do......	2	24	30	15,000	125,000	235	13	No......	Flat, $5.
Willmar......	43	...do......	80–100	Direct.....	$5\frac{1}{2}$	46	300	100,000	750,000	1,500	30	....	Meter, 47 to 11 c.
Wilmont.....	40	...do......	40	Gravity...	$\frac{1}{3}$	5	1	500	150,000	None.	0	No......	
Windom.....	65	...do......	65	...do......	4	28	100	15,000	300,000	450	25	Yes.....	Flat, $5; meter, 50 to 25 c.
Winnebago ..	40	Direct.....	100	Direct.....	5	14	250	100,000	....	....	....	....	
Winona......	50	Gravity...	90	...do......	36	365	2,735	2,000,000	....	....	....	....	
Winsted.....	....	....	....	....	....	10	....	....	....	....	....	No......	
Winthrop....	45	Gravity...	45	Gravity...	2	17	....	4,500	75,000	....	....	No......	
Wood Lake..	45	...do......	45	...do......	$\frac{1}{5}$	5	0	Small.	35,000	None.	0	No......	
Worthington.	40–60	Direct.....	100–110	Direct.....	$4\frac{1}{2}$	26	317	65,000	Great.	1,000	40	Yes.....	Flat; meter, 25 to 20 c.
Wykoff......	45	Gravity...	45	Gravity...	$1\frac{1}{2}$	15	85	12,000	250,000	500	90	Yes.....	Flat, $5.
Zumbrota....	65	...do......	65	...do......	$2\frac{1}{2}$	21	100	5,000	....	250	15	Yes....	Meter, 30 c.

[a] Portable fire engines.

[b] Daily capacity of plant, 20,000,000 gallons.

CITIES AND VILLAGES EQUIPPED WITH PUBLIC WATERWORKS.

The foregoing table includes all public waterworks (as far as known) that have pressure mains, and also a few where no mains have been laid, the system furnishing a very limited service. It does not, however, include villages provided merely with fire engine and hose and an adequate source from which to pump, although their fire protection may be comparably good. DeGraff, Holland, Nerstrand, Shakopee, Trosky, and Wabasso are examples of this class.

As is shown in a table below, nearly all the larger settlements and many that are still very small are equipped with systems of waterworks. It will be seen that the list includes three-fourths of the villages having a population between 500 and 1,000 and one-half of those having between 250 and 500, as well as eight progressive hamlets whose population is still less. In all but five or six cases the waterworks are owned and operated by the municipalities. Indeed, the great majority of the settlements are too small to attract private capital for such an enterprise.

Number of cities and villages in southern Minnesota with public waterworks.

Population.	With waterworks.	Without waterworks.	Per cent with waterworks.
1,000 or more	77	4	95
500 to 1,000	50	18	74
250 to 500	51	52	50
Less than 250	8		
Total with 500 or more	127	22	85
Total with 250 or more	178	74	71
	186		

USES OF PUBLIC WATERWORKS.

The manifold and varied uses made of the water from public supplies may be grouped as follows:

- Public use:
  - Fire protection.
  - Public buildings—schools, etc.
  - Sprinkling streets, irrigating parks, etc.
- Domestic use:
  - Drinking and cooking.
  - Toilet and laundry.
  - Disposal of sewage.
  - Irrigation and sprinkling.
  - Live stock.
- Industrial use: Boiler supplies, etc.

In nearly all the smaller municipalities protection against fire is regarded as the primary function of a system of waterworks, all other uses being considered incidental and of minor importance. Indeed, experience has proved that almost without exception, even in the smallest villages, the money expended in this way is saved to the community before many years elapse, in the immunity from disastrous fires which is thus afforded.

That the value of the public supply for domestic use is not popularly appreciated is clearly proved by the data presented in the table below. As will be shown later, the waterworks have, as a rule, been efficiently equipped at considerable cost and are usually provided with pure water. Considering only the municipalities in which waterworks have been installed, in nearly one-third of those having less than a thousand inhabitants the public supply remains virtually unused for domestic purposes, in less than one-fourth it is used by 50 per cent of the population, and altogether it is used by only 25 per cent of the people residing in these villages. This failure to utilize the public supplies where they are available can be traced to several causes, the principal ones being as follows: (1) The fact that fire protection was the end in view when the waterworks were installed, and that the people are to a great extent oblivious to the other advantages brought within their reach; (2) a persistent but unwise prejudice in favor of private wells; and (3) the expense involved in making service connections and in paying for the water itself.

The extent to which the public supply is used by the people increases with the size of the settlements. Thus in the cities and villages having a population of more than 1,000, excluding Minneapolis and St. Paul, it is used by about 44 per cent of the inhabitants, while in the two large cities the great majority depend at least partly upon the public supplies.

The industrial applications of the public water likewise increases with the population. The principal requirement of this character in many of the smaller towns is for the railway locomotives, which at numerous points are provided from the public supply. In the larger centers, however, the demands for water in various commercial operations are much more extensive, and the dependence of industry upon the public supply has become an important matter.

Number of cities and villages in which specified percentages of people use the public water supplies provided.

Percentage of people using the public supply.	Cities and villages with more than 1,000 inhabitants.[a]		Villages with less than 1,000 inhabitants.	
	Number.	Per cent of total.	Number.	Per cent of total.
90 to 100 per cent	4	5.7	7	6.6
50 to 90 per cent	30	42.9	18	17.0
25 to 50 per cent	22	31.4	19	18.0
5 to 25 per cent	10	14.3	31	29.2
Less than 5 per cent	4	5.7	31	29.2
	70	100.0	106	100.0

[a] Excluding Minneapolis and St. Paul.

SOURCES OF SUPPLY.

In selecting a public water supply the principal features that require attention are the following: (1) The quantity of water available, (2) the quality of the water, and (3) the cost.

Quantity.—In estimating the quantity that can be drawn from any proposed source it is not usually sufficient to know the normal or average amount. Where only limited storage facilities are provided, calculations should rather be based upon the minimum production—the supply afforded in the most protracted periods of drought. Likewise it is not safe to base estimates upon the average consumption. There will be times when much more than the ordinary amount of water will be used, and unless the supply is adequate to meet these unusual demands, much inconvenience will result. Moreover the seasons of minimum supply and maximum demand are likely to coincide. Finally, it is important to take into account the probable increase in population and industrial development, and to provide for the enlarged needs at least of the immediate future.

Quality.—The quality of the water should be considered with reference to its sanitary character, agreeability, and mineral composition. The numerous causes of pollution which exist in cities and villages render it relatively difficult and expensive to obtain water supplies that are removed from all danger of contamination. As will be shown later, a large proportion of the private wells in cities and villages are polluted, and it is therefore especially important that the public waterworks should be provided from a source that is carefully safeguarded. The agreeability of the water refers to those properties which render it pleasant or offensive to the senses; that is, its appearance, odor, taste, temperature, etc., without reference to its effect upon the health. An illustration is afforded by the "irony" water, so abundant in southern Minnesota. The iron in solution gives this water a characteristic taste, and upon precipitation renders it turbid. The water may be entirely wholesome, but the people frequently refuse to use it, and any supply that the people reject is a failure. Indeed, the popular preference for private wells and the prevalent disinclination to use the public water for drinking and culinary purposes is in large measure due to the fact that for the public supply agreeability is ignored and the water is not rendered attractive to the consumers. The mineral quality of the water has already been exhaustively discussed in a preceding chapter.

For fire extinction, flushing of sewers, sprinkling of streets, etc., the quality of the water is of no consequence; for drinking and cooking the sanitary character and agreeability are important; while for bathing and laundry purposes, and for boiler and most other industrial uses, the mineral properties are important, as soft a water as possible usually being required. The mineral content is also a consideration for drinking and cooking purposes, and, less frequently in this area, for irrigation.

Cost.—The cost includes (1) the original outlay for the well or other source and (2) the cost of operation. While there should be no hesitation in making the expenditures necessary to secure a source that is satisfactory both in quantity and quality, yet there has undoubtedly been too great a willingness on the part of many of the communities of this section to spend large sums of money in drilling deep wells where adequate and safe supplies could have been obtained at much less cost, and where the benefits expected to accure from the deep drilling were not of an essential character justifying the great expenditure even if they had been assured. Too often, especially in small municipalities where competent engineering advice is not employed, the cost of operation is not given sufficient weight when plans for installing a public supply are considered. The cost of pumping the water is an important matter, as it may be the determining factor in the use of the system by the public.

Surface sources.—If a settlement is located near a river or lake, surface water can in most cases be obtained with less original cost and less expense for pumping than underground water. Moreover, there is ordinarily no limit to the quantity available, and it usually has the advantage of being softer and better adapted for bathing, laundry, and boiler purposes than underground water. On the other hand, it is more subject to pollution, and small communities do not find it feasible effectively to guard the source or to install and maintain an efficient filter or other means of purification. A river is liable to be polluted by settlements upstream, while a lake may become locally contaminated by the sewage and wash from the settlement concerned. But, aside from the real merits of the case, a practical difficulty is the fact that the popular reluctance to use a public supply is much greater where surface water is drawn upon.

Underground sources.—In regard to underground supplies there are a number of difficulties and disadvantages, those most commonly experienced being the following: The yield may be insufficient or not permanent; the expense of lifting the water to the surface may be great; the water may contain organic impurities; or it may be highly mineralized. In southern Minnesota the last-named difficulty is the most general and perhaps the most serious.

Underground water derived from shallow sources may be impure. Open wells sunk into surficial deposits should be relied upon as safe only if their environs are protected from pollution. On the other hand, water from deep horizons is almost invariably free of organic impurity at its source, but, as has been shown by comparative chemical and bacteriological analyses, it frequently does not possess the same quality when it reaches the consumers. This is because of pollution at the well or in the reservoirs or other parts of the system. The remedy for this condition is theoretically simple: If all parts of the system are kept tight the introduction of shallow water or sewage will be prevented, and the water will be delivered at the tap uncontaminated.

The introduction of organic matter may occur in any of the following ways: (1) Surface water may pass downward on the outside of the well casing and mingle with the deep water. Where there is a thin overlying impervious layer or none and the casing extends only a short distance down, there is perhaps considerable danger of pollution in this manner; but where there is an impervious bed of reasonable thickness and the casing projects well below the level to which the deep water rises, this cause of contamination can not be conceived to be common. (2) The casing may leak. If a suction pump is used (the well casing acting also as the pump pipe) water at or near the surface may be drawn into the system; otherwise it may flow in more slowly. (3) The casing may extend only up to the bottom of the manhole or "pit" of the well, and the leakage from the pump together with ground water and surface wash may enter the manhole and flow into the well. A large proportion of the drilled wells used for public supplies in southern Minnesota are intentionally so finished that they serve also as drains for the waste water—an arrangement that deserves condemnation. A better method is to dispense with the manhole altogether and to bring the casing above the surface of the ground. (4) Water is sometimes conducted by gravity from the source to a reservoir, especially where springs at some distance from the settlement are utilized. Since there is no pressure in the pipes or mains in such a system, surface water or sewage may enter where leaks occur. If the water in the pipes is under constant pressure there is no danger of pollution, since any opening will then allow water to escape but will not permit anything to enter. (5) Reservoirs sunk into the ground are seldom entirely waterproof, and where they are employed, contaminating agencies should be kept at a distance. Moreover the reservoir should have its top built well above the ground and should be kept as nearly filled as possible, so that the pressure will be outward and polluting liquids will get no opportunity to enter. In no case should the water be stored in cisterns placed under the pump house. It is obvious that there is no advantage in having a deep-water supply if the water is allowed to be exposed to contamination anywhere in its journey from the source to the consumer's tap. However, as has already been said, the principles involved in preventing pollution are for the most part simple, and consist substantially in the application of common sense all along the line.

Data for southern Minnesota.—The following table shows the sources from which the public waterworks in southern Minnesota are supplied:

Sources of public water supplies in southern Minnesota.

Source.	Number.	Per cent.
Wells	162	87
Springs	8	4
Lakes	7	4
Rivers	6	3
Combinations	3	2
	186	100

About 91 per cent of the waterworks are provided with underground water; about 67 per cent, or approximately two-thirds, from drilled wells more than 100 feet deep. Although small glacial lakes are remarkably numerous throughout most of this region, they are utilized by only a few communities as a source for public supplies. Of the few villages which use surface water, in perhaps the majority the supply is intended for fire protection only (for example, Silver Lake and New London); while in several others it is utilized because a satisfactory underground source is wanting (for example, Granite Falls and Cottonwood); in only a very few is the water used extensively for drinking and cooking.

The following table shows the geologic sources of the underground water used for public supplies. Where the water is drawn from different sources, only the principal one is considered; supplies whose geologic source is in doubt are omitted from the tabulation.

Sources of underground water used for public supplies in southern Minnesota.

Source.	Number.	Per cent.
Alluvium and outwash deposits	16	10
Glacial drift	60	39
Total surface deposits	76	49
Cretaceous system	9	6
Platteville, Galena, and higher Paleozoic formations	14	9
St. Peter sandstone	13	8
Shakopee dolomite, New Richmond sandstone, and Oneota dolomite	5	3
Jordan sandstone	15	10
Dresbach sandstone and underlying shales	19	12
Total Paleozoic	66	42
Sioux quartzite	4	3
	155	100

METHODS OF LIFTING WATER.

The type of pump employed for bringing water to the surface depends to a great extent on the depth from which it must be raised. If the lift is less than the height of a water column that will balance the pressure of the atmosphere, the pump can be stationed at the surface and the water can be raised by means of a suction pipe let into the well; but if the water stands at a lower level, the pump must be let down into the well. The cost of pumping is much less where the water rises near enough to the surface to make it possible to pump by suction. Deep-well pumps are necessarily limited in their capacity, are expensive to keep in repair, and work at a mechanical disadvantage. However, where the water stands low in the wells or is lowered very much by pumping, this is usually the only feasible way of lifting it. A third method which is employed at several places, but has not yet come into general use, is known as the air lift. This is a very simple device. An iron pipe is placed in the well, extending from the top nearly to the bottom. Air is driven down the pipe. Escaping near the bottom of the well far below the water level, the air displaces the water and lessens the weight of the water column sufficiently so that the water will rise and discharge from the well (fig. 9). This method is not limited absolutely by the depth to the water, but it is most successful where the water rises nearly to the surface.

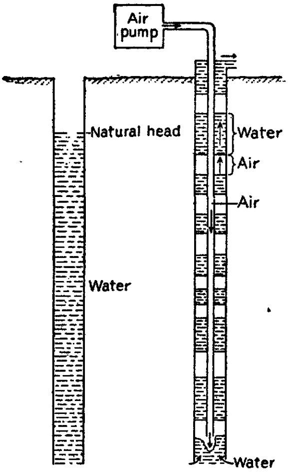


FIGURE 9.—Diagram showing the principle of the air lift.

The following table shows the various methods used in southern Minnesota:

Methods of lifting water to the surface in public wells.

Deep-well pumps	79
Suction pumps	37
Natural flow	17
Air lifts	5
Deep-well and suction pumps	1
Deep-well pumps and natural flow	1
Deep-well pump and air lift	1
Suction pump and air lift	1
Suction pumps and natural flow	6
	148

Much interest is being manifested in the air lift, and it seems probable that it could be advantageously used in some wells where pumps are at present employed. For these reasons the data in regard to the air lifts now installed are given in the following table:

Data in regard to air lifts in public water wells.

City or village.	Depth of well.	Depth of water in well.	Ratio.	Yield per minute.
	Feet.	*Feet.*		*Gallons.*
Blue Earth	672	640	0.95	350
Boyd	62	54	.87	....
Brownton	304	280	.92	95
New Prague	289	173	.60	25 to 50
Pipestone	200 350	104 254	.52 .73	140
Sleepy Eye	222	177	.80	100
Waseca	600 1,157	475 1,032	.79 .90	100

POWER.

The following table shows the different methods of generating power at the various pumping stations:

Power used at public pumping stations in southern Minnesota.

	Over 1,000 inhabitants.	Less than 1,000 inhabitants.	Total.
Internal combustion engines (gasoline and gas)	9	75	84
Steam engines	44	11	55
Electric motors	4	1	5
Windmills	0	1	1
Water power	1	0	1
Artesian pressure	1	0	1
Combinations	3	5	8
Total reported	62	93	155

The great convenience of gasoline engines in the pumping stations of the smaller villages is obvious, and the table shows how largely this relatively new device for applying energy is being employed. In most of the cities and larger villages, where more expensive machinery has been installed and where more power is required and longer hours of pumping are necessary, the steam engine has for the most part been retained. Water power is used (directly or indirectly) at three pumping stations, windmills in three, and an hydraulic ram in one. Where windmills, hydraulic ram, or artesian pressure are employed, there is usually an arrangement by which gasoline or steam engines can be used in case of fire or other emergency.

STORAGE AND DISTRIBUTION.

In order to make the water available it is essential that it be forced to all parts of the system of mains and branch pipes. For ordinary purposes it is only necessary to have sufficient pressure to deliver the water readily from the taps at the highest elevations at which it is to be used, but in case of fire the system is not effective unless the pressure is great enough to project the water forcibly for some distance so that it can be lodged in quantity in the heart of the flames and at other inaccessible points. The following table shows the different methods employed in southern Minnesota for applying both the domestic and fire pressures:

Number of public water systems using specified methods of applying pressure.

	Domestic.	Fire.
Gravity [a]	142	97
Direct from pump	8	62
Compressed air	17	17
Direct from source (natural head)	2	....
No pressure	3	....
Total reported	172	176

[a] Hydrostatic pressure from a standpipe, a tank mounted upon a tower, or a reservoir situated on elevated ground.

Closely related to the question of pressure is that of storage. There are several principal reasons for storing water. It is frequently a matter of economy. Where the consumption is small, the supply for one or more days can be pumped in a few hours, and by storing it at an elevation or under compressed air a nearly constant pressure can be maintained without further attention. In many cases storage is required in order to provide adequate protection against fire, for unless the rate at which the source and pumps can furnish water is equal to the rate at which the water will be used in case of fire it is necessary to maintain a reserve supply. It is evident that these reasons for storing water apply to small villages rather than to large cities. Where the normal consumption is great it may become economical to keep the plant in continuous operation and to pump directly from the source into the mains, thus exerting direct pressure and dispensing with all reservoirs. Moreover, the capacity of the source and pumps is necessarily so great that extra demands in case of fire can easily be met.

There are many possible combinations for storage and distribution, each of which has certain advantages and disadvantages. The particular combination best adapted for any given municipality depends upon the conditions to be met, involving a large number of intricately interdependent factors.

For fire protection it is necessary to have (1) a strong pressure, (2) a sure pressure, and (3) an ample reserve of water. It is important at this point to emphasize the fact, too often overlooked, that in small settlements where fires are infrequent and where it is not feasible to support a well-disciplined fire department, the weak feature in the system, as far as fire protection is concerned, most commonly consists in not providing for a pressure that can be depended on. Where reliance is placed upon machinery not in operation every day or at least every week, or upon the concerted action of men not constantly working together, the fire protection is very much poorer than it appears to be. In villages the protection is good in proportion as the human element in the system is eliminated. In most of the large cities where the system is extensive the domestic pressure is kept constant and relatively low, while special pressure is obtained in case of fire by the use of portable fire engines; but in smaller cities better results are invariably secured by applying the pressure to the entire system by means of the pumps at the pumping station, the pressure thus being obtained more promptly and certainly; and in the villages gravity pressure is found to be the surest. Any system employing compressed air or direct pumping relies upon the working of an engine and pump (in a village generally a gasoline engine), and since it is impossible to have as good machinery or as well-trained engineers in a village as in a city, the danger of a breakdown at the critical moment is much greater, and experience has shown that it is not uncommon for the engine to refuse to work at the very time when it is most needed. A good arrangement adopted in many villages is to have gravity pressure which can be reinforced by direct pumping.

Underground reservoirs are liable to pollution, and where storage is required it is therefore desirable to employ either compression chambers or reservoirs so high as to be above the reach of contamination by sewage. Mechanical considerations frequently require reservoirs at or near the surface. Thus where deep-well pumps must be used it is often advantageous to allow these to discharge into surface reservoirs, and to utilize duplex or triplex force pumps for raising the water higher, rather than to compel the deep-well pumps to make the entire lift; also where air lifts are installed it is generally necessary to have a surface reservoir into which the water may be discharged; but in such cases it may be advisable to build the reservoir just above the surface rather than to sink it into the ground.

CONSUMPTION OF WATER.

The following table gives approximately the amount of public water consumed in southern Minnesota:

Consumption of water from public supplies in southern Minnesota.

	Total daily consumption.	Total number of people supplied.	Average daily consumption per capita.
	Gallons.		*Gallons.*
Minneapolis	17,591,854	*a* 261,974	67
St. Paul	10,781,044	*a* 197,023	55
Other cities and villages with more than 1,000 inhabitants	8,911,000	106,490	84
Villages with less than 1,000 inhabitants	695,000	16,221	43
	37,978,898	581,708	65

a The total population according to the 1905 census is here given.

It should be understood that the above figures generally represent only rude estimates and include certain vitiating factors which destroy their value for drawing refined inferences. The daily per capita consumption is derived by dividing the total daily consumption by the number of people supplied; but this gives a result uniformly too high, since under "total consumption" are included the water used for industrial and public purposes and also that lost through leakage—a by no means inconsiderable amount. It is not easy to allow even approximately for the last-named items. Although industrial consumption increases with the population, the proportion of people in the smaller communities using the public supply is so low, and in so many places large amounts of water are sold to the railway companies for use in locomotives, that it is not at all evident that the per capita allowance should be greater in the large than in the small municipalities. The per capita estimates for Minneapolis and St. Paul are rendered relatively too low by the fact that they are based upon the total population. From a general consideration of the subject it seems safe to say that, on an average, village inhabitants (those provided with public supplies) consume less water than the residents of cities; and it is believed that the chief explanation of this difference is that the latter have better facilities for applying water to useful purposes (bathrooms, sewage disposal, irrigating lawns, etc.) than the former, and moreover have learned to use these facilities more liberally.

PRICE CHARGED.

The following table shows the methods of charging for water, in so far as they have been reported:

Number of cities and villages using specified methods of charging for water.

Flat rates	55
Meter rates	34
Both flat and meter rates	31
Free	3
Total number reporting price	123

The method of installing meters and charging for the water actually used is found to be much more satisfactory than that of collecting a fixed (or flat) rate per annum. By the latter method a small proportion of the consumers frequently waste more than is used by all of the rest of the community.

The relative prevalence of different minimum flat rates (including the minimum charge where meters are used) is shown below. In most towns meter rates are arranged according to a sliding scale, the larger consumer getting a better rate than the person using only a small quantity of water.

Number of cities and villages having specified minimum annual flat rates (including minimum charges where meters are used).

Free	3
$2	1
$3	10
$3.75	1
$4	13
$4.50	1
$4.75	2
$5	36
$5.40	1
$6	19
$8	1
$9	1
$12	2
$18	1

In the following statement the relative prevalence of different maximum meter rates is shown. The maximum rates represent most closely the price paid for domestic consumption. The average maximum rate is 33 cents per 1,000 gallons.

Number of cities and villages having specified maximum meter rates per 1,000 gallons.

8 cents	1
10 cents	1
12 cents	1
13 cents	1
14 cents	1
15 cents	1
20 cents	8
25 cents	11
27 cents	3
30 cents	7
33 cents	1
35 cents	1
40 cents	12
45 cents	1
47 cents	2
50 cents	7
53 cents	1
56 cents	1
80 cents	2
$1	1

Although in most instances the price is not high, it appears formidable to many village inhabitants who have always been accustomed to think of water as a commodity that nature furnishes free to all, and with many of the people this is the real barrier to the use of the public supply. In a large proportion of the smaller villages so little use is made of the waterworks that the resulting revenue is almost negligible. These communities have already gone to great expense to install the system, and they are paying a considerable sum each year for maintenance and operation. The additional cost involved in furnishing the domestic supplies for all the people would not be great. In view of these facts it is pertinent to raise the question whether it would not be good public policy for municipalities of this class to furnish water for domestic purposes free of charge and to pay for the maintenance and operation of the waterworks wholly by taxation. The conditions at Hanley Falls, described in the report on Yellow Medicine County, are instructive in this connection. In this village the water is supplied free and is used by all the people. There is no extra expense for services, since the village marshal attends to the pumping, as the usage is in many other villages. Almost the only additional cost is for gasoline to run the engine, and this is nearly negligible. The daily per capita consumption is only about 30 gallons, which fact shows that there is little disposition on the part of the people to abuse their privilege. Indeed, the total consumption is not much greater than in some villages where the supply is almost unused for domestic purposes, but where the water is wantonly squandered at a few taps for which a flat rate of only a few dollars is annually paid.

THE SANITARY PROBLEM.

The domestic water supply for a great majority of the village inhabitants of southern Minnesota is derived from shallow, open wells, a situation resulting from the geologic conditions already described. Since few villages have sewers, these wells are necessarily near one or more privies or cesspools. In order to ascertain to what extent they are affected by these sources of pollution, water was analyzed from eleven private dug or bored wells situated in as many different villages. These wells are believed to be fairly representative of the most common type in use in the smaller settlements, as care was taken to select only such as were not more exposed to pollution than the average. The water of nearly all these wells is used extensively for drinking and cooking. Water from ten of them showed the presence of *Bacillus coli*, which is considered a conclusive evidence of contamination by human or other animal excreta. In the water from the eleventh well the results were uncertain, but there were some indications of *B. coli*. A brief description of the wells follows:

1. Well about 2 feet in diameter and 40 feet deep, cased with wood. Hotel privy about 30 feet distant. The water is used extensively for drinking and cooking. *B. coli* found in the water.
2. Well about 2 feet in diameter and 20 feet deep, cased with tile. The surroundings are clean and tidy. Privy 20 or 25 feet distant. The water is used for drinking and cooking. *B. coli* present.
3. Well 18 inches in diameter and 50 feet deep, cased with tile. Hotel privy about 50 feet distant. The water is used extensively for drinking and cooking. *B. coli* present.

4. A dug well 37 feet deep, cased with boards. Privy and stable about 50 feet distant. The water is used for drinking and cooking. *B. coli* present.
5. A bored well of the usual construction and with the usual surroundings. Water used extensively for drinking and cooking. *B. coli* present.
6. Well 2 feet in diameter and about 30 feet deep, cased with wood. There is a privy 75 feet distant. The water is used for drinking and cooking. *B. coli* present.
7. Well 2 feet in diameter and 25 feet deep, cased with glazed tile. A privy is 50 feet from the well. *B. coli* present.
8. Well 2½ feet in diameter and 35 feet deep, cased with wood. Privy is 40 feet distant. The water is used for domestic purposes. *B. coli* present.
9. A shallow, private bored well of usual construction and surroundings. Used extensively for drinking and cooking. *B. coli* present.
10. Well about 3 feet in diameter and 30 feet deep, cased with brick. The surroundings are clean and tidy. Privy 80 feet distant on lower ground. Dwellings near by on higher ground. Water used for drinking and cooking. *B. coli* present.
11. Well 2 feet in diameter and 22 feet deep, cased with wood. The casing is in good condition, and the ground is graded up around the well. Two privies at distances of about 80 and 100 feet, respectively. Stable nearer the well. Water used for domestic purposes. The results of the analysis were not conclusive, but there were some indications of *B. coli.*

It can not be affirmed that the bacillus is in all cases derived from the environing privies; in some instances it may be washed into the well with the fæces of domestic animals, or it may be introduced in other conceivable ways. Neither is it intended here to imply that all this water is dangerous to health. Nevertheless it must be admitted by everyone that the situation is far from satisfactory from either a sanitary or an esthetic point of view.

In conclusion, it is desired to make a plea for higher ideals of cleanliness and sanitation in the villages of southern Minnesota. Either a system of waterworks or a system of sewers is incomplete in itself. Every community should aim to procure an adequate and safe source of water supply, to install an efficient system of waterworks with mains reaching as nearly as possible to every home, and to construct an approved and extensive system of sewers. The people should then avail themselves of the opportunity afforded, thus securing pure water for drinking and cooking, an abundant and convenient supply for toilet and laundry purposes, and an effective, cleanly, and sanitary method of disposing of sewage and waste water.

It is commonly objected that such a system of waterworks and sewers would be financially ruinous to an ordinary village, but this need not be so if it is rightly planned in the beginning. A common difficulty is that too much is expended upon makeshifts. A source is obtained which is unsatisfactory or inadequate; a tank that is too small is erected upon a tower that is too low; mains are laid which are too small or are inferior in quality; and if a sewer is constructed it is improperly built or not laid deep enough to make its extension feasible. The result is that money must constantly be spent for reconstructing defective parts, and no progress can be made in extending the system. Every village, when it first takes up the problem, should, with the aid of expert engineering advice, plan a complete system that will be satisfactory and adequate for the present and for a considerable time to come. The essential portions of the system should first be provided, and future expenditures can then be applied to extension rather than to remodeling.

In progress toward ideal conditions the main reliance must be placed in the education of the people in the elementary principles of sanitation. When once they comprehend that in drinking the "clear, cold" water from their shallow private wells they are imbibing the bacteria-laden seepage from their privies or barnyards, and when, furthermore, they understand that better conditions are within their reach, they will be ready to do their part in the work of improvement.

DESCRIPTIONS BY COUNTIES.

ANOKA COUNTY.

By C. W. Hall and M. L. Fuller.

SURFACE FEATURES.

The upland surface of Anoka County is comparatively low, averaging but little over 900 feet above sea level and only about 100 feet above Mississippi River. In general it is flat or gently undulating, with many broad shallow sags occupied by swamps or lakes, but in the extreme northwest it consists of morainic hills. The streams occupy shallow valleys which do not affect to any extent the general character of the country. Everywhere the surface of the county indicates a recent origin. It has been modified but little since the glaciers withdrew from it.

SURFACE DEPOSITS.

The glacial drift has considerable thickness, but is exposed at the surface chiefly along the southeastern edge and in several small areas on the western border of the county; elsewhere it is covered by outwash deposits. It is prevailingly clayey, but in places is sandy and may include layers of clear sand or gravel which contain considerable amounts of water but do not yield it as generously as the sandstones beneath the drift. The red clay was doubtless derived from the Lake Superior region, its color being due to the decomposition of the basic eruptive rocks; the blue clay, which overlies the red, was deposited in part by glaciers from the northwest, and is derived, in large part at least, from the Ordovician and Cretaceous shales.

The outwash deposits consist of gravel and sand 20 to 50 feet thick, laid down by streams issuing from the melting ice sheet and flowing over the flat upland surface. The materials thus deposited cover by far the greater part of the surface of Anoka County, being absent in only a few narrow strips along the eastern and western edges. Because of their open and porous character they readily absorb the rain falling on their surface. Hence they are saturated wherever they lie below drainage level, and will usually yield supplies adequate for domestic and farm purposes.

Alluvial deposits are limited to narrow strips along Mississippi and Rum rivers and several smaller streams. They generally contain water and afford supplies to many private wells.

In Grow Township, north of Anoka, dunes are prominently developed, forming hills of very clean sand 10 to 30 feet in height. They readily absorb the rain falling on them, but because of their exposed position are of little consequence as a source of water supply.

ROCK FORMATIONS.

The Platteville limestone is represented in this county only by the basal 25 feet or more found in a few small areas in the extreme southern portion of the county.

Below the Platteville is the St. Peter sandstone, which extends over much of the southern half of the county. Because of the thickness of the overlying drift and the abundance of water that it usually contains, very few wells have been sunk into the St. Peter, but wells drilled at Centerville penetrate it, finding rather large supplies. Locally water from this formation is under considerable head and rises nearly or quite to the surface.

Next below the St. Peter lies the Prairie du Chien group, consisting, in succession, of the Shakopee dolomite, New Richmond sandstone, and Oneota dolomite. The Shakopee is probably about 35 feet thick. The exact position of the area in which it lies immediately beneath the drift has not been definitely determined, but it is known to extend in the southern part of the county from the east edge westward and southwestward, crossing Mississippi River near Anoka. The New Richmond is a thin bed, but carries considerable water and will afford satisfactory supplies to private wells. The Oneota extends across the county probably from near the northeast corner to the river, a little west of Anoka. It is compact and contains little water.

The Jordan sandstone, which is next beneath the Oneota, underlies a considerable area of the county and is a strong water-bearing formation.

Below the Jordan are the St. Lawrence formation, the Dresbach sandstone and underlying shales, and the red clastic series, the latter resting upon granite. The St. Lawrence formation, characterized by considerable green sand with green shale partings, probably underlies the county throughout practically its whole extent, although it has been reached by wells in but few localities. The Dresbach sandstone and underlying shales underlie all of Anoka County and make a strong water zone. At Elk River, less than 3 miles east of this county, the red clastic series has been penetrated to a depth of 215 feet. Granite was encountered at St. Francis at the depth of 550 feet, and outcrops are found only 20 miles from the northern border of the county.

At several points in the vicinity of Centerville Lake, wells have been sunk for the city of St. Paul. Below is given the record of one of these wells which at the surface is 883 feet above sea level and ends at about 404 feet above sea level.

Section of well near Centerville Lake.[a]

	Thickness.	Depth.
Glacial drift:	*Feet.*	*Feet.*
Black muck	4	4
Blue clay	8	12
Sandy clay	30	42
"Hard pan"	10	52
Sand and gravel	72	124
Clay	10	134
St. Peter:		
Sandstone (remnant)	12	146
Shakopee:		
Magnesian limestone	33	179
New Richmond:		
Soft sand	7	186
Oneota:		
Hard magnesian limestone	127	313
Jordan:		
Sandstone	87	400
St. Lawrence:		
Green and blue shale (penetrated)	79	479

[a] Fourteenth Ann. Rept. St. Paul Board of Water Commissioners, 1895, p. 134.

At Anoka the stratigraphic section begins approximately at the horizon at which the Centerville wells end. The first formation encountered below the surface deposits, which here are 80 feet thick and consist of alluvial and outwash materials and red bowlder clay, is a 40-foot layer of soft blue shale, beneath which there is a series of harder layers, most of which are probably more indurated shales. The old well of the Minnesota Potato Starch Company is 390 feet deep and is reported to have entered a white sandstone to a depth of 30 feet. The new well owned by the same company is 420 feet deep and has penetrated this sandstone somewhat farther. The lower portion of the section revealed by these wells no doubt belongs to the Dresbach sandstone and underlying shales.

UNDERGROUND WATER CONDITIONS.

Yield of water.—Owing to the fact that a great sheet of out-wash sand and gravel lies at the surface throughout most of the county and is underlain by a bed of impervious bowlder clay, the conditions are unusually favorable for obtaining generous and permanent supplies of water at shallow depths. For larger supplies the various sandstones described above can be penetrated. The heaviest demands upon the underground water are made in the southeastern corner of the county, where on occasions millions of gallons are pumped in one day for the St. Paul public supply.

Head of the water.—In the Mississippi Valley above Anoka and also some distance below that city, as well as in the lower portion of the valley of Rum River, the water from the deeper sandstones will rise above the surface, and flowing wells can be obtained. Both of the deep wells of the Minnesota Potato Starch Company at Anoka flow at the surface. In the new well the water will rise about 20 feet above the level of Rum River, or 880 feet above sea level. This well is 8 inches in diameter, and with the top of the casing at approximately 867 feet above sea level the natural flow is about 210 gallons per minute. Advantage has not yet been taken of the artesian conditions in the vicinity of Anoka, although they have considerable potential value. More wells should be drilled into the deep sandstone, and no water should be allowed to run to waste, as this will inevitably deplete the supply and diminish the artesian pressure.

On the uplands the water from the sandstones will rise nearly to the surface, but probably no flows can be obtained. In the deep wells at Centerville the water rises virtually to the surface or 883 feet above sea level, and in the deep well of the St. Francis Potato Starch Company, at St. Francis, near the opposite corner of the county, the water also rises within a few feet of the surface.

Quality of the water.—The water from the outwash sand and gravel, as well as that from the sandstone formations, is moderately hard, but not excessively mineralized. An analysis of water from each source is given below.

SUMMARY AND ANALYSES.

Unfailing supplies for farm and domestic purposes can generally be obtained from the porous sand and gravel near the surface. Where larger supplies are required or where a source less exposed to polluting agencies is sought, drilling should be continued to the underlying sandstones. In the valleys and on some of the terraces of the Mississippi and its principal tributaries, flowing wells can be obtained from the deeper horizons, and throughout the county the water is under sufficient head to rise nearly to the surface.

The only city that has a system of waterworks is Anoka. The plant is owned by a private company and the water is taken from Rum River.

Mineral analyses of water in Anoka County.

[Parts per million.]

	1.	2.
Silica (SiO_2)	17	8.8
Iron (Fe)	1.1	1.2
Calcium (Ca)	19	65
Magnesium (Mg)	12	18
Sodium and potassium (Na+K)	12	31
Carbonate radicle (CO_3)	......	.0
Bicarbonate radicle (HCO_3)	142	264
Sulphate radicle (SO_4)	2	20
Chlorine (Cl)	1	48
Nitrate radicle (NO_3)	......	.0
Total solids	149	332

1. Spring at Itasca in outwash gravel. Analysis by C. W. Drew.
2. The new flowing well of the Minnesota Potato Starch Company at Anoka, 420 feet deep, in the Dresbach sandstone and underlying shales. Analysis made for this Survey December 9, 1907, by H. A. Whittaker, chemist Minnesota state board of health.

BIGSTONE COUNTY.

By O. E. Meinzer.

SURFACE FEATURES.

The greater part of Bigstone County consists of a nearly level upland plain about 1,100 feet above sea level, abruptly limited on the west and south by a broad, deep valley, incised to a depth of 125 to 150 feet below its surface. This valley, which is now occupied by Lake Traverse, Bigstone Lake, and Minnesota River, originated at a time when the present outlet of Red River of the North was blocked by an ice sheet and its discharge forced southward. The lakes are due to the dams that have been thrown across the valley by the small, swift streams tributary to it. The alluvial fan of Little Minnesota River forms the dam that separates Lake Traverse from Bigstone Lake, and is thus the divide between the Mississippi and Hudson Bay drainage basins. The upland plain is for the most part very poorly drained and abounds in small lakes. Immediately adjacent to the valley there are many short gulleys, but they are of such slight extent that they interrupt the regularity of the upland surface but little.

SURFACE DEPOSITS.

Description.—The glacial drift consists of bowlder clay and deposits of sand and gravel. The latter are usually interbedded with the bowlder clay, but locally lie at the surface. In the valley the drift and older formations are generally concealed beneath a thin layer of recently deposited alluvium.

Considering only the uneroded upland areas, the drift sheet is most attenuated in the southern and in the northwestern and northeastern parts of the county, where it is in many places not much over 100 feet thick, and is most developed in the central portion, where it is locally more than 300 feet thick. In the valley, for some miles south from the northern boundary of the county, older formations are virtually at the surface; and the same is true below Ortonville (Pl. II).

Yield of water.—The sand and gravel beds at various depths in the drift are generally saturated with water, which they deliver to wells at greatly differing rates. In most localities, however, there is at least one bed that will furnish enough for all ordinary purposes. In general it is more difficult to get satisfactory supplies from the drift in the northern than in the southern part of the county, apparently because there are fewer beds of coarse sand.

In the region between Odessa and Appleton, and in other sections of the county, the sand and gravel that lies at the surface yields water freely.

Head of the water.—Only one flowing well supplied from the drift has been recorded in the county. This well is on the farm of Albert Struck, a short distance northwest of Correll (NE. ¼ sec. 7, T. 121 N., R. 44 W.), and is 186 feet deep. Along the sides of the valley there are numerous springs, all of which are fed by the waters that saturate the drift. Springs of this kind furnish the public supply of Brown Valley and are largely drawn upon at Ortonville. The drainage of the drift waters toward the valley lowers the head beneath the uplands at all points near the valley border. Throughout most of the county the water in the deeper wells remains at some distance below the surface, but northward it rises increasingly near the surface, and about 10 miles beyond the county line flowing wells are obtained.

Quality of the water.—None of the water from the glacial drift is soft, and some of it is extremely hard and very highly mineralized. The analyses in the accompanying table seem to show that water from the upper portion is apt to be harder than that from the deeper beds, and also that it is generally harder in the northern than in the southern part of the county. However, the water from the sand and gravel deposits at the surface may contain only moderate amounts of mineral matter in solution.

CRETACEOUS SYSTEM.

Description.—The Cretaceous rocks consist of soft blue shale ("soapstone") and interbedded sandstone strata. A small shale outcrop occurs in the valley near the north end of Bigstone Lake (sec. 23, T. 124 N., R. 49 W.), and another has been described by N. H. Winchell on the Dakota side nearly opposite the northwestern corner of this county.[a] For some miles along the valley these shales lie near the surface, but no other exposures have yet been observed. The well sections shown in Plate VII illustrate the character of the Cretaceous rocks in this region. They have considerable thickness in the northwestern part of the county, but thin out toward the east

[a] Second Ann. Rept. Geol. and Nat. Hist. Survey Minnesota, 1873, p. 190.

and especially toward the southeast, a condition resulting in part from the irregularities of their upper surface, but chiefly from the inclination of the granitic surface upon which they rest.

Altitude of granitic surface and thickness of overlying Cretaceous rocks, Bigstone County.

Locality.	Altitude of granitic surface above sea level.	Altitude of top of Cretaceous rocks above sea level.	Thickness of Cretaceous rocks.
	Feet.	*Feet.*	*Feet.*
Brown Valley	540	980	440
Graceville	630	830	200
East of Johnson	850	900	50
Dumont	840	875	35
Ortonville	975	....	0
Appleton	950	....	0

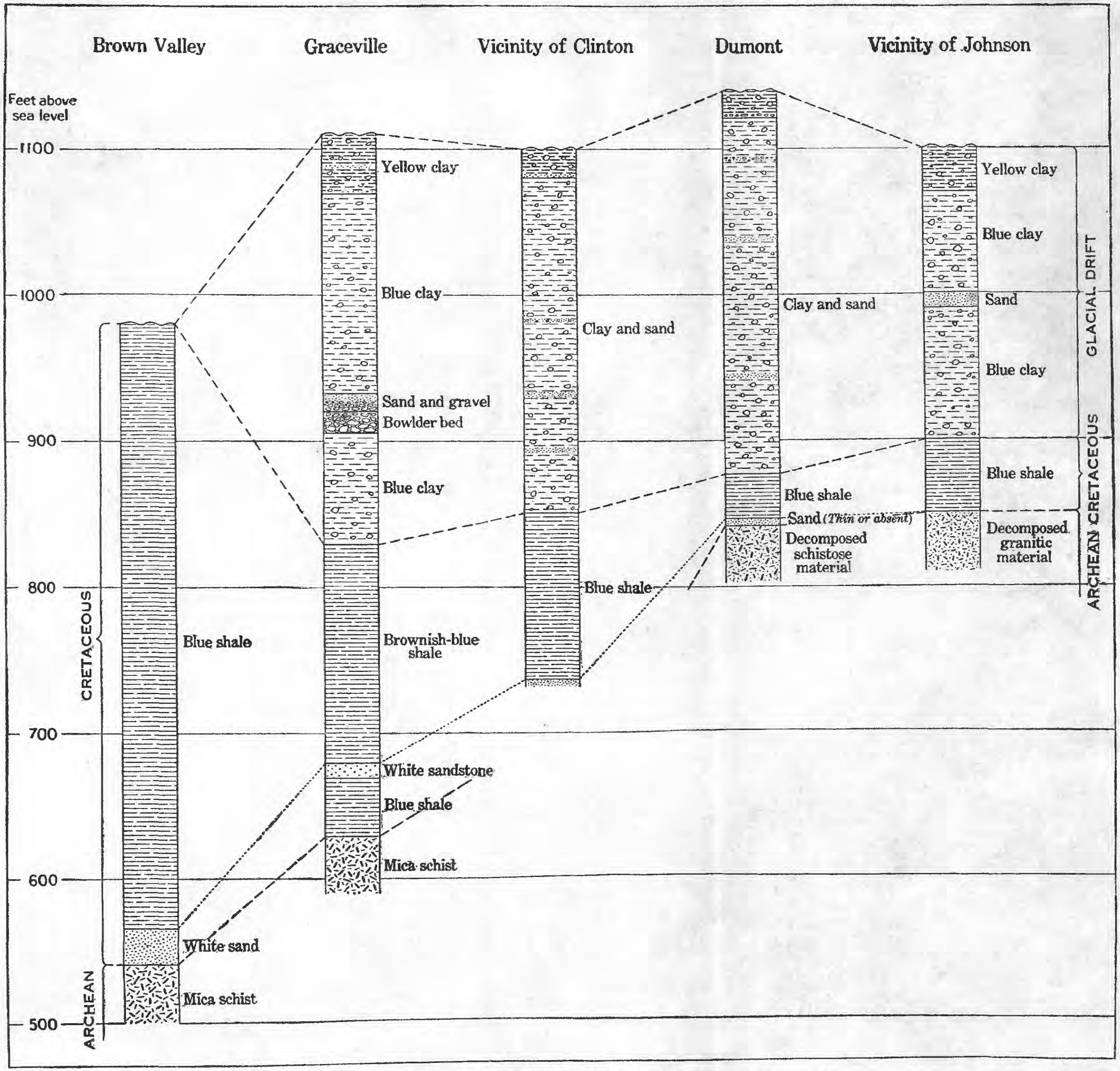
Yield of water.—Sandstone strata usually produce liberal supplies of water. An example is the new village well at Graceville, which has been pumped for 48 hours continuously at the rate of 60 gallons per minute. But in a large portion of the county, especially in the eastern and southern parts where the series is thin, there is nothing but shale, and no water-bearing beds are found.

Head of the water.—In the valley, from the northern boundary of the county for some miles southward, the Cretaceous sandstone gives rise to flowing wells. Both of the deep village wells at Brown Valley overflow at the surface, the upper of the two at 1,014 feet above sea level. There is also a flowing well 6 miles south of this village (sec. 25, T. 124 N., R. 49 W.), but it has not been determined how much farther down the valley flows could be secured. At Graceville the Cretaceous water rises to a level about 70 feet below the surface or 1,040 feet above the sea, and at Dumont, 10 miles north, it is lifted virtually to the surface, which is about 1,040 feet above sea level. In Bigstone County flowing wells can be expected only in the valley.

Quality of water.—The water from the Cretaceous rocks is soft, in which respect it is radically different from the water of more shallow sources. It is, however, very rich in alkali sulphates and chlorides. Especially is this true at Brown Valley. (See the analyses in the accompanying table and also Pl. V.)

ARCHEAN ROCKS.

The Archean system includes several types of crystalline rocks. The drillings from the wells at Brown Valley and Graceville consist of mica schist, but the rocks exposed near Ortonville are granite and gneiss. The upper portion of the system is usually greatly decomposed where it is overlain by Cretaceous strata which protected it from glacial erosion. One of the decomposition products especially conspicuous in some localities is a white kaolin. The Archean rocks are reached at different depths down to about 600 feet. They



GEOLOGIC SECTIONS IN NORTHERN BIGSTONE COUNTY.

By O. E. Meinzer.

outcrop at various points in the valley below Ortonville, but nowhere else in the county (Pl. III), and there is only a small part of the county in which they are less than 300 feet below the surface. In general they are not water bearing, but in rare instances small supplies are derived from the disintegrated upper portion.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Ortonville.—Ortonville is at the point where Bigstone Lake discharges into Minnesota River. Granite lies at no great depth below the valley level, and numerous outcrops occur a short distance from the city. The public supply is taken from a combination dug and drilled well which is about 60 feet deep, ends in a bed of gravel immediately above the granite, and yields several hundred gallons per minute. The water rises within 12 feet of the surface, or 966 feet above sea level. It is used by about 500 people and by the railway company and electric-light plant, about 65,000 gallons being consumed daily. Perhaps 75 per cent of the inhabitants depend upon private supplies. On the upland the wells are commonly dug or drilled through blue bowlder clay to a depth of about 80 feet, at which level there is a recognized layer of water-bearing sand. Many springs issue from the side of the valley, and these are utilized largely for domestic purposes.

Graceville.—The public supply at Graceville is derived from two 8-inch wells which tap the Cretaceous sand stratum about 435 feet below the surface. The stratigraphic section is shown in Plate VII. The test of one of the wells was mentioned above (p. 134). The water is soft but rich in the alkalies. An analysis is given in the table (pp. 137–138). Virtually all the people use this supply, and an average of 10,000 gallons is consumed daily. The well at the mill is 440 feet deep, ends in the same sand stratum as the village wells, and also furnishes soft water, which rises to a level 70 feet below the surface, and is yielded freely.

Beardsley.—Nearly the entire water supply for the village of Beardsley is derived from a thick bed of outwash gravel at the surface. Underlying this deposit there is glacial drift, resting, no doubt, upon a series of Cretaceous shales and sandstones, beneath which lies the granite. The section below the drift is probably similar to that given for Brown Valley. The public supply, which comes from a well 6 feet square and 40 feet deep, is only moderately hard, and is used by about two-thirds of the people, approximately 6,000 gallons being consumed daily.

Clinton.—The glacial drift is unusually thick in this locality. Water-bearing beds have been found beneath the village as follows:

1. Gravel at 120 feet. The water is hard and strongly charged with iron.

2. Blue clay with layers of fine sand between 125 and 195 feet. The fine sand and hard water will clog and encrust well screens in a short time.

3. Gravel at 195 feet. The water is less strongly charged with iron than that in the 120-foot bed. It rises to about 120 feet below the surface. The 5-inch well of J. L. Erickson, which extends to this horizon, has been tested at 25 gallons per minute.

4. Sand at 240 feet.

5. Gravel at 330 feet. This is penetrated 14 feet by the 8-inch village well, which is finished with a screen and has been pumped for six hours continuously at the rate of 80 gallons per minute. The water rises to a level about 120 feet below the surface and is only moderately hard, as is shown by the analysis given in the table (pp. 137–138).

About 80 per cent of the people use the public supply, the remainder depending for the most part upon cisterns, in which they collect rain water.

FARM WATER SUPPLIES.

The farm supplies in the county are obtained chiefly from the following sources: (1) Drilled wells, (2) bored and dug wells, (3) driven wells, and (4) springs. A large proportion of the wells at the present time are of the drilled type, ranging from 50 to more than 300 feet in depth, but commonly between 100 and 200 feet. Most of the drilled wells are 2 inches in diameter and are finished with screens that become effectually clogged in a few years, but there are also some 5-inch wells, which as a rule do not require screens.

SUMMARY AND ANALYSES.

Throughout the county the granitic rocks lie within several hundred feet of the surface, and since they are essentially nonwater-bearing and there is no water-bearing formation below them, the entire supply must be developed from the overlying formations at limited depths. The first indications that the granitic rocks have been reached in drilling are given by the decomposition products that so commonly mantle the hard rock in this region. These consist of clays of a brilliant red, yellow, or green, or frequently of a nearly white color, and may contain silvery flakes of mica or allied minerals, and angular grains of transparent quartz. Drillers can not fail to notice these striking characteristics, but they are frequently puzzled because they do not understand their meaning.

There are two distinct sources of underground water to be drawn upon in the municipal and rural developments in the county—(1) the sand and gravel beds in the glacial drift and (2) the sandstone strata beneath the shale ("soapstone"). The drift will nearly everywhere contribute supplies sufficient for ordinary purposes, but unfortunately the water is very hard. The sandstone beneath the shale yields generously in some places (as Graceville) but is absent in others (as Ortonville), and the localities in which it will prove to be a satisfactory source can be determined only by actual trial, although the chances are best in the northern and western portions of the county. The water is soft, but in some places (as Brown Valley) contains an objectionable amount of alkalies. There are three possible reasons for drilling through the drift and shale to the deeper beds of sand or sandstone—(1) to obtain a sufficiently large supply in a few localities where the yield from the drift is inadequate; (2) to obtain soft water; and (3) to obtain flows, in the valley only, for the water will not rise to the upland level.

Mineral analyses of water in Bigstone County.

[Analyses in parts per million.]

	Surface deposits (glacial drift, etc.).								
	Upper portion.						Lower portion.		
	South part of county.			North part of county.					
	1.	2.	3.	4.	5.	6.	7.	8.	9.
Depth ... feet..	22	50	96		90	50	188	190	344
Diameter of well ... inches..			6		4	(a)	4	4	8
Silica (SiO_2)				32		28			31
Iron (Fe)				.4		.8			2.6
Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)			12	6	4		4.5	7.4	
Calcium (Ca)	72	108	130	224	366	482	152	146	82
Magnesium (Mg)	53	37	72	93	293	243	116	76	36
Sodium and potassium (Na+K)	251	64	127	43	151	156	282	277	255
Carbonate radicle (CO_3)				.0		.0			.0
Bicarbonate radicle (HCO_3)	464	213	946	424	664	366	413	439	420
Sulphate radicle (SO_4)	477	320	97	650	1,749	2,143	1,065	856	502
Chlorine (Cl)	48.7	37	12	6	56	15	15	17	36
Nitrate radicle (NO_3)				5		.3			.0
Total solids	1,132	671	915	1,272	2,946	3,277	1,838	1,595	1,165

	Cretaceous.						
	Vicinity of Graceville.				Vicinity of Dumont (Traverse County).	Vicinity of Brown Valley.	
	10.	11.	12.	13.	14.	15.	16.
Depth ... feet..	440	440	530	530	304	480	520
Diameter of well ... inches..		8	8	8	2		
Silica (SiO_2)	23	10			5	19	17
Iron (Fe)					.4		
Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	8	6	13	9	4	4.4	4.5
Calcium (Ca)	18	17	17	17	25	17	17
Magnesium (Mg)	10	9	11	10	10	8	8
Sodium and potassium (Na+K)	351	321	337	341	951	1,021	1,029
Carbonate radicle (CO_3)	.0	.0			.0	.0	.0
Bicarbonate radicle (HCO_3)	527	493	566	562	478	400	400
Sulphate radicle (SO_4)	284	248	252	256	871	1,167	1,161
Chlorine (Cl)	78	65	67	68	535	490	505
Nitrate radicle (NO_3)	.0	.0			.0	.0	.0
Total solids	1,044	931	977	978	2,662	2,946	2,959

a Large.

1. Well at Ortonville. November 6, 1907.
2. "Hunter's well" at Ortonville. November 24, 1907.
3. Well at Correll. September 19, 1888.
4. Springs which furnish the public supply at Brown Valley (Traverse County). October 5, 1907.
5. Well at Graceville. October 26, 1889.
6. Village well at Dumont (Traverse County). October 5, 1907.
7. Railway well at Graceville. January 20, 1890.
8. Well at Graceville. September 21, 1895.
9. Village well at Clinton. October 3, 1907.
10. Mill well at Graceville. October 5, 1907.
11. New village well at Graceville. October 5, 1907.
12. Well at Graceville. October 24, 1895.
13. Well at Graceville. September 11, 1895.
14. Well at the hotel at Dumont (Traverse County). October 5, 1907.
15. Lower village artesian well at Brown Valley (Traverse County). October 5, 1907.
16. Upper village artesian well at Brown Valley (Traverse County). October 5, 1907.

Analyses 4, 6, 9, 10, 11, 14, 15, and 16 were made for the United States Geological Survey by H. A. Whittaker, chemist Minnesota state board of health. Analyses 1, 2, 3, 5, 7, 8, 12, and 13 were furnished by G. N Prentiss, chemist Chicago, Milwaukee and St. Paul Railway Company.

BLUE EARTH COUNTY.

By C. W. Hall and M. L. Fuller.

SURFACE FEATURES.

The surface of Blue Earth County is that of an elevated plain, the continuity of which is broken at varying intervals by narrow and rather sharp valleys of several tributaries of Minnesota River. The average elevation above sea level is somewhat less than 1,000 feet, which is considerably less than that of the counties to the east and west. The highest points are near the southeastern and southwestern corners, whence the surface slopes gradually northward to the uplands that border the Minnesota and lie about 150 feet above that river. The surface, except for the valleys mentioned, is generally rather flat, but is marked by broad shallow depressions containing lakes or marshes, and at some points near the southern border is somewhat rolling. A noticeable feature of the valleys is the series of terraces along the larger streams, especially along the Minnesota. The quarry districts north of Mankato and northwest of Minneopa Falls are located on such terraces, while Mankato itself is on a low alluvial terrace.

SURFACE DEPOSITS.

The alluvium of Blue Earth County is found along the present streams and especially in the valley of Minnesota River. The thickness varies, rock projecting through in some places, while in others wells fail to strike rock at considerable depths. Water occurs in rather large quantities, but is given up slowly, owing to the fineness of the deposit.

Terrace gravels are simply alluvial deposits of greater age than those now forming. They represent the deposits of glacial and postglacial streams flowing at levels considerably above the present river. Originally these older deposits extended entirely across the valley of the Minnesota, but later the stream cut through them, leaving only remnants. The gravels and sands are seldom more than 10 to 20 feet thick and rest upon shelves cut into the drift or older rocks. Owing to their position in the valleys, they are not important as sources of water supply.

The glacial drift is a gray, heterogeneous, pebbly clay, with intermingled masses of sand and gravel. Its thickness increases from southeast to northwest, being between 100 and 150 feet at the southeastern corner and over 200 feet at the northwestern, while in the intervening area it is between 150 and 200 feet, except beneath the stream valleys, where it varies from 25 to 125 feet. A belt of deep drift, apparently representing an old channel either of the Minnesota or one of its tributaries, extends from Mankato beyond Janesville, in Waseca County, the thickness along this tract being 50 to 100 feet greater than on either side.

The sandy and gravelly layers of the drift contain water in considerable amounts, enough being available in nearly all cases for farm and industrial supplies. The amount of sand, and consequently of available water, generally increases with the depth.

A striking and persistent feature of the drift of this and adjacent counties is the yellow layer which covers all older deposits and varies in thickness from approximately 5 to 20 feet. There is frequently present at the bottom of this oxidized zone a water-bearing bed of some economic significance for shallow supplies.

CRETACEOUS DEPOSITS (?).

Some years ago clay and fine sand, probably derived from Cretaceous deposits, were excavated near Mankato for the manufacture of fire bricks. They formed a mass of more or less broken and transported material within the glacial drift, and the original bed whence they were derived has not been found. Whether there are other Cretaceous deposits in the county, and whether those deposits are Cretaceous, are questions not yet settled.

PALEOZOIC FORMATIONS.

Blue Earth County is so deeply covered with drift that no rocks are exposed on the uplands, but along Minnesota River and the lower portions of its tributaries Paleozoic formations outcrop.

The Galena and Platteville limestones have not been definitely recognized, but from the fact that they are found in wells a short distance south of this county and also in the deep well at Waseca, 13 miles east, it is probable that they underlie the eastern edge of the county.

The St. Peter sandstone is not known to outcrop anywhere in the county, but is penetrated by wells at a number of points along the eastern border, where it is about 100 feet thick. It differs from the sands of the glacial drift in its uniformity, its great thickness, and the absence of clay partings. It affords much water for domestic and farm supplies.

The rocks of the Prairie du Chien group outcrop along Minnesota River, forming terraces marked by numerous quarries, and occur as a broad subglacial belt across the center of the county. They consist essentially of buff and pink dolomite. The presence of a sandy zone corresponding to the New Richmond sandstone is not fully established. The dolomite carries some water in joints and solution passages, especially in its weathered upper surface at the base of the drift, and in a number of wells yields water rising nearly or quite to the surface. Upon the uplands, however, the water must be lifted a considerable distance to bring it to the surface.

The Jordan sandstone lies below the alluvium of the Minnesota Valley north of Mankato, and below the drift along a belt stretching from this city to the southwestern corner of the county. It is about 75 feet thick and generally yields supplies sufficient for all purposes. However, on the uplands the water must be lifted a considerable distance.

The St. Lawrence formation consists chiefly of shale and magnesian limestone and appears to be about 200 feet thick. It outcrops in the Minnesota Valley near Judson and probably extends beneath the drift to the southwestern corner of the county. It carries little water except in occasional sandy layers and near its upper surface.

The Dresbach sandstone and underlying shales have not been seen at the surface, but they underlie the drift and the Paleozoics throughout the county. From the record of deep wells at Mankato these beds appear to include about 420 feet of material, mainly sandstone. They are saturated with water and yield large supplies to wells at Mankato, the public waterworks and several large industrial plants depending chiefly on it for their supplies.

Beneath the shales that underlie the Dresbach sandstone is a series of red sandstones, shales, and quartzites which has been penetrated nearly 1,300 feet in the Mankato well, but which affords only an insignificant amount of water compared to that yielded by the overlying formations. Beneath these red sediments is Archean granite, which is likewise virtually not water bearing.

WELL RECORDS.

Below are given three well sections, two of which extend to Archean rocks, showing a rapid rise of the latter toward the west, with a corresponding thinning of the stratified series. With such conditions the correlations are necessarily conjectural.

Section of deep well on Bunker Hill, at Mankato.[a]

	Thickness.	Depth.
Glacial drift, etc.:	*Feet.*	*Feet.*
Clay, sand, and gravel	290	290
Paleozoic and lower formations:		
Limestone, green shale, and sandstone [St. Lawrence]	205	495
Sandstone and shale [Dresbach sandstone and underlying shale]	420	915
Red sandstone and shale (entered)	1,289	2,204

[a] Upham, Warren, Final Rept. Geol. and Nat. Hist. Survey Minnesota, vol. 1, 1882, pp. 422-424. The correlations are not by Mr. Upham.

Section of well at Minneopa Falls.

	Thickness.	Depth.
Glacial drift, etc.:	*Feet.*	*Feet.*
Soil, sand, gravel, and weathered limestone	100	100
Paleozoic and lower formations:		
Blue shale	10	110
White sandstone (Jordan?)	35	145
"Red claylike stone"	20	165
"Blue slate, white when dry"	100	265
Pink sand	10	275
White sand (Dresbach?)	100	375
Red quartzite, conglomerate, etc	200	575
Dark-gray quartzose sandstone or conglomerate, with some red shale	60	635
Crystalline rocks (Archean)	365	1,000

Section of village well at Lake Crystal.

	Thickness.	Depth.
	Feet.	*Feet.*
Glacial drift	145	145
Paleozoic and lower formations:		
Sandstone (lower part of Jordan?)	40	185
Limestone and shale (St. Lawrence)	140	325
Limestone, shale, and white sandstone (Dresbach sandstone and underlying shale)	324	649
Red clastic series	50	699
Granite (entered)	20	719

FLOWING WELLS.

In the lower areas of the county there are many flowing wells, some of which are supplied from Paleozoic formations, but the majority of which end in the drift at depths of 50 to 100 feet. A chain of these wells extends along Blue Earth River from the Faribault County border to its confluence with the Minnesota, and others are located along Watonwan, Maple, Little Cobb, and Lesueur rivers, but none are obtained on the upland prairie.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Mankato.—Within the city of Mankato is to be found a wide range of well conditions. Some supplies are obtained from the drift, others from the successive sandstones and limestones, and many from the alluvium lying along the flood plain of Minnesota River. A large number of artesian wells have been drilled. For a time all of them yielded generously, but in recent years they have shown signs of decrease in flow, this tendency being greatest in the wells that furnish water with high iron content. When hard deposits, such as iron crusts, travertine layers, etc., form in the well, shooting with dynamite will frequently give relief. The observations made upon the data collected at Mankato seem to indicate that more attention can be given with profit to the shallower Paleozoic sources. While the water from these has a lower head, it seems to be somewhat softer than that in the deeper beds.

The public supply is obtained from four flowing wells 650 feet deep. About two-thirds of the population use this water, and an average daily consumption of 783,000 gallons is reported.

Lake Crystal.—The public supply at Lake Crystal is derived from a well 719 feet in depth, the log of which is given on page 141. Shallow wells furnish the supply for a large part of the population, although there are several deeper wells also ending in glacial drift.

Mapleton.—The public supply of Mapleton village, which is used by virtually all of the people, is drawn from a 4-inch well 224 feet deep, in which the water rises to about 30 feet below the surface. The deeper wells enter a sandstone which is probably the St. Peter. Patches of limestone have been found overlying the sandstone, indicating that the Galena or the Platteville limestone is present in some localities but not in others.

Good Thunder.—The public supply at Good Thunder is taken from a well that is 374 feet deep and ends in sandstone. Most of the people use private wells.

Amboy.—In Amboy village the public supply is derived from a 6-inch well that extends to a depth of 486 feet and taps a standstone which is probably the Jordan. Fully two-thirds of the people use water from private wells.

Vernon Center.—The waterworks are supplied from a well 147 feet deep. The public water is not extensively used.

SUMMARY AND ANALYSES.

For ordinary purposes the glacial drift usually affords adequate supplies, but, except possibly in the northwestern portion of the county, the deep-lying sandstones will yield still more generously. The three well sections given above show the stratigraphic succession. Although flows are commonly obtained in the valleys from both the drift and the sandstones, they can not be secured on the upland prairie from either source.

Mineral analyses of water in Blue Earth County.

[Analyses in parts per million.]

	St. Peter sandstone.	Jordan sandstone.	Dresbach sandstone and underlying shales.		
	1.	2.	3.	4.	5.
Depth ... feet..	225	486	650	650	650?
Silica (SiO_2)	17	22	9	6	65
Calcium (Ca)	152	170	111	79	126
Magnesium (Mg)	46	58	38	35	52
Sodium and potassium (Na+K)	78	85	64	44	25
Bicarbonate radicle (HCO_3)	464	455	461	417	380
Sulphate radicle (SO_4)	310	470	174	85	233
Chlorine (Cl)	4	14	8	4.8	20
Total solids	855	1,037	635	459	654

1. Village well at Mapleton. November 15, 1906.
2. Village well at Amboy. November 14, 1906.
3. Well at the Hubbard Mills, No. 1, in Mankato, 1889.
4. City wells at Mankato.
5. Well at the flouring mill in Mankato.

Analyses 1 and 2 were made for the United States Geological Survey by Prof. W. S. Hendrixson. Analysis 4 was furnished by G. M. Davidson, chemist Chicago and Northwestern Railway Company. Analysis 5 was made by the Kennicott Company.

BROWN COUNTY.

By O. E. Meinzer.

SURFACE FEATURES.

The surface of Brown County is a nearly level plain, most of which lies between 1,000 and 1,100 feet above sea level. The southwestern corner, however, is higher and has a more irregular topography, probably being part of the moraine that can be traced northwestward across Yellow Medicine County and in the opposite direction through Martin County into Iowa.[a] The northeastern boundary is formed by Minnesota River, which occupies a valley 150 to 200 feet deep. Big Cottonwood and Little Cottonwood rivers flow eastward across the county through shallow trenches until they approach the Minnesota, where their grade increases and their valleys are deep and gorgelike. In other words, these valleys are not in topographic adjustment with that of the Minnesota. The latter was excavated rapidly at the close of the last glacial epoch by the abundant waters issuing from the melting ice, while the former are still flowing on the surface of the upland throughout the greater part of their course. The wide interstream areas have only a very imperfect and sluggish drainage, and contain numerous swamps, ponds, and lakes. Near the Minnesota Valley the upland is dissected by many deep valleys, which do not, however, exceed a few miles in length.

[a] Upham, Warren, Final Rept. Geol. and Nat. Hist. Survey Minnesota, vol. 1, 1882, p. 581.

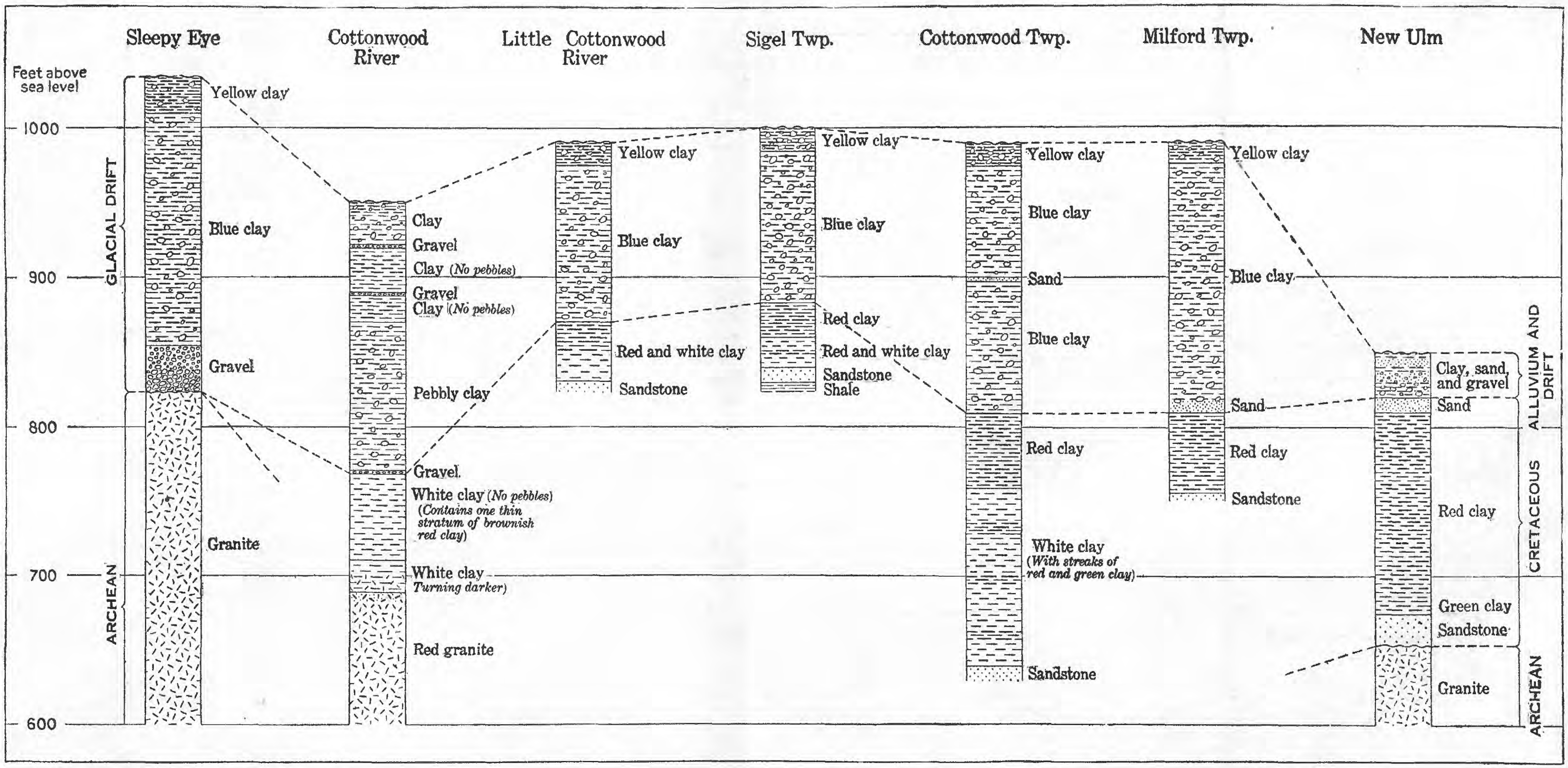
SURFACE DEPOSITS.

Description.—The surface deposits include recent alluvium and glacial drift. The former is found only in the valleys of Minnesota River and its tributaries, and is not important; the latter is present everywhere except in small tracts in the valleys of Minnesota and Cottonwood rivers, and in a few other localities where underlying formations are exposed. The entire drift mantle has frequently been pierced in drilling wells. Throughout most of the county it is between 100 and 200 feet thick, but over a restricted section in the eastern part it has a somewhat greater thickness, while in the southwestern corner, where the quartzite occurs, and in the valleys of Minnesota and Cottonwood rivers, where postglacial erosion has taken place, it is generally thinner. The drift consists of unassorted bowlder clay with interbedded deposits of sand and gravel, which are roughly assorted and stratified and comprise the pervious, water-bearing members. Porous, gravelly beds also frequently lie at the base of the drift, and in the southeastern part of the county these attain a remarkable thickness, as is shown by the section of the mill well at Hanska given in Plate XVI.

Yield, head, and quality of the water.—The sand and gravel which occurs in the drift or at its base usually yields generous supplies of water. In most of the county the water rises within 50 feet of the surface, but in the deeper wells on the upland prairie near Minnesota River it frequently remains at depths of 100 to 200 feet. Especially is this true in the vicinity of New Ulm. In the valley of Cottonwood River at Springfield there is a small area of flowing wells that are about 30 feet deep and end in a bed of sand beneath a layer of clay. These wells have a head of only a few feet and flow several gallons per minute each. Along the Minnesota and its tributaries there are many springs, one of the largest of which is the "Big Spring," in the Golden Gate vicinity. The water derived from the drift has invariably been found to be hard but otherwise good. (See the analyses in the accompanying table, p. 148.)

CRETACEOUS DEPOSITS.

Description.—Between the drift and the older indurated formations, there is a series of beds consisting of layers of clay, shale, marl, sand, sandstone, lignite, etc. The sandstone is generally white, while the clays and shales have various colors but are predominantly red. The fossil leaves, the oxidized condition of the clay, the marked cross-bedding, the lack of continuity of the strata, and the presence of lignite, all indicate that these are either nonmarine or littoral deposits. The fossil leaves determined by Leo Lesquereux and James Hall seem to correlate them with the Dakota sandstone of the



GEOLOGIC SECTIONS IN BROWN COUNTY.

By O. E. Meinzer.

Sleepy Eye.—Generalized section from field notes of M. L. Fuller.

Cottonwood River.—Well 3 miles southeast of Sleepy Eye, on bank of Cottonwood River. Reported by N. H. Winchell in Fourteenth Ann. Rept. Geol. and Nat. Hist. Survey Minnesota, 1885, p. 15, on authority of C. M. Phelps, who drilled the well.

Little Cottonwood River.—Well on farm of George Helget, NE. ¼ sec. 36, T. 109 N., R. 32 W.

Sigel Township.—Well on farm of J. Zimmerman, SE. ¼ sec. 19, T. 109 N., R. 31 W.

Cottonwood Township.—Well on farm of George Haas, SE. ¼ sec. 6, T. 109 N., R. 30 W.; approximate.

Milford Township.—Well on farm of J. M. Haubrick, SW. ¼ sec. 24, T. 110 N., R. 31 W. This section and the three preceding are given on the authority of Fred. Hamann, driller, New Ulm.

New Ulm.—City wells on a terrace about 45 feet above the river. Authority, Charles Stoll and others.

The altitudes for all except the first and last sections are only approximately known.

Upper Cretaceous.[a] They are exposed in the Minnesota Valley at New Ulm and for several miles below that city, and also at various points in the valley of Cottonwood River. They have been penetrated in numerous wells south of the Cottonwood and in the vicinity of New Ulm (Pl. VIII). From the data at hand it may be said that the Cretaceous deposits range up to at least 200 feet in thickness, and that they are present throughout most of the southern section of the county except in the southwestern corner, where the quartzite is near the surface. At Sleepy Eye and in much of the northern part they appear to be absent, but in this county they may so far resemble the drift that it is difficult to differentiate them in well sections. The red, green, and white clays or shales, the white sandstones, and the layers of lignite are at once recognized as Cretaceous, but it is probable that the blue and yellow clays and the sand and gravel which are referred to the drift are in fact partly Cretaceous. If this is true, the thickness of the drift is not everywhere so great as is supposed and a thin layer of Cretaceous material may exist beneath the drift in localities where it has not been recognized as such.

Yield of water.—Where Cretaceous sandstones are found they will produce large quantities of water. The three city wells at New Ulm are together pumped at the rate of 350 gallons per minute, and all the Cretaceous farm wells that were reported yield ample supplies.

Head of the water.—The water from the sandstones has about the same head as that from the drift. As far as is known, there is no place in the county where they will produce flowing wells. At New Ulm, on the first terrace, the water rises to 75 feet below the surface, which is about 30 feet below the level of the river, or 765 feet above the sea. Near the river it will therefore stand about 200 feet below the level of the upland prairie. According to report, when the first well was sunk into the Cretaceous sandstone at New Ulm, nearly twenty years ago, the water rose 35 feet higher than it does at present.

Quality of the water.—Although the sandstone water is not soft, it is generally considered less hard than that from the drift, and it stands in marked contrast to the extremely hard water found in Watonwan County in the formations that lie below the drift and are supposed to be Cretaceous. It contains considerable quantities of sodium chloride, as is shown by analyses 5 and 6 in the accompanying table (p. 148).

PALEOZOIC FORMATIONS.

It is probable that remnants of the white Dresbach sandstone and underlying shale exist in the southeastern corner of the county, and they may have been penetrated in the mill well at Hanska. (See

[a] U. S. Geol. and Geog. Survey Terr., vol. 6, pp. 6, 68, 76, 90, 93. Final Rept. Geol. and Nat. Hist. Survey Minnesota, vol. 1, 1882, pp. 98, 574, 576.

Pl. XVI and also the reports on Blue Earth and Watonwan counties.) Wherever these formations are present they yield copiously.

SIOUX QUARTZITE.

Bodies of Sioux quartzite are known in several localities in the southwestern corner of this county, and in Nicollet County in the vicinity of New Ulm. The former, which is a part of the large quartzite area to the southwest, has several outcrops; the latter, which belongs to the smaller Courtland area, comes to the surface only in Nicollet County, opposite New Ulm. It is not known whether this rock is continuous between the two areas. It may exist at considerable depths in the south-central and southeastern parts of the county, but at Sleepy Eye and throughout the northern portion generally it is known to be absent. It contains only small quantities of water, of no economic value except in the southwestern corner, where no other supply is available.

ARCHEAN ROCKS.

Granitic rocks are exposed at various points in the Minnesota Valley on both sides of the river and are encountered at Sleepy Eye at a depth of about 200 feet (Pl. III). In much of the northern part of the county the granitic surface probably lies directly under the drift, but southward from Sleepy Eye and New Ulm it slopes down and disappears below the Cretaceous, Paleozoic, and Algonkian sediments. These rocks, which extend to an indefinite depth, will yield little or no water.

WATER SUPPLIES FOR CITIES AND VILLAGES.

New Ulm.—The city of New Ulm is situated upon several terraces on the west side of Minnesota River. The Cretaceous formations are exposed in the city, but on the undissected upland are covered by a thick mantle of glacial drift. At the pumping station of the city waterworks granite occurs at a depth of about 200 feet, but on the east side of the river both the quartzite and the granite come to the surface. The main water-bearing bed is a 20-foot stratum of sandstone at the base of the Cretaceous, about 150 feet below the river level. The public supply is taken from three wells about 195 feet deep, which tap this sandstone. The head and yield of these wells have already been given (p. 145). The water, an analysis of which will be found in the accompanying table (p. 148), is used by about 3,400 people, and on an average about 80,000 gallons is consumed daily. Perhaps 40 per cent of the inhabitants depend upon private wells, which can be classified into two groups—(1) shallow dug wells ending in sand and gravel and generally supplying considerable water, and (2) drilled wells extending to the sandstone and yielding liberally. The Chicago and Northwestern Railway Company and several of the breweries are supplied from wells belonging to the second group. An analysis of the water from the railway well is given in the table (p. 148).

Sleepy Eye.—The stratigraphic section for this locality is shown in Plate VIII. The public supply is obtained from two wells, one of which is 4½ inches in diameter and 180 feet deep and has been tested at 40 gallons per minute, and the other 4 inches in diameter and 222 feet deep and has been tested at 100 gallons per minute. The water is reported to rise to a level between 45 and 60 feet below the surface, or between 975 and 990 feet above the sea. It is used by about 400 people, approximately 29,000 gallons being consumed daily. The private wells for domestic supplies are generally between 15 and 75 feet in depth, but a few domestic wells and the wells which supply the Chicago and Northwestern Railway Company, the Sleepy Eye flouring mill, the electric-light plant, and several other industrial concerns extend to the 200-foot bed. The maximum test reported for any well entering this bed is 185 gallons a minute. The water is hard, as is shown by the analyses in the table.

Springfield.—The village of Springfield lies on the banks of Cottonwood River. The business portion is in the valley, while most of the dwellings are on the terraces and the upland. On the first terrace, which is only 5 or 10 feet above the flood plain, flows are obtained from a layer of sand about 30 feet below the surface. The uplands are underlain by glacial drift, but Cretaceous outcrops are found in the valley near the village. The people are at present dependent on private supplies. There are four types of wells—dug, driven, bored, and drilled. The dug wells are generally between 10 and 20 feet deep; the driven, between 10 and 35 feet; the bored, between 30 and 100 feet; and the drilled, between 100 and 150 feet. The dug and driven wells are chiefly in the valley and on the first terrace, where an abundance of water can be obtained from the alluvial deposits at shallow depths, while the drilled wells are on the upland. For boiler purposes water from the river is chiefly used. The public waterworks were formerly supplied from two wells, 4 inches in diameter and 36 feet in depth, but are now reported to be supplied from springs. The water is pumped into an elevated tank and thence distributed through the mains by gravity pressure to about twenty-five taps. The average daily consumption is estimated at 30,000 gallons.

Comfrey.—The village of Comfrey has a system of public waterworks supplied from a well which is 8 inches in diameter and 140 feet deep, but the people generally use water from private wells.

FARM WATER SUPPLIES.

There are two principal types of farm wells in the county—(1) bored and dug wells and (2) drilled and driven wells. In the western part of the county the former predominate, while in the eastern the latter are more numerous; but everywhere the drilled wells are gradually supplanting the dug and bored ones. Some of the latter stop in the surficial zone of yellow clay, but many extend into the blue bowlder clay and penetrate seams of sand and gravel at depths of 50 to 100 feet. The drilled wells extend to the deeper, gravelly portions of the drift, or, less frequently, enter the Cretaceous strata. They range from about 100 to 350 feet in depth, but seldom exceed 225 feet. The 2-inch wells that end in sand must be provided with screens, but screens are not generally necessary in wells of larger diameter, nor in wells that penetrate sandstone, even though their diameter is small. As elsewhere in southwestern Minnesota, the screens cause considerable annoyance by becoming incrusted with mineral substances deposited by the water.

SUMMARY AND ANALYSES.

Except in the southeastern part of the county, either the quartzite or the granite lies relatively near the surface. The quartzite contains small stores of water, but should not be penetrated except in the southwestern corner, where no other supplies can be obtained. The granite is not water bearing, and drilling should therefore not be continued when it is encountered. The beds of gravel, sand, and sandstone, in the formations above the quartzite or granite, generally contain supplies sufficient for all ordinary purposes. No flows are to be expected except in small and unimportant areas, such as the one at Springfield. The water is generally hard, but averages somewhat softer in the sandstone than in the sand and gravel nearer the surface.

Mineral analyses of water in Brown County.

[Analyses in parts per million.]

	Springs.	Surface deposits (glacial drift, etc.).			Cretaceous.	
	1.	2.	3.	4.	5.	6.
Depth ... feet	...	190	215	216	195	210
Diameter of well ... inches	...	...	...	4	6 and 8	8
Silica (SiO_2)	17	28	28	28	9	10
Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	...	2.2	2.1	...	2	.8
Calcium (Ca)	89	149	223	150	77	71
Magnesium (Mg)	40	59	87	60	33	36
Sodium and potassium (Na+K)	35	61	82	47	163	144
Carbonate radicle (CO_3)	...	...	...	...	.0	...
Bicarbonate radicle (HCO_3)	472	743	565	606	288	270
Sulphate radicle (SO_4)	26	123	589	208	223	257
Chlorine (Cl)	34	5	10	7	131	104
Nitrate radicle (NO_3)	...	...	...	...	.7	...
Total solids	473	793	1,300	798	789	756

1. Springs at New Ulm. February 5, 1890.
2. Well at the roller mill in Sleepy Eye. July 1, 1889.
3. "City well" at Sleepy Eye. March 17, 1900.
4. Well at Sleepy Eye. July, 1890.
5. City wells at New Ulm. August 16, 1907.
6. Depot well at New Ulm. April 30, 1892.

Analysis 5 was made for the United States Geological Survey by H. A. Whittaker, chemist Minnesota state board of health; the others were furnished by G. M. Davidson, chemist Chicago and Northwestern Railway Company.

CARVER COUNTY.

By C. W. HALL and M. L. FULLER.

SURFACE FEATURES.

In the northeastern part of Carver County there is an area of rough topography, whence the surface stretches off toward the southwest into a broad level area. On the southeast the county is bounded by the deep, wide Minnesota Valley, near which the upland is considerably dissected.

SURFACE DEPOSITS.

The glacial drift is in general between 200 and 300 feet thick and yields satisfactory supplies of water from its gravelly beds.

Upon the uplands stretching out from the morainic region of Hennepin County and the northeastern part of Carver County lies a broad expanse of outwash gravels, sands, and clays, reaching quite across the county toward the south and west.

Extensive deposits of clays, which appear at Chaska and Carver, indicate an interesting lake stage in the history of Minnesota River near the close of glacial times.

An unusual development of the terrace gravels is seen along the course of the Minnesota where it forms the boundary of the county. This gravel zone locally narrows to a few hundred feet, but is generally 2 miles or more. Water is found in it in considerable quantities, except near the edges of the terraces. Recently deposited alluvium occurs in the Minnesota Valley and along several of the smaller streams, but is not important.

ROCK FORMATIONS.

Although the Cretaceous has never been found in this county it is possible that it will be discovered in future well drillings. The uppermost Palezoic formation present is probably the Oneota dolomite, which has been found in the neighborhood of Lake Minnesota and at Eden Prairie, in Hennepin County, and also in adjacent parts of Scott County. The first formation yet disclosed in the well drillings recorded from Carver County is the Jordan sandstone, which is present in the eastern part and has a thickness, where not eroded, of about 115 feet. It carries an abundance of water and is a valuable source of supply.

The St. Lawrence formation, although usually containing much shale, in this county consists to a considerable extent of a yellow to red magnesian limestone. According to well records available, it is as much as 185 feet thick. It is not seen at the surface within this county, but St. Lawrence Township, in Scott County, on the opposite side of Minnesota River, is the type locality of the formation.[a]

[a] Second Ann. Rept. Geol. and Nat. Hist. Survey of Minnesota, 1873, p. 150.

Though it is saturated with water, it is so compact that it is not important as a water-bearing formation.

The Dresbach sandstone and underlying shale were penetrated in the deep well at Chaska, where the drill apparently entered them a distance of 215 feet and reached an abundant supply of water under artesian pressure. It is probable that in the western part of the county the St. Lawrence and Jordan formations are both absent and that the Dresbach sandstone lies immediately below the drift.

The section of the deep well at Glencoe to the west (given in the report on McLeod County) and the sections of wells to the north and south make it reasonably certain that water-bearing sandstones are present throughout this county.

The following two well sections also give valuable information on this important point:

Section of city well at Chaska, on the flood plain of Minnesota River.

[Authority, the mayor of Chaska.]

	Thickness.	Depth.
	Feet.	*Feet.*
Brick clay	150	150
"Hardpan"	50	200
White sandstone [Jordan?]	80	280
Shale [St. Lawrence?]	185	465
White and red sandstone	200	665
Shale	15	680

Section of railway well at Hamburg.

[Authority, chemist Minneapolis and St. Louis Railroad.]

	Thickness.	Depth.
	Feet.	*Feet.*
Surface soil	1	1
Yellow clay	7	8
Blue clay	67	75
"Hardpan"	44	119
Soft yellow clay	6	125
"Hardpan"	78	203
Water-bearing sand	6	209
White sandstone	35	244

HEAD OF THE WATER.

On the uplands the water in the surficial sand and gravel stands very near the surface, while that from the deeper horizons, although under considerable pressure, remains some distance below the surface. In the Minnesota Valley, along the southeastern border of the county, however, the water from the deeper formations rises above the surface, good flowing wells being obtained at Chaska and Carver. In the abandoned railway well at Hamburg the water stood 90 feet below the surface, or about 910 feet above sea level; in the city well at Chaska it is reported to rise 30 feet above the surface, or about 780 feet above sea level.

TABLE OF ANALYSES.

In the following table, analysis 3 was furnished by the chemist of the Minneapolis and St. Louis Railroad; the others by G. N. Prentiss, chemist, Chicago, Milwaukee and St. Paul Railway Company:

Mineral analyses of water in Carver County.

[Analyses in parts per million.]

	Glacial drift.		Oneota(?) dolomite.	Jordan sandstone.	
	1.	2.	3.[a]	4.	5.
Depth ....feet..	100	233	....	491	400
Calcium (Ca)	150	145	147	69	145
Magnesium (Mg)	53	50	....	32	52
Sodium and potassium (Na+K)	20	51	2	9.7	44
Bicarbonate radicle (HCO_3)	482	625	416	387	600
Sulphate radicle (SO_4)	228	152	22	6.6	169
Chlorine (Cl)	2.7	1.9	3	2.1	2.8
Total solids	695	712	....	310	707

[a] Spring.

1. Well at Chanhassen. November 22, 1897.
2. Well at Cologne. November 15, 1894.
3. Spring at Carver, owned by the Minneapolis and St. Louis Railroad Company. 1892.
4. Well at Chanhassen. August 14, 1902.
5. Well at Cologne. August 4, 1902.

CHIPPEWA COUNTY.

By O. E. Meinzer.

SURFACE FEATURES.

Chippewa is a typical prairie county, with very imperfect drainage and numerous lakes and ponds. Minnesota River, which here occupies a valley 1 to 2 miles wide and 100 to 150 feet deep, forms the southwestern boundary. Its principal affluents in this county are Chippewa River and Hawk Creek, two streams which have cut rather deep trenches into the upland but have developed only short tributaries and hence have left the extensive interstream areas quite unaffected by erosion.

There are several interesting deserted river channels associated with the Minnesota Valley. One of these starts from the bend of Pomme de Terre River, east of Appleton, and extends southeastward to the vicinity of Watson, where it joins the valley of Chippewa River, which has an unusual width from this point to where it opens into the Minnesota Valley at Montevideo. This deserted channel is also connected with the Minnesota Valley by a channel north of Milan and another more prominent one midway between Milan and Watson.[a]

[a] Upham, Warren, Final Rept. Geol. and Nat. Hist. Survey Minnesota, vol. 2, 1885, p. 208.

SURFACE DEPOSITS.

Description.—The glacial drift forms a continuous cover for the entire county except in a number of small areas near Minnesota River where the granite has been exposed by stream erosion. Its average thickness is 200 feet or somewhat less. On the upland bordering the Minnesota Valley it is about 150 feet, but it increases gradually toward the northeast. However, on account of irregularities in the surface upon which the drift rests, the thickness varies considerably within short distances.

Yield of water.—The glacial drift is the only source of water that can be relied on. Where it is thick enough it usually includes one or more sand and gravel seams saturated with water and capable of providing supplies adequate for ordinary purposes; but where it is thin it is likely to be devoid of any satisfactory water-bearing bed, as at Montevideo and in other localities.

Head of the water.—The water from the drift nearly everywhere rises close to the surface. Flowing wells with slight pressure are found in the valley of Chippewa River north of Watson, and one or two are reported in the village of Milan. It is probable that they can be secured in other low tracts, but there is no important flowing area.

Quality of the water.—The reports on Swift, Kandiyohi, and Renville counties show that in this region the water from the upper portion of the drift includes large quantities of calcium and sulphates, while that from the lower portion generally contains less calcium and relatively small quantities of sulphates. The shallow water is therefore harder than that from deeper sources and is poorer for boiler purposes. What is true in the adjoining counties is probably also true in this county, although no specific data were obtained.

CRETACEOUS DEPOSITS.

The Cretaceous deposits consist of soft, blue shale ("soapstone") and thin strata of sand. They have been encountered in several wells in this county and are found in all the counties bordering on Chippewa. Their total thickness is nowhere great, perhaps rarely 100 feet, while in the vicinity of Montevideo and Granite Falls, and in other localities, they are known to be absent. When the Cretaceous shale is reached in drilling there is little probability of obtaining water, but in rare instances a satisfactory water-bearing bed of sand is discovered below the shale. The typical Cretaceous water is soft, but contains large quantities of alkali and of sulphates and chlorine. (See the reports on Bigstone, Lac qui Parle, and Yellow Medicine counties.) There is probably no Cretaceous water in this county that has not been mixed with water from the drift.

ARCHEAN ROCKS.

The granitic rocks are exposed in a number of places near Minnesota River (Pl. III) and underlie this entire county at depths which at few if any points exceed 500 feet. On the uplands near Granite Falls granite was struck at a depth of about 200 feet; in the vicinity of Montevideo, at about 130 feet; and in the village of Milan, at about 200 feet. In the northeast it is more deeply buried, but from the available data it appears improbable that it lies very far below the surface anywhere within this county.

As in other sections of southwestern Minnesota, the upper part of the granite is generally much decomposed, and in many places is overlain by white clay. At the stock yards in Montevideo this clay is reported to have been penetrated to a depth of 70 feet. It is without doubt a product of the granitic rock, but its thickness in some localities, its freedom from grit in many places, and the fact that it includes some interbedded layers of sand, all indicate that in part it has been transported and redeposited by water; in other words, it is a sedimentary deposit rather than a granitic residuum. If, as is probable, the sedimentation took place when the Cretaceous seas invaded the region, the white clay is in part a sort of basal Cretaceous formation. When the white clay or ordinary granitic residuum is encountered there is little probability of securing water, though successful wells are occasionally finished in these materials. After the solid granite has been entered there is virtually no hope of getting water.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Montevideo.—The granite lies near the surface and in many places is covered by a layer of white clay. The glacial drift is thin, but is virtually the only water-bearing formation, there being no deep or strong water zone. No soft water is available, but the analyses given in the table show a considerable variation in hardness.

The public supply is secured from springs about 1 mile north of the village, whence the water is conducted by gravity to the pumping station. In 1907 the springs yielded about half a million gallons per day, only about one-fifth of which was utilized. In view of the meager ground-water resources of the village, these springs must be considered invaluable. About two-thirds of the people use water from private wells, which are either bored or dug and end in sand or yellow clay at depths of about 20 to 30 feet. The yield of these wells is small and is easily affected by drought.

Milan.—In the village of Milan the granitic rocks are about 200 feet below the surface, and are overlain by a thin bed of shale. The water supply is derived from the glacial drift, chiefly from wells ranging between 20 and 60 feet in depth. The public supply, which is not yet extensively used, comes from a well 9 feet in diameter and 25 feet in depth.

Maynard.—All the people in this settlement use water from private wells, the public waterworks being maintained almost exclusively for fire protection.

FARM WATER SUPPLIES.

There are two principal types of farm wells, bored and drilled. The former, which are shallow and do not always yield adequate supplies in dry years, are gradually being replaced by drilled wells. The latter do not average much over 100 feet in depth. The 2-inch wells require screens, but the wells of larger diameter are finished successfully with open ends. Since the screens are liable to become clogged in the course of a few years, their use should be avoided wherever possible, and for this reason 6-inch wells are recommended for farm purposes.

SUMMARY AND ANALYSES.

In all sections of the county the granitic rocks lie within a few hundred feet of the surface. Since granite will not yield water and there is no water-bearing formation below it, deep drilling should not be undertaken. In rare instances small supplies are found after the shale ("soapstone"), the white clay, or the ordinary decomposed granite are reached, but the glacial drift is the only reliable source of water.

Analyses of water from the upper and lower portions of the drift at Benson, Willmar, Grove City, Renville, Olivia, Bird Island, Hector, and other places east of Chippewa County show that the water from the lower portion has much less permanent hardness than that from the upper. Since the same is probably true in the parts of Chippewa County where the drift has considerable thickness, drilling to the deeper drift horizons is recommended. Near the Minnesota Valley, where the drift is relatively thin, the beds containing the softer water are likely to be absent.

Mineral analyses of water in Chippewa County.

[Analyses in parts per million.]

	1.	2.	3.	4.
Depth .... feet	....	60	75	91
Calcium (Ca)	146	100	201	32
Magnesium (Mg)	43	32	67	19
Sodium and potassium (Na+K)	37	42	195	190
Bicarbonate radicle (HCO_3)	439	464	651	663
Sulphate radicle (SO_4)	241	5	99	....
Chlorine (Cl)	7	8	399	19
Total solids	689	461	1,281	588

1. Springs north of Montevideo, used for public supply. November 23, 1907.
2. "Casgreve's well" at Montevideo. November 23, 1907.
3. "Clark's well" at Montevideo. November 23, 1907.
4. Railway well at Milan. December 2, 1897.

The above analyses were furnished by G. N. Prentiss, chemist Chicago, Milwaukee and St. Paul Railway Company.

COTTONWOOD COUNTY.

By O. E. Meinzer.

SURFACE FEATURES.

The prevailing topography of Cottonwood County is that of a nearly level and poorly drained prairie. But this topography is modified in the north by a ridge of quartzite and in the south and west by a morainic belt.

The eastern portion of the quartzite ridge rises from 1,300 to 1,500 feet above sea level and stands prominently above the surrounding country, especially above the region to the north. Westward it becomes wider but less conspicuous as a physiographic feature. Its trend is shown in Plate IV. Mound Creek, Little Cottonwood River, and one of the branches of Watonwan River all flow across this ridge and have cut little canyons into it.

The morainic belt forks at Windom, one arm extending to the north, and the other to the northwest in the direction of Westbrook and Currie. The Blue Mounds constitute the most prominent portion of the moraine, and reach an altitude of about 1,500 feet above the sea.[a]

Cottonwood County is drained northward into Cottonwood River, eastward into the Watonwan, and southward into the Des Moines. The last-named stream flows through the southwestern part, following a peculiar course. It enters from Murray County, running southeastward apparently along the trend of an ancient valley in which Lake Shetek and Heron Lake now lie. Where it reaches the Jackson County line it turns abruptly and flows northeastward for 8 or 9 miles, where it meets a valley from the north and again turns toward the southeast. It occupies a valley that has been cut considerably below the upland surface.

SURFACE DEPOSITS.

Description.—The glacial drift forms a nearly continuous cover for the older formations, being interrupted only in the small areas where the Sioux quartzite comes to the surface. A general conception of its thickness can be acquired from Plate II and from the ensuing discussion of the Cretaceous and Algonkian. Over an extended region in the central, east-central, and northeastern parts of the county it has an average thickness of less than 100 feet, and in many localities of less than 50 feet; but in the southern, western, and extreme northern parts its thickness ranges from 200 to more than 300 feet. In drilling the city well at Windom the drift was found to be 250 feet deep, and in a number of other wells in this

[a] Upham, Warren, Final Rept. Geol. and Nat. Hist. Survey Minnesota, vol. 1, 1882, p. 491 et seq.

vicinity between 250 and 300 feet. Near the western margin of the county the entire drift sheet has seldom been penetrated.

Yield of water.—Where the drift is thick it usually includes layers of sand or gravel that afford sufficient water for farm purposes and also for ordinary industrial and public supplies; but in the central and eastern parts, where it is thin, it is frequently found to be devoid of any bed that will yield much water. The alluvium of the Des Moines Valley yields abundantly from very shallow depths.

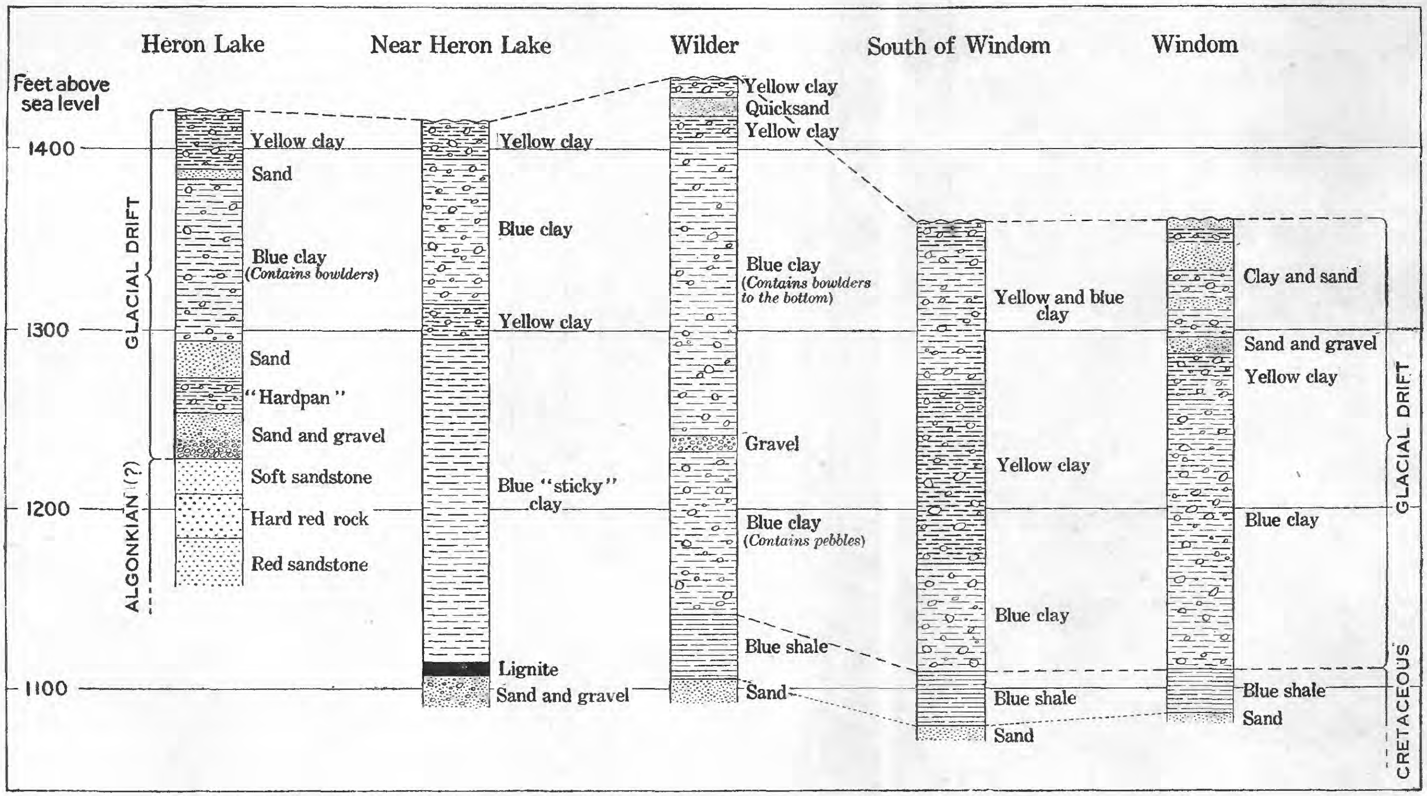
Head of the water.—Throughout the county the water from the drift is under considerable artesian pressure, commonly rising within 50 feet and frequently within 25 feet of the top of the well. Although there is no extensive area in which flows can be obtained, there are several small ones, most of which are related to the quartzite ridge. The latter stands higher than the surrounding country, and the drift laps up over it. A part of the rain that falls on this elevated ground is transmitted, either directly or through the pervious portions of the rock, to the sand and gravel seams of the drift. Wherever there is an opportunity the water leaks out and flows to a lower level, thus producing many springs along the margins of the ridge. But where the impervious bowlder clay extends up over the rock the water is confined, and hence accumulates head and gives rise to conditions requisite for obtaining flowing wells. These relations are shown in a diagrammatic way in figure 4.

In the valley of Des Moines River all along its course the water from shallow horizons is raised approximately to the surface, and flowing wells could probably be secured in some localities.

Quality of the water.—The water from the glacial drift is all hard. In the accompanying table of analyses (p. 162), Nos. 3, 4, and 5 represent water from moderate depths in the drift, and it will be seen that all three of these samples have an extremely high content of calcium and of the sulphate radicle for which reason they have a very great permanent hardness and will produce much hard scale in boilers. In the same table Nos. 1 and 2 represent water from deposits of sand and gravel near the surface, which, although also hard, has a much smaller content of scale-forming minerals.

CRETACEOUS SYSTEM.

Description.—Shales and sandstones have been encountered in several wells in the vicinities of Windom and Westbrook and in many wells immediately north of this county. The section of the city well at Windom shown in Plate IX is typical for that region. The well at the flouring mill at Westbrook, 568 feet deep, and the one drilled for the railway company in the same village, 642 feet deep, are both reported to pass through a certain amount of shale and to end in sandstone. It is evident from these data that a wedge



GEOLOGIC SECTIONS IN SOUTHERN COTTONWOOD AND NORTHERN JACKSON COUNTIES.

By O. E. Meinzer.

Heron Lake.—Well drilled in 1905 in village of Heron Lake for Chicago, St. Paul, Minneapolis and Omaha Railway Company. Authority, G. J. Savidge, driller, Wayne, Nebr.

Near Heron Lake.—Well on farm of Mr. Runser, 1½ miles northeast of Heron Lake. Authority, E. W. Anderson, driller, Heron Lake.

Wilder.—Well 1 mile northwest of Wilder, on farm of C. B. Cheadle.

South of Windom.—Well 5 miles south of Windom, on farm of Arthur Johnson. This section and the one preceding are given on the authority of H. Hanson, driller, Windom.

Windom.—Approximate section reported for the deep city well.

The altitudes of the second, third, and fourth sections are only approximately known.

of shale and sandstone enters the county from the south, west, and north, between the glacial drift and the quartzite. It is probably all Cretaceous in age, although the lower portion may be in part Paleozoic. If the drift were all removed from Cottonwood County, about one-half of the surface (the central, northeastern, and east-central parts) would constitute a quartzite area standing conspicuously above the adjacent region and surrounded and overlapped by nearly horizontal strata of Cretaceous sediments, somewhat as the ocean surrounds and overlaps an island.

Yield of water.—In the vicinity of Windom several wells have been successfully finished at a depth of about 300 feet in beds of Cretaceous sands. The city well at Windom, which was given the most severe test, was pumped continuously for twenty-four hours at the rate of 120 gallons a minute. At Westbrook and Lamberton drilling into the Cretaceous has been less successful. The mill well at Westbrook does not yield a great supply, and the railway well seems never to have been satisfactory. At Lamberton no water-bearing stratum of consequence was found after the shale was entered, but in the vicinities of Walnut Grove, Revere, and Sanborn there are many good wells supplied apparently from the Cretaceous.

Head of the water.—At Windom the Cretaceous water rises to a level about 100 feet below the surface, or approximately 1,260 feet above the sea; in the mill well at Westbrook (according to report) to about 50 feet below the surface, or 1,370 feet above the sea; and at Walnut Grove, near the northwest corner of this county, to about 12 feet below the surface, or 1,216 feet above the sea. The Cretaceous area of flowing wells of Lyon and Redwood counties extends approximately to the Cottonwood county line (Pl. IV).

Quality of the water.—Two distinct types of water are derived from the Cretaceous strata of this region. Both are highly mineralized and both are rich in sulphates, but in one the sulphate radicle is in equilibrium chiefly with calcium and magnesium, giving the water a great permanent hardness and causing it to form much hard scale in boilers, while in the other the content of calcium and magnesium is low, and the sulphate radicle is to a much greater extent associated with sodium and potassium, producing a soft water, which is liable, however, to cause foaming in boilers. The water obtained from the Cretaceous wells in the vicinity of Windom and that from the deep railway well at Westbrook belong to the first type, while the water from the mill well at Westbrook and that from the Cretaceous wells in the region of Walnut Grove and Revere belong to to the second. Analyses 6, 7, 9, and 10, in the accompanying table, represent water of the first type; No. 8, water of the second. Soft-water horizons occur under Walnut Grove at 900 feet above sea level and higher, and under Westbrook at about 850 feet above sea level. Hard water seems to be found both above and below the soft. The city well at Windom terminates about 1,080 feet above the sea, and the other Cretaceous wells of that section at approximately the same level. Although it is by no means safe to infer that softer water can be secured at Windom by drilling deeper, yet there is reason for believing that it may. It must be remembered that the mill well at Westbrook has only a small yield, and probably draws from a thin layer which may not furnish enough water to supply a well in other localities, and which, in careless drilling, can readily be passed through unnoticed.

SIOUX QUARTZITE.

Description.—This formation consists of a hard, red, siliceous rock, properly called quartzite, but commonly known throughout the region as the "red rock." The second tier of townships from the north contains the main quartzite ridge, and east of Highwater Creek there are many outcrops. The most westerly exposure is found along Highwater Creek, east of the village of Storden; the most southerly, in sec. 12, T. 106 N., R. 37 W.; and the most northerly, along Mound Creek, in T. 108 N., R. 36 W. (Pl. III).

A ledge of rock, with an east-west or slightly southeast-northwest trend, seems to run beneath the village of Mountain Lake. It is entirely covered by drift, but is frequently encountered in drilling. Quartzite was struck 5 miles east and a little south of Mountain Lake, at a depth of 90 feet; in the village of Mountain Lake, at 70 feet; 7 miles west and a little north of the village, at 60 feet; 2 miles farther west, at 40 feet; and at intermediate points along this line, at less than 100 feet. The well data that have been secured are too meager to show whether this is a ridge separated by a depression from the main ridge in the northern part of the county or rather the southern edge of a quartzite plateau continuous with the main ridge. West of the last-named locality (which is sec. 25, T. 106 N., R. 36 W.), the rock has not been encountered, and there is good reason to believe that it lies at a considerable depth; but 7 miles northwest (sec. 12, T. 106 N., R. 37 W.) it comes to the surface. Likewise, east of Jeffers (NW. ¼ sec. 22, T. 107 N., R. 36 W.), a well 230 feet deep was drilled without reaching rock, while in the village of Jeffers it occurs at 104 feet. These data seem to indicate an ancient valley in the quartzite of this region.

Yield of water.—This formation affords small quantities of water from its joint fissures and less firmly cemented layers. If in drilling a well a moderate yield is obtained before the rock is struck, the rock should not be penetrated for additional supplies; but where the quartzite is near the surface and the yield of the overlying drift is small and uncertain, it is advisable to drill into the rock. Where attempts to get water from the quartzite have failed the reason has usually been that drilling was not continued to a sufficient depth.

Quality of the water.—The quartzite itself contributes very little mineral matter, but its water, if it is derived from overlying glacial drift or Cretaceous strata, receives mineral constituents from these sources before it enters the quartzite. There is therefore a wide range in the content of the water from this formation.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Windom.—The city of Windom lies on the banks of Des Moines River. On the upland the glacial drift is about 300 feet deep, and the entire valley has been excavated out of this material (Pl. IX). The public supply is a mixture of water from three zones—(1) surface clay and sand, which contribute water to a reservoir 14 feet in diameter and 16 feet deep; (2) a bed of sand and gravel at a depth of 65 feet, which supplies five 3-inch driven wells, the water rising about 10 feet below the surface; and (3) a stratum of sand at a depth of 280 feet, which supplies an 8-inch drilled well already mentioned. The 16-foot well is intended at present only as a reservoir to receive the natural flow of the driven wells, but it is not entirely waterproof and admits some shallow water. In 1907 the five driven wells would together yield several hundred gallons per minute when the 16-foot well was emptied so that they were given a head of about 6 feet. They furnish most of the public supply, having an advantage over the deep well both in head and in the mineral quality of the water. Perhaps 25 per cent of the inhabitants utilize the public supply to some extent, but few use it exclusively. About 15,000 gallons are consumed daily. Nearly all the people have private wells, many of which are driven into the surficial sands. The railway company uses water from a shallow well.

Mountain Lake.—Quartzite has here been found at a depth of 70 feet. Above the rock lies the glacial drift, which in some parts of the village contains beds of water-bearing sand. The public waterworks are supplied from a well that is 12 feet in diameter and stops in a bed of sand at a depth of 40 feet. Its yield is not great and is much affected by drought. In July, 1907, pumping at the rate of approximately 50 gallons per minute lowered the water level from 20 feet below the surface to 30 feet, while in the autumn of 1906 the well could be emptied in 2½ hours. Although the water is hard, it is much better in this respect than that from the bottom of the drift, as can be seen by a comparison of analyses 2 and 3 in the table. About 400 people use the public supply, and it is also used at the mill and the creamery. On an average approximately 20,000 gallons is consumed daily. The private wells are for the most part bored a short distance into the glacial drift. Where good beds of sand occur they provide ample supplies for domestic purposes, but where these are wanting it is often difficult to get a sufficiently large and permanent yield, and the water is not always good. The railway company has a well that is drilled into the quartzite.

Westbrook.—The drift, which is deep in this locality, is underlain by Cretaceous shales and sandstones. Drilling 642 feet deep has not reached the quartzite. All the people use water from private wells, which are commonly between 15 and 30 feet in depth and rarely exceed 75 feet. They end in yellow clay or in sand and gravel and many of them furnish only small quantities of water and fail in dry years. A bored well, 3 feet in diameter and 64 feet deep, supplies the public waterworks. It is reported to have the following section:

Section of village well at Westbrook.

[Authority, Bert Milligan, borer, Westbrook.]

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow clay	17	17
Blue clay, Blue sand, Blue clay	47	64
Sand (water).		

In this well the water stands about 25 feet below the surface, and pumping at the rate of 25 gallons per minute empties the well in a little over an hour. The water that it yields is hard, as is shown by analysis 4 in the table, and is used only for the railway locomotives, for sprinkling the streets, and for fire protection. The mill well, which yields soft water, and the deep well drilled for the railway company have already been discussed.

FARM WATER SUPPLIES.

The wells which furnish farm supplies may be grouped into the following classes: (1) Wells driven into the surficial sandy deposits, (2) wells bored into yellow clay or gravelly beds near the surface, (3) wells bored into seams of sand and gravel interbedded with the blue bowlder clay, (4) wells drilled into these deeper seams, (5) wells drilled into Cretaceous strata of sand or sandstone, and (6) wells drilled into quartzite. The wells of the first group are virtually confined to the valley of Des Moines River. Those of the second are generally unsatisfactory because of their small and uncertain supplies of water, and have to a great extent been abandoned for deeper wells, while most of those of the third group yield adequate and permanent supplies and comprise a majority of the farm wells of the county. There are also many wells belonging to the fourth group and a few belonging to the last two. Drilled wells have a number of advantages over bored ones, and wells from 4 to 6 inches in diameter prove more satisfactory than those which are only 2 inches in diameter.

Drilling into quartzite is avoided as much as possible because of the expense and difficulties involved. It is necessarily an expensive process, and it is well for a farmer fully to understand that fact beforehand. It is sometimes necessary to sink several hundred feet into the rock in order to get an adequate yield, while the cost per foot is great and increases with the depth. However, rock wells rarely need be failures. A driller with a heavy rig and a comprehensive knowledge of his trade can penetrate quartzite to an indefinite depth, and is seldom obliged to abandon a hole. But this kind of work presents peculiar difficulties and should not be undertaken without a thorough apprenticeship, nor with an outfit that is too light. The drilling of wells in quartzite is discussed on pages 87–88.

SUMMARY AND ANALYSES.

Public, industrial, and private supplies are obtained chiefly from seams of sand and gravel interbedded with bowlder clay, and these will always be the most accessible and valuable sources.

The strata of sand and sandstone found beneath shale ("soapstone") in the southern and western portions of the county, at depths of 300 feet or more, generally but not always yield large quantities of water. The water from this source will rise to a level about 100 feet below the surface at the southern margin of the county, and virtually to the surface at the northern. Deep drilling should not be undertaken for the purpose of securing flowing wells except in the northwestern corner.

In the northern part both hard and soft water horizons have been discovered. In the southern only hard water has thus far been found, although it is possible that softer water exists at greater depths than have yet been reached. (See the reports on adjoining counties.)

Where the Sioux quartzite ("red rock") is so near the surface that no adequate source of water is found above it, it is advisable to drill into the rock, which if penetrated to a sufficient depth will in nearly all instances provide permanent though small supplies.

Mineral analyses of water in Cottonwood County.

[Analyses in parts per million.]

	Surface deposits (glacial drift, etc.).					Cretaceous.				
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Depth ... feet..	30	40	60	64	96	292	320	568	642	642
Diameter of well ... inches..	168	144	156	36	3	2	8	2	8	8
Silica (SiO_2)...	29	4	28	24	26	14	31	8	33	21
Iron (Fe)...	.....	.2	.....	.....	.....	2.5	.....	.14	.....	.....
Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)...	7	.....	.....	1.7	4	11	8	.....	.....	6.4
Calcium (Ca)...	132	133	313	235	302	158	219	37	287	159
Magnesium (Mg)...	59	42	105	78	102	57	75	9	99	46
Sodium and potassium (Na+K)	30	21	127	142	114	43	150	512	129	348
Carbonate radicle (CO_3)...	.....	.0	.....	.....	.....	.0	.....	.....	.....	.....
Bicarbonate radicle (HCO_3)...	504	456	527	504	620	459	539	283	713	385
Sulphate radicle (SO_4)...	187	157	1,012	769	876	346	705	933	759	971
Chlorine (Cl)...	21	11	3	3	.9	3	6	13	19	12
Nitrate radicle (NO_3)...	.....	3.5	.....	.....	.....	.0	.....	2.1	.....	.....
Total solids...	713	611	1,846	1,501	1,729	845	1,545	1,710	1,677	1,797

1. Railway well at Windom. December 5, 1900.
2. Village well at Mountain Lake. July 18, 1907.
3. Well at Mountain Lake. January, 1900.
4. Village well at Westbrook. July 9, 1903.
5. Creamery well at Bingham Lake. January, 1900.
6. Well of A. E. Johnson, 5 miles south of Windom (Jackson County). July 19, 1907.
7. Railway well at Bingham Lake. June 21, 1900.
8. Well at the flouring mill at Westbrook. December 26, 1907.
9. Railway well at Westbrook. May 16, 1901.
10. Railway well at Westbrook. June 28, 1901.

Analyses 2 and 6 were made for the United States Geological Survey by H. A. Whittaker, chemist Minnesota state board of health. Analysis 8 was made for the United States Geological Survey by M. G. Roberts, chemist Minnesota state board of health. Analyses 1, 3, 4, 5, 7, 9, and 10 were furnished by G. N. Prentiss, chemist Chicago, Milwaukee and St. Paul Railway Company.

DAKOTA COUNTY.

By C. W. Hall and M. L. Fuller.

SURFACE FEATURES.

Dakota County is one of the lowest of those bordering Mississippi River in southeastern Minnesota. The greater part of the land is less than 1,050 feet above sea level, or only 200 to 300 feet above the river. The plateau character is less marked than in most counties, owing to the irregularity of the morainic surface in the eastern and northern parts of the county. Throughout this morainic area the surface is a confused jumble of sharp cones and irregular gravelly hills of all sorts, alternating with sharp hopper-shaped or irregular basins of great depth, often occupied by ponds and lakes. In many places the elevation varies 100 to 150 feet within a distance of a few rods. The rock surface south of the moraine, and especially in the southern portion of the county, is somewhat irregular, owing to the fact that the softer rocks have been worn down to levels considerably lower than the more resistant beds, such as the Galena limestone, Decorah shale, and Platteville limestone afford. At several points these limestones give rise to mounds and flat-crested hills, resembling the buttes and mesas of the West.

Both Mississippi and Minnesota rivers are bordered by bluffs, but of different character, those of the former being generally of rock, while those of the latter are commonly of drift. Both streams have flood plains 1 to 2 or more miles in width. With the exception of these streams and Vermilion and Cannon rivers, the county is without important drainage lines, and shows little to suggest the deep sharp valleys and intervening narrow-crested ridges so characteristic of the counties of the southeast. This fact is due in part to its slighter elevation above the Mississippi and the consequent low grade of the streams, and in part to the presence of the drift covering which has filled the ancient valleys.

Other irregularities are due to the effect of glacial and interglacial drainage in scouring out channels or forming terraces along the sides of the valleys. Among these lines of glacial drainage may be mentioned particularly one leading from near Mendota southeastward across the moraine to the Mississippi Valley near Gray Cloud Island; one extending from Minnesota River near the county line in T. 115 N., R. 20 W., southeast to the vicinity of Farmington; another entering the county near Prairie Lake and extending eastward to the Vermilion Valley by way of Fairfield and Farmington; and those through the valley of Cannon River by way of its tributary, Chub Creek. Through all these ancient valleys large volumes of water poured from the ice in the west, excavating broad channels, often bordered by noticeable bluffs, and depositing extensive sheets of sand and gravel. At this time the Mississippi was flowing at an elevation of 100 to 150 feet above its present level, and, together with the glacial channels mentioned, formed the long terrace at Inver Grove and extensive terrace flats in the vicinity of Hastings. At a later period the drainage of this region became readjusted, several of the valleys were filled with morainic material, and the streams then remaining began to erode the earlier deposits, eventually excavating the channels in which they now flow. On their sides remnants of the old levels are preserved as terraces standing 100 to 200 feet above the present bottoms. These terraces are now prominent features of the valley walls along Mississippi, Minnesota, and Cannon rivers.

SURFACE DEPOSITS.

The alluvium of Dakota County is a loamy stratified sand and gravel deposited by the present streams in the Mississippi and associated valleys. Its thickness reaches a maximum of 100 feet or more. Considerable water occurs in the materials, but owing to the silt present it is sometimes given up very slowly. Supplies for domestic purposes and for small industrial establishments can generally be obtained.

The terrace sands and gravels lie 100 to 125 feet or more above the streams. They occur in narrow belts along the Mississippi south of St. Paul, widening out at the eastward swing of the river to a point near Hastings, where they are over 10 miles wide. They are 100 feet thick or more in most places, and at a few points reach a thickness of over 200 feet, as in the buried channel of the Mississippi beneath the Hastings Prairie. They contain considerable water in places, but, because of their porous nature, are freely drained on the side toward the valleys, making it necessary for wells to go nearly to the river level before obtaining permanent supplies. In many localities rock or drift is encountered before this level is reached, and here the wells usually fail to secure adequate supplies from the terrace deposits. This is true at several points on the Hastings Prairie.

Outwash gravels, which are stratified deposits made by the waters flowing from the ice front in the Pleistocene epoch, occur in valleys southeast of Mendota, at Crystal Lake, along Vermilion River near Farmington, and along Cannon River in the southern part of the county. Water is found in them in considerable amounts, supplied partly by rainfall and partly by inflow from the surrounding hills. It is usually near the surface and is available to wells of ordinary depth, affording ample supplies for farm and domestic or small industrial purposes.

The glacial drift is of two types—(1) the older or pre-Wisconsin drift, which underlies the uplands in the eastern two-thirds of the county, and is usually a thin deposit and not an important source of supply, although it carries some water in its sandy beds; and (2) the younger or Wisconsin drift, which is distinguished from the older drift by the absence of weathering. It constitutes the surface formation over a considerable part of the western portion of the county, in places reaching a thickness of 100 feet or more. Being of greater depth, it is a better source of supply than the older drift and yields water to a large number of farm wells. In general, however, the available amounts are not sufficient for large industrial or public supplies.

ROCK FORMATIONS.

In this county the series comprising the Galena limestone, Decorah shale, and Platteville limestone is prevailingly shaly, but contains some thin layers of limestone. The lowest 20 feet consists of two beds of magnesian limestone separated by a bed of crumbling and rapidly disintegrating shale. The maximum thickness of these rocks in this county appears to be about 175 feet. They underlie the larger part of northwestern Dakota County, the best exposures being in the highlands south of St. Paul. Over the greater part of the area they are covered by thick deposits of drift and are penetrated by but few wells. Near the river the water from these beds has been drained away, but elsewhere the supply is somewhat larger, though generally less than in the overlying drift.

The St. Peter sandstone has a maximum thickness in Dakota County of about 160 feet. It outcrops along the valley of the Mississippi and forms the surface formation over extensive upland areas in the southwestern part of the county. Beneath the shaly beds that occur in the lower part of the formation considerable amounts of water under artesian pressure are found. The upper part of the formation, however, has been largely drained of its supplies by the deep gorge of the Mississippi. In the uplands, where they are not drained by adjacent valleys, good supplies are afforded to dug and drilled wells, but the water, being unconfined, is under little head and is not sufficient in amount to meet the needs of large industries or public supplies.

The Shakopee dolomite, which here is about 25 feet thick, underlies considerable areas of the uplands as well as the Vermilion and Cannon river valleys. It carries some water in interbedded lenses of sandstone and in the joints and caverns formed by the extensive leaching the formation has undergone, but the amounts are less than in the overlying drift. Near the Mississippi even these small supplies are lost by drainage.

The New Richmond sandstone, which appears to have a considerable thickness in its typical development in southern Minnesota, is not recognized everywhere in this county. In some localities, however, it appears to be present and to yield supplies to many private wells. The yield would probably nowhere be sufficient for public supplies.

The Oneota dolomite, which is petrographically similar to the Shakopee, occurs at the surface along Mississippi River near Hastings and for some distance south, and underlies the entire county. It carries a little water which is yielded to private wells, especially near Hastings. It is important as providing a cap to confine the waters of the underlying sandstone.

The Jordan sandstone underlies the Mississippi Valley in the northern part of the county and affords abundant supplies for all ordinary purposes. The water is under sufficient head to carry it considerably above the river level.

The St. Lawrence formation consists of alternating beds of limestone, shale, etc. It has a total thickness of about 200 feet, of which 75 feet is exposed above the river level below Hastings. It contains little water.

The Dresbach sandstone lies beneath the St. Lawrence formation and is in turn underlain by shales. The sandstone beds are generally saturated with water under considerable pressure and afford supplies adequate for all ordinary demands. In the valleys of Mississippi and Cannon rivers they give rise to flows.

The red clastic series underlies the shales last mentioned, and is found in all drillings in southeastern Minnesota which have penetrated to that depth. In thickness these rocks vary more than any other division in this part of the State. They are of but little value for yielding water supplies.

WELL RECORDS.

Below are given three typical well sections together with the probable correlations of the strata:

Section of Chicago, Milwaukee and St. Paul Railway well at Mendota.

[Authorities: W. E. Swan. driller; N. H. Winchell, Thirteenth Ann. Rept. Geol. and Nat. Hist. Survey Minnesota, 1885, pp. 55-56; C. W. Hall, Bull. Minnesota Acad. Nat. Sci., vol. 3, No. 1, 1889, p. 141.]

	Thickness.	Depth.
	Feet.	*Feet.*
St. Peter sandstone, including talus	147	147
Shakopee dolomite	40	187
New Richmond sandstone (estimated)	15	202
Oneota dolomite	90	292
Jordan sandstone	95	387
St. Lawrence and lower formations:		
Gray shale	50	437
Green shale	110	547
Limestone	10	557
Blue shale	30	587
Sandstone	125	712
"Hard" rock, inclosing beds of shale (not sandstone)	145	857

Section of Swift & Co. well at South St. Paul.

	Thickness.	Depth.
	Feet.	*Feet.*
Alluvium	40	40
Shakopee dolomite, New Richmond sandstone, and Oneota dolomite	125	165
Jordan sandstone	130	295
St. Lawrence and lower formations:		
Limestone	155	450
Sandstone	50	500
Shale	140	640
White sandstone	200	840
Red clastic series	40	880

Section of Chicago, Milwaukee and St. Paul Railway well at Hastings.[a]

	Thickness.	Depth.
Oneota dolomite:	*Feet.*	*Feet.*
Ordinary magnesian limestone	80	80
White sandstone	15	95
Sandy magnesian limestone	12	107
Jordan sandstone:		
Sandstone, somewhat ferruginous	95	202
St. Lawrence and underlying formations:		
White sandy shale	25	227
Sand, sandy shale, and dolomite	43	270
Sand, and green sand	20	290
Green shale and green sand	110	400
Sandy shale, sand, and green sand	15	415
Dresbach sandstone, with lumps of iron pyrite	60	475
Green sandy shale	20	495
Blue shale	70	565
Sand, and green sand	20	585
Gray shale, sand, and limestone	5	590
Sandstone and lumps of iron pyrite and some limestone	30	620
Fine to coarse sandstone	160	780
Red clastic series:	40	820
Fine to coarse sandstone, with traces of red shale		
White and pink sands	30	850
Red shale with some white sand	20	870
Red and white sandstones	15	885
Red shale	40	925
White sand and some red shale	235	1,160

[a] Drilled in 1885 by W. E. Swan; see references for the well at Mendota, above.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Hastings.—This city stretches from the flood plain of the Mississippi to the summits of the morainic bluffs which stand to the west. The business part is built upon a shelf of the dolomites of the Prairie du Chien group, and the larger part of the residence district lies upon the broad terrace 100 to 120 feet above Mississippi River. Wells sunk upon this terrace have furnished the water supply for most of the inhabitants. Several deeper wells penetrating the sandstone formations have also been drilled, among which may be mentioned the one at the Gardiner Mills, 850 feet in depth, the one at the state asylum, 830 feet in depth, and the one belonging to the Chicago, Milwaukee and St. Paul Railway Company, the section of which is given above. Recently a well 495 feet deep has been drilled for the city, and a system of public waterworks is being installed.

South St. Paul.—The residence portion of South St. Paul is built upon the terrace that lies along the west side of Mississippi River at an elevation of 100 feet above the stream. Wells 165 feet in depth obtain an abundant supply of water from the Jordan sandstone, while a second great reservoir of underlying water occurs at a depth of 500 feet, and the most copious reservoir of all is tapped at a depth of 650 feet. All these water-bearing formations yield artesian supplies in abundant quantities. The section shown by the group of wells owned by Swift & Co. is given above. Here as elsewhere there is a question as to the permanence of the artesian supply. A few years ago the well belonging to the Union Rendering Company, which is a short distance from the plant of Swift & Co., flowed continuously at the surface. At the present time this well flows intermittently. On Sundays there is always a flow, caused, no doubt, by the shutting down of some of the wells belonging to Swift & Co., the Stock Yards Company, and others. This indicates that the flow is not as good as formerly and that the diminution of head is due to the heavy demands made upon the deep water. The public supply, which is used by about one-half the people, is obtained from a flowing well 880 feet deep.

Mendota.—In this village the supply is derived chiefly from comparatively shallow wells. The St. Peter sandstone affords a reservoir of great capacity. The section of an artesian well drilled for the Chicago, Milwaukee and St. Paul Railway Company in 1884 is given above. The water from this well is rather hard but does not differ materially from the water drawn from the same formation in Minneapolis and St. Paul. The well originally flowed 300 gallons a minute at 14 feet above the ground, but now barely flows at the surface.

SUMMARY AND ANALYSES.

The largest and most permanent stores of water exist in the sandstones, but supplies adequate for farm and domestic use can frequently be obtained at less depths from the surface deposits. In the valley of the Mississippi, and probably also in the valley of Cannon River, flows can be obtained from the sandstone strata. When the red clastic series is encountered drilling should be discontinued.

Mineral analyses of water in Dakota County.

[Analyses in parts per million.]

	Glacial drift.			St. Peter sandstone.	Shakopee to Oneota dolomite.		Jordan sandstone.	
	1.	2.	3.	4.	5.	6.	7.	8.
Depth .... feet..	20	20	20	90	142	69	160	140
Silica (SiO_2)	....	....	22	15	16	....	....	....
Iron (Fe)	....	....	....	1.6	4	1.4	24	....
Iron and aluminum oxides (F_2O_3+Al_2O_3)	5.5	....	.5	....	....	....	....	5
Calcium (Ca)	87	86	87	50	78	68	49	55
Magnesium (Mg)	26	28	27	38	22	28	23	25
Sodium and potassium (Na+K)	10	3.2	7.5	7	5.1	9	4.4	35
Bicarbonate radicle (HCO_3)	348	338	337	333	269	352	222	264
Sulphate radicle (SO_4)	50	51	44	17	76	6	13	61
Chlorine (Cl)	5.5	4.9	68	7.3	2.7	7.7	5.3	26
Total solids	356	339	354	303	358	295	263	358

Mineral analyses of water in Dakota County—Continued.

	Dresbach sandstone and underlying shale.							
	9.	10.	11.	12.	13.	14.	15.	16.
Depth .... feet..	857	857	661	1,160	1,160	855	880	475
Silica (SiO_2)	....	....	12	11	1.7	.9	....	13
Iron (Fe)	....	....	....	....	....	Small.	12	....
Iron and aluminum oxides (F_2O_3+Al_2O_3)	2.1	....	12	....	....	....	....	3
Calcium (Ca)	52	52	98	64	85	75	52	49
Magnesium (Mg)	17	17	39	28	32	30	14	26
Sodium and potassium (Na+K)	12	11	58	185	215	106	6.4	16
Bicarbonate radicle (HCO_3)	262	259	414	195	425	313	258	244
Sulphate radicle (SO_4)	7	8.8	94	80	86	147	6.6	45
Chlorine (Cl)	1.3	1.8	65	308	266	92	12	12
Total solids	220	220	580	773	897	620	254	288

1. Chicago, Milwaukee and St. Paul Railway well at Farmington. August, 1890.
2. Chicago, Milwaukee and St. Paul Railway well at Farmington. November 1, 1901.
3. Chicago, Milwaukee and St. Paul Railway well at Farmington. November, 1906.
4. "Husausa water" well at Mendota.
5. Well of Magnus Brown at Farmington. November, 1906.
6. Chicago, Rock Island and Pacific Railway well at Inver Grove.
7. Swift & Co. well at South St. Paul.
8. City well at Hastings; water taken at the depth of 140 feet. November, 1907.
9. Railway well at Mendota. August, 1890.
10. Railway well at Mendota. May, 1901.
11. Chicago, St. Paul, Minneapolis and Omaha Railway well at Mendota. April, 1901.
12. Chicago, Milwaukee and St. Paul Railway artesian well at Hastings. 1885.
13. Chicago, Milwaukee and St. Paul Railway well at Hastings. 1885.
14. Gardiner Mills well at Hastings.
15. Swift & Co. well at South St. Paul. 1905.
16. City well at Hastings. November, 1907.

Analyses 8 and 16 were made by H. A. Whittaker, chemist, Minnesota state board of health. Analyses 3 and 5 were made for the United States Geological Survey by H. S. Spaulding. Analyses 1, 2, 9, and 10 were furnished by G. N. Prentiss, chemist, Chicago, Milwaukee and St. Paul Railway Company. Analysis 4 was made by Prof. C. F. Sidener, University of Minnesota. Analysis 6 was furnished by J. M. Brown, division engineer, Chicago, Rock Island and Pacific Railway Company. Analyses 7 and 15 were furnished by W. D. Richardson. Analysis 11 was furnished by G. M. Davidson, chemist, Chicago, St. Paul, Minneapolis and Omaha Railway Company. Analysis 12 was made by Prof. J. A. Dodge, University of Minnesota. Analysis 13 was made by J. P. Magnusson, University of Minnesota.

DODGE COUNTY.

By C. W. Hall and M. L. Fuller.

SURFACE FEATURES.

Much of the surface of Dodge County is very even, including large expanses in which there is hardly a noticeable irregularity. The highest land is along the southern edge, where the elevation above sea level reaches 1,350 feet and is generally more than 1,300 feet. In the northern portion most of the land stands between 1,200 and 1,300 feet but descends to 1,100 feet along the northern border. The country is so flat that the drainage is very poor, considerable areas being wet and marshy before they are artificially drained. The county is crossed by the two middle branches of Zumbro River; the southern branches head along the eastern border. In the southwestern part there is a series of marshy depressions which at high water drain south into Cedar River. Most of the streams flow in shallow and somewhat indefinite channels, but the middle forks of the Zumbro near the eastern edge of the county have valleys 200 feet in depth, bordered in places by more or less precipitous banks.

SURFACE DEPOSITS.

The surface deposits consist chiefly of glacial drift, which is a heterogeneous mixture of clay with pebbles and bowlders, locally containing interbedded layers of water-bearing sand and gravel. In most instances adequate supplies for domestic and farm purposes and even for small industries may be obtained.

PALEOZOIC FORMATIONS.

Beneath the surface deposits there is a succession of alternating beds of shale and limestone, the latter greatly predominating. At the southern margin of the county these are believed to embrace the Platteville limestone, Decorah shale, and Galena limestone, and also to include the lowest beds of the overlying Maquoketa shale, attaining a total thickness of several hundred feet. Toward the northeast this series of beds gradually thins out, the beds terminating successively from the top downward, until, in the valleys near the northeastern corner, underlying formations come to the surface. Below are given two well sections which illustrate this series in a general way. The first is the log of the well drilled for the Chicago Great Western Railway Company in the village of Hayfield, near the southern extremity of the county. This well apparently passed through 390 feet of Ordovician strata without reaching the St. Peter sandstone. The second section is that of the well drilled for the same railway company at Dodge Center, which lies very near the geographic center of the county. In this section the Maquoketa shale appears to be absent.

Well section at Hayfield.

[Authority, J. J. Banks.]

	Thickness.	Depth.
Glacial drift:	*Feet.*	*Feet.*
Black soil	2	2
Gravel	2	4
Yellow clay	8	12
Quicksand	3	15
Blue clay	112	127
Sand and clay	28	155
Maquoketa, Galena, etc.:		
Limestone	335	490
Shale	25	515
Limestone	10	525
Shale	20	545

Well section at Dodge Center.

[Authority, Mr. Knowlton, assistant chief engineer Chicago Great Western Railway Company.]

	Thickness.	Depth.
Glacial drift:	*Feet.*	*Feet.*
Clay	28	28
Clay and quicksand	12	40
Blue clay and bowlders	44	84
Blue clay	28	112
Galena limestone and lower formations:		
Limestone and yellow clay	10	122
Limestone	102	224
"Hard rock"	52	276
Shale	73	349
"Hard rock"	17	366
White shale	11	377
Shale	82	459
Sandstone (probably St. Peter)	31	490
Shale	14	504

Though the Galena and Platteville limestones contain no strong water-bearing beds, they yield supplies adequate for most ordinary purposes wherever they lie below the ground-water level, and especially where they are immediately underlain by a bed of impervious shale.

The St. Peter sandstone, which is about 100 feet thick, is exposed along the Zumbro Valley in the northeastern portion of the county, whence it dips southwestward and passes beneath the Platteville. Except near its outcrop it affords strong supplies of water.

Beneath the St. Peter sandstone occurs a succession of limestones, shales, and sandstones. Several of the sandstones are important water-bearing beds. These include (1) the New Richmond, about 20 feet thick and 35 feet below the base of the St. Peter; (2) the Jordan, about 120 feet thick and 250 feet below the St. Peter; (3) the Dresbach, about 80 feet thick and 600 feet below the St. Peter. All these would yield copiously, but there is no object in drilling to them so long as adequate supplies can be obtained from the St. Peter.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Kasson.—The village of Kasson is provided with a public supply drawn from the St. Peter sandstone, which lies at a depth of about 300 feet and yields a safer and more permanent supply than any zone nearer the surface.

West Concord.—In West Concord the water supply is virtually all derived from private wells. The public waterworks take water from a drilled well 150 feet deep.

Hayfield.—The stratigraphic section near Hayfield is shown by the log of the railway well which is given above. Adequate water supplies are obtained at moderate depths from the glacial drift and the Galena and Platteville limestones. The public waterworks are supplied from a well 377 feet deep, which ends in either the Galena or the Platteville. An analysis of the water is given in the accompanying table.

SUMMARY AND ANALYSES.

Except in the northeastern corner of the county, an adequate supply of water for ordinary purposes can be obtained at moderate depths from the glacial drift or the Galena and Platteville limestones. Owing to the unbroken surface and to the impervious strata beneath the water-bearing beds, the water usually stands relatively near the top of the wells. As is shown by the analyses, the water is all moderately hard.

Whenever supplies are desired larger than can be derived from the drift or the Galena and Platteville limestones, drilling should be continued to the St. Peter sandstone, which underlies virtually the entire county and is nowhere more than a few hundred feet below the surface. Nothing would generally be gained from drilling to still lower zones, for the water which they contain is fully as hard as that from the St. Peter and will rise no higher.

Mineral analyses of water in Dodge County.

[Analyses in parts per million.]

	Glacial drift and Galena limestone.				St. Peter sandstone.
	1.	2.	3.	4.	5.
Depth ....feet..	120	140	240	377	504
Silica (SiO_2)	14	12	21	8.7	18
Iron (Fe)	....	....	....	2.8	1.3
Calcium (Ca)	92	73	114	88	88
Magnesium (Mg)	34	21	35	28	24
Sodium and potassium (Na+K)	5	7.5	8.5	11	19
Bicarbonate radicle (HCO_3)	447	329	446	234	328
Sulphate radicle (SO_4)	5.9	5.8	58	39	53
Chlorine (Cl)	4.5	7.2	13	13	7.3
Total solids	377	289	487	326	374

1. Chicago and Northwestern Railway well at Claremont. November, 1888.
2. Chicago and Northwestern Railway well at Kasson. June, 1889.
3. Chicago and Northwestern Railway well at Claremont. October, 1896.
4. Well furnishing the public supply at Hayfield. November, 1906.
5. Chicago Great Western Railway well at Dodge Center. November, 1906.

Analyses 4 and 5 were made for the U. S. Geological Survey by H. S. Spaulding and Prof. W. S. Hendrixson, respectively. Analyses 1, 2, and 3 were furnished by G. M. Davidson, chemist Chicago and Northwestern Railway Company.

FARIBAULT COUNTY.

By C. W. Hall and M. L. Fuller.

SURFACE FEATURES.

Of the nine counties bordering on Iowa, Faribault occupies the middle place. The highest tracts within this county are the morainic belt about Elmore, on the southern border, where the elevation exceeds 1,250 feet above sea level on either side of Blue Earth River, and the morainic belt culminating in the Kiester Hills, which reach an elevation of more than 1,400 feet above sea level. The Kiester Hills and their extension stretch across the county with a northwest-southeast trend for 25 miles. The remainder of the county is strikingly level and plateau-like. According to Winchell the northern part is probably the bed of an ancient lake, known as Lake Minnesota.[a]

The surface drainage of Faribault County is effected through Blue Earth River and its tributaries. This stream rises in northern Iowa and flows almost due north across Faribault County, descending approximately 5 feet to the mile and occupying a valley which has been cut on an average to a depth of nearly 100 feet. The branches of the Blue Earth also lie in deeply grooved valleys cut into the plain that comprises a large proportion of the surface of the county.

SURFACE DEPOSITS.

Faribault County is everywhere deeply covered with glacial drift, the older rocks rarely occurring within 100 feet of the surface. The drift is a heterogeneous mixture of gray pebbly clay containing gravelly or sandy layers that commonly yield good supplies of water. The morainal deposits, which have already been referred to, contain much gravel and sand and are marked by irregular rolling surfaces. Water is present in ample quantities, but on the elevations the ground-water level is relatively far below the surface. The glacial lake deposits, which were laid down when Lake Minnesota existed as a result of the obstruction of Minnesota River to the north, consist of ill-assorted sands and gravels about 10 feet thick, or too thin to be important as water bearers.

The alluvium of Faribault County consists of silty sands and gravels deposited along the present streams. These deposits, wherever utilized, seem to afford sufficient water for all ordinary purposes.

PALEOZOIC FORMATIONS.

On the map of the Geological Survey of Iowa[b] the Mississippian limestone is indicated as reaching the state line opposite the western half of Faribault County. As in this region the drift is thick and there has been little deep drilling, it is uncertain whether the Mississippian actually extends into Minnesota. It has never been recognized.

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[a] Final Rept. Geol. and Nat. Hist. Survey Minnesota, vol. 1, 1882, pp. 460-461.

[b] Ann. Rept. Geol. Survey Iowa, vol. 17, 1906, Pl. I.

Devonian rocks are supposed to underlie the drift throughout a small area in the southwestern corner of the county. Fair supplies of water are generally obtained from the sandstone layer that is present locally in these beds.

The Galena limestone, Decorah shale, and Platteville limestone, according to the record of the well in Freeborn, in the next county to the east, appear to have a combined thickness of about 300 feet. The limestones contain a large quantity of water fed from the overlying drift. This water is given up generously to wells and in some instances is under sufficient head to be lifted nearly or quite to the surface.

The St. Peter sandstone appears to lie immediately beneath the drift in an area northwest of a line extending approximately from Minnesota Lake through Blue Earth to Martin County. It is about 100 feet thick and consists of white or yellow sands commonly carrying large amounts of water which is available to wells penetrating through the overlying materials.

The Prairie du Chien group (which when complete includes the Shakopee, New Richmond, and Oneota formations) is present immediately below the drift in the northwestern corner of the county. The rocks of this group here present consist of pink to buff magnesian limestone, apparently characterized by joints and other fissures in the upper part, in which is found considerable water derived from the overlying drift. The New Richmond sandstone, a prominent water-bearing formation of this group in more easterly counties, has not been recognized.

The Jordan sandstone is about 75 feet thick. It probably comes to the subglacial surface in the northwestern corner of the county, but dips southeastwardly beneath the Prairie du Chien group and thus underlies the whole county. It is reached by deep rock wells and affords large supplies of water, supplementing to an important degree the other water-bearing beds.

Beneath the Jordan lie about 200 feet of St. Lawrence formation (limestone and shale), below which, in turn, is the Dresbach sandstone and underlying shales, several hundred feet in thickness. Their water-bearing capacity here is similar to that which they have in other counties. The Dresbach sandstone could be depended on for supplies if the overlying beds should fail. The red clastic series and the granite beneath are not water bearing to an important degree.

WELL RECORDS.

Below are given the sections revealed by drilling in two localities of this county, together with the probable correlations of these sections. The first is the log of the deep well sunk for the city of Blue Earth; the second is that of a boring in the village of Wells.

Well section at Blue Earth.

[Authority, G. W. Buswell.]

	Thickness.	Depth.
	Feet.	*Feet.*
Glacial drift:		
Soil	3	3
Yellow and blue clay	3	6
Gray clay	58	64
Sand and quicksand (water)	40	104
Blue clay	25	129
White sand (water)	69	198
Gravel	5	203
"Drift rock"	2	205
Platteville and Galena (?):		
Limestone	80	285
"Hard rock"	2	287
St. Peter:		
Sandstone	91	378
Prairie du Chien group:		
Limestone	215	593
Jordan sandstone	80	673
St. Lawrence formation (limestone and shale)	170	843
Dresbach sandstone	65	908
Shales	115	1,023
Red shale and sand	200	1,223
Granite	20	1,243

Well section at Wells.

[Authority, C. F. Loweth, civil engineer.]

	Thickness.	Depth.
	Feet.	*Feet.*
Glacial drift	125	125
Limestone (probably Galena)	30	155
Sandstone (water)	3	158
Blue shale	42	200
Blue limestone	8	208
White shale	18	226
White limestone and sandstone (water)	10	236
Green shale	30	266
Sandstone (St. Peter) entered.		

UNDERGROUND WATER CONDITIONS.

Wells.—As the ground-water level is generally near the surface there are many very shallow wells. These have not, however, proved to be entirely satisfactory either in their yield or in the quality of their water, and in many localities it has been necessary to sink wells to deeper water horizons. Some of these deeper wells obtain their supplies from sandy or gravelly layers in the lower portion of the drift, but many of them enter the underlying rock and draw from sandstone or limestone. The wells penetrating to the deep-lying, water-bearing sandstones have been sunk for industrial and public supplies and for the use of large stock farms.

Head of the water.—Everywhere within the glacial drift the water is under pressure, the layers of bowlder clay furnishing a confining bed. Thus wherever wells are drilled the water rises, and many wells flow when casing is applied. The head of the water is derived from the morainal districts in the eastern and southern parts of the county. The valleys of the larger streams have cut below the general level of the ground-water table, giving rise to springs from the upper beds and to flowing wells from the lower. Few of the flowing wells are more than 75 feet deep and many are less than 60 feet. They are situated along Blue Earth and Maple rivers and their tributaries, from the southern boundary of the county northward to the Blue Earth county line. In fact, it is possible to obtain flowing wells in nearly every valley in the county, the conditions being especially favorable in the deepest ones or those nearest the morainal ridges (Pl. IV). Flows are also obtained on the lower ground in the vicinity of Wells, the head and supply apparently originating in the morainal ridge a few miles southwest of the village.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Blue Earth.—The position and extent of the water-bearing layers beneath the city of Blue Earth are shown in the careful record given above of the well drilled in 1889. Several thick water-bearing beds occur in the glacial drift, which is here 200 feet deep. The lowest of these beds yields the largest supplies. Probably the best source of water for the city is the St. Peter sandstone, which is reached at 285 feet and is 90 feet thick or more. Below the St. Peter lies the Jordan sandstone, which is 80 feet thick. At the depth of 840 feet the Dresbach sandstone is reached, and this, with the underlying shaly sandstone, extends 180 feet downward. It furnishes large supplies but the water has not the quality of that from the St. Peter and Jordan.

The deep city well was drilled to a depth of 1,243 feet in the hope of obtaining a flow. The water from the lower beds was somewhat salty and hard, and consequently the well was plugged at the top of the red sandstone and shale 200 feet above the bottom. Subsequently the well filled still higher, and the supply of water gradually diminished while the population of the city increased. Hence, in 1904 a second well was sunk to the bottom of the Jordan sandstone. The new well is very near the old one and its log is essentially the same. During the drilling of the well any connection that might exist between the two was carefully noted. It was observed that in the new well, as in the old, water came freely from the deeper layers of glacial drift. When the St. Peter sandstone was entered, pumping at the old well lowered the supply in the new. The new well was cased to the top of the Jordan, or to a depth of about 590 feet. Subsequent operation, however, has convinced the authorities that the St. Peter is the stronger water producer of the two and steps are being taken to utilize both instead of confining the supply to the Jordan. The new well yields 350 gallons per minute.

Wells.—The village of Wells stands on a prairie 1,150 feet above sea level. From this point the surface rises very gradually toward the east and southeast, attaining an altitude considerably above that of the village. The water supply comes from two rather distinct zones—beds of sand and gravel in the glacial drift beneath the blue bowlder clay and sandstone strata at greater depths. (See the section given above.) In former years the water flowed several feet above the surface wherever a pipe was driven through the blue clay, and consequently it was a very simple matter to obtain water. As the quantity diminished and as citizens sought for further supplies, they found, on passing through the blue shale and limestone, that a white sandstone was reached and that this also yields generously. Analysis 11 gives the composition of the water from this zone. The supply for the waterworks is derived from two wells, one of which is 216 and the other 265 feet deep. About two-thirds of the inhabitants use the public water, and about 100,000 gallons of it is consumed daily.

Winnebago.—At Winnebago the public supply is obtained from an 8-inch well, drilled to a depth of 266 feet, in which the water stands 6 feet below the surface. Supplementary to the public supply, there are along the valley of Blue Earth River many flowing wells, the number of which has constantly increased from the settlement of the county to the present time. These flowing wells have always yielded water of a fairly uniform head and volume, being but little influenced either by abundant rains or by periods of drought. Their head is about 20 feet above the river. The following statement is made by Mr. Pierce:

There are at present flowing wells all along Blue Earth River, the valley of which is about 60 to 80 feet lower than the surrounding country. The wells all flow when a depth of about 50 feet is reached, and should this vein fail a second one is reached at a depth of 75 feet. Several veins of nonrising water are drilled through before reaching these flows. The vein yielding the flow is invariably preceded by an extremely hard layer of blue clay, a genuine hardpan. The water is always located in a bed of coarse sand, which seems to have the same appearance and quality wherever penetrated.

Elmore.—The public supply at Elmore is drawn from a well 110 feet deep, in which the water stands 8 feet below the surface. An analysis of the water from the railway well, which is 177 feet deep, is given in the accompanying table.

Bricelyn.—The public supply of Bricelyn, which is used by about three-fourths of the people, is derived from a well 107 feet deep, in which the water stands 19 feet below the surface. The private wells vary greatly in depth. Many flowing wells have been obtained on the lower ground in the valley of Brush Creek, the one nearest Bricelyn being a half mile east of the village. Their average depth is about 75 feet, and they apparently procure their water from a bed of gravel that lies upon the Paleozoic of this part of the county.

Easton.—The public supply at Easton is taken from a well 110 feet deep, in which the water stands virtually at the surface. Nearly one-half the people use this supply, the water being furnished free of charge.

Delavan.—The public supply at Delavan is taken from a well 473 feet deep, and is evidently drawn from the Jordan sandstone. The water stands 15 feet below the surface. The Chicago, Milwaukee and St. Paul Railway Company uses a well that obtains its supply from a depth of 60 feet. An analysis of this water is given in the table.

Kiester.—In the village of Kiester the public supply is drawn from a well 400 feet deep, but most of the inhabitants rely on private wells.

Minnesota Lake.—The public supply at Minnesota Lake is obtained from a drilled well 185 feet deep. Most of the people have private wells.

SUMMARY AND ANALYSES.

The beds of sand and gravel in the deeper portion of the glacial drift afford a convenient and satisfactory source of water supply, and a large reserve is stored in the underlying rock formations, especially in the St. Peter, Jordan, and Dresbach sandstones. The section of the deep well at Blue Earth given above will serve to show the position and approximate thickness of these formations. The water from the lower beds will not rise higher than that from the glacial drift, and deep drilling for flowing wells is therefore not advised.

Mineral analyses of water in Faribault County.

[Analyses in parts per million.]

	Glacial drift.							Mixture.	Paleozoic.		
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
Depth ....feet..	60	40	40	40	58	114	266 and 150	266	265	1,240	177
Calcium (Ca)..........	111	90	96	59	102	82	168	184	81	179	96
Magnesium (Mg)......	37	33	35	41	38	29	53	55	29	50	31
Sodium and potassium (Na+K)...........	34	11	15	......	19	112	97	51	95	98	67
Bicarbonate radicle (HCO_3)............	494	431	461	323	449	547	402	398	522	442	435
Sulphate radicle (SO_4).	91	30	43	47	72	110	491	451	91	476	146
Chlorine (Cl)..........	1.5	1.5	1.0	......	4.1	6.0	5.9	4.0	2.9	6.6	4.5
Total solids...........	520	386	426	496	462	615	1083	944	558	1,044	603

1. Railway well at Delavan. October 13, 1888.
2. Railway well at Huntley. October 16, 1888.
3. Railway well at Huntley. October 12, 1892.
4. Railway well at Huntley. December 27, 1899.
5. Railway well at Huntley (new source). September 18, 1901.
6. Railway well at Wells. 1892.
7. Mixture of water from the village and railway wells at Winnebago, 266 and 150 feet deep, respectively. April 8, 1895.
8. Village well at Winnebago. April 8, 1895.
9. Village well at Wells. February 19, 1896.
10. City well at Blue Earth. 1899.
11. Railway well at Elmore.

Analyses 1, 2, 3, 4, 5, 6, 8, and 9 were furnished by G. N. Prentiss, chemist Chicago, Milwaukee and St. Paul Railway Company. Analyses 7, 10, and 11 were furnished by G. M. Davidson, chemist Chicago and Northwestern Railway Company.

FILLMORE COUNTY.

By C. W. Hall and M. L. Fuller.

SURFACE FEATURES.

Fillmore County lies on what was originally a broad plateau. In the western and southern portions of the county the plateau character is still preserved, but in the northern and eastern parts the surface is very rugged, consisting of deep, sharp valleys separated by ridges with flat or gently rolling crests, the latter representing remnants of the original surface. The elevation of the plateau in the western half of the county is more than 1,300 feet above sea level, but to the east it descends to 1,250 feet, or about 550 to 600 feet above the Mississippi. In the western part of the county, where the plateau has not been dissected, it is fairly level, the flatness being due in part to the mantle of glacial drift that rests upon it. Farther east there is little or no drift, but the upland surface is covered by a thin mantle of yellowish silt or loess, which, though it somewhat masks the inequalities of the rock surface, does not completely hide them, leaving a rather rolling surface. In the areas underlain by the Galena limestone and Decorah shale occasional basins or sink holes as well as mounds and low hills of the limestone occur.

The principal valleys are those carved by Root River and its tributaries. In the harder rocks the valleys are narrow and canyon-like, but those in the softer rocks reach a width of a mile in places and contain extensive deposits of alluvium. The streams generally flow in rapids where they cross from harder to softer rocks, the change also being marked by terraces along the sides of the valleys. In some places bluffs and picturesque pinnacles border the valleys.

SURFACE DEPOSITS.

The surface deposits include alluvium, loess, and glacial drift. The alluvium of Fillmore County includes the gravels and sands deposited by Root River and its tributaries. The thickness of these deposits in some places is not known, but perhaps reaches 50 feet or more, the average probably being between 25 and 30 feet. They contain considerable water and usually yield ample supplies for domestic and farm purposes. The loess is a fine yellow loamy silt deposited over the uplands to a depth rarely exceeding 10 feet. It is unimportant as a water-bearing bed, but is of value owing to the fact that it collects rainfall and feeds it to the underlying rock.

The glacial drift of Fillmore County consists chiefly of clay mixed with pebbles and bowlders, but locally it contains gravel and sand layers and in some places deposits of peat. It is found mainly in the western third of the county, where its greatest thickness is 100 feet.

In the eastern part it is very thin, in many places occurring only in scattered patches. No water is found in these thin isolated deposits, but in the sand and gravel layers of the thick accumulations quantities sufficient for farm and domestic purposes occur. Certain dark clays, about 20 feet thick and underlain by several feet of water-bearing sandstone, have been thought to be Cretaceous, but there is little ground for this assumption.

PALEOZOIC FORMATIONS.

The Devonian rocks in Fillmore County consist of thin-bedded, even-grained, granular, yellow magnesian and arenaceous limestones. They outcrop on the hilltops in the southwestern townships and have a total thickness of about 100 feet. They afford a small supply of water to shallow wells and give rise to occasional springs.

The Maquoketa shale consists of calcareous and sandy shales, aggregating about 80 feet in thickness. It outcrops along a northwest-southeast line from a point near Hamilton on the western to Granger on the southern boundary. Because of their impervious character the shales contain practically no water, but intercept the water seeping through the overlying Devonian and residuary material, forming an important spring horizon.

The Galena limestone, Decorah shale, and Platteville limestone outcrop in a number of bluffs bordering the headwaters of Root River. On the uplands the Galena limestone yields moderate quantities of water, but near the valley edges the water is largely lost by leakage. The supplies from the Platteville limestone are very small, as the water either escapes into the adjacent valleys where the formation outcrops or sinks into the underlying St. Peter sandstone.

The St. Peter sandstone outcrops in the upper parts of the bluffs bordering the principal streams and constitutes the surface rock on the upland areas in the eastern third of the county. It yields large supplies except near the valleys, where leakage has removed most of the water.

The Shakopee dolomite is about 75 feet thick and is exposed in the bluffs bordering the principal streams in the eastern half of the county. Where it lies beneath the St. Peter sandstone it seems to hold up the water in that formation and makes shallow wells possible. It carries some water in its bedding planes and sandy layers, but rarely affords supplies to wells. It gives rise to some springs along the valleys.

The New Richmond sandstone is from 25 to 40 feet thick and outcrops in the principal valleys. It is not an important source of water supply.

The Oneota dolomite is essentially a magnesian limestone, but in this county carries some green sand and occasionally shaly layers.

It is about 200 feet thick and is exposed in the valleys of Root River and its tributaries. It carries less water than the alluvium of the valleys and less than the overlying New Richmond. In itself it is not to be regarded as a source of water supply.

The Jordan sandstone is about 100 feet thick. It outcrops in the Root River valley as far upstream as Lanesboro and also along several tributaries of this stream in the eastern portion of the county. Along its exposures in the valleys the supplies of water that it yields are usually small, but to the west where it passes under the uplands it carries large amounts of water and is the strongest water-bearing bed encountered. Here the water must, however, be raised several hundred feet to bring it to the surface.

The St. Lawrence formation consists of about 175 feet of limestones, shales, and sandy beds, of which about 75 feet are exposed in the bottom of the Root River valley below Peterson. It carries a little water in the sandy beds, but because everywhere except in the valley mentioned it is overlain by the Jordan, which is a much stronger water bearer, it is of little importance as a source of supply.

The Dresbach sandstone occurs about 125 feet below Root River at the eastern boundary of the county. It is an open porous sandstone, saturated with water under considerable pressure, and yields supplies that rise nearly or quite to the surface of the river bottoms. In the valleys and near the edge of the uplands this sandstone affords the best source of water, but where it is deep below the surface, as in the western part of the county, there is no advantage in sinking to it, as equally satisfactory supplies can be obtained from the Jordan at a considerably less depth.

Beneath the Dresbach sandstone are shales that carry little or no water. Below these shales is a sandstone that affords large volumes of water, but perhaps no more than the Dresbach sandstone, although it is under somewhat greater head. At still greater depths is the red clastic series, resting in turn on a granite foundation.

UNDERGROUND WATER CONDITIONS.

Head of the water.—Flowing wells are obtained in the valleys of Root River and its affluents as far upstream as Rushford. The water comes from the Dresbach and underlying sandstones and rises to 730 feet above sea level. It will not, however, rise to the surface in the upper parts of the valley, and on the uplands stands several hundred feet below the surface. Even in the highest portions of the county, the water from shallow horizons underlain by impervious formations may stand near the surface. The head of the drift wells varies with their position, depending on the altitude of the surrounding morainic masses and outwash plains. There are several flowing wells in T. 101 N., R. 13 W., near the state line, and others occur along upper Iowa River in Iowa.

Quality of the water.—The water of the county is all moderately hard. It contains considerable quantities of calcium and magnesium and the bicarbonate radicle, but is not otherwise highly mineralized. See the analyses given in the accompanying table.

Wells.—The wells of Fillmore County may be divided into several groups, the most important of which are (1) the shallow wells in glacial drift, (2) the shallow wells in alluvium, (3) the nonflowing rock wells, and (4) the flowing rock wells. The drift is not commonly a source of water except near the western border of the county, where it is 50 to 75 feet thick or more in places and usually carries considerable water at a level within easy reach of shallow open wells. Eastward across the county the drift decreases rapidly in thickness and yields but little water, so that it is necessary for wells to enter a rock formation. Except near the edge of the uplands, satisfactory supplies can be obtained at depths of 100 to 150 feet. Near the deepest valleys, however, the water is free to escape from the bluffs, and many of the upland wells must penetrate to depths of several hundred feet. It is not unusual for wells near the bluffs to go 250 to 350 feet for their supplies, and in some of them water is not obtained until the level of the valley bottom is reached. In general the wells on the south side of the valleys are deeper than those on the north side, because of the southward dip of the rocks. In the deep valleys many farm and village wells obtain their supplies from the alluvium at very shallow depths, but more satisfactory wells are procured in the valleys by drilling into the underlying sandstones, which are reached at moderate depths and from which the water rises nearly or quite to the surface.

Springs.—In the deep valleys everywhere cut into the rock in the eastern portion of the county the water is free to escape and issues in numerous springs, some of them very large. These springs occur along lines that mark the upper surface of impervious shales and limestones. Many of the streams fed by such springs are capable of affording water power, and some of them are sources of supply for public waterworks. The strongest springs are said to be on the north side of the east-west valleys, the emergence of the water being facilitated by the southward dip of the rock.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Lanesboro.—The village of Lanesboro obtains much of its supply from large springs issuing from the New Richmond sandstone and possibly from the Oneota dolomite and Jordan sandstone. The spring known locally as the City Spring is inclosed to form a cement-lined cistern about 15 by 30 feet in size, from which the water is pumped by an electric motor into the village system. Although only about 27,000 gallons is consumed daily, the spring is said to be capable of yielding four times that amount. Analyses of the water are given in the tables (Nos. 4 and 5). There is a large spring in the park near the village, the water of which apparently comes from the Jordan; another 1½ miles south of the village is one of the largest springs in this locality and was formerly used for water power. These springs are interesting geologically as well as economically, because they indicate that large streams flow through deep-lying Paleozoic rocks. The drainage of the region is sufficient to produce such underground erosion that long cavernous passages have been carved out of the limestone. Where these springs are used for drinking supplies, the source should be sought out and guarded against pollution.

Spring Valley.—The public supply at Spring Valley was at first obtained from springs issuing from the limestones and shales. This source soon became inadequate and the present supply is derived chiefly from a well 40 feet in diameter, sunk into the limestone and shale 18 feet below the surface.

Preston.—One of the most notable springs of the county is that furnishing the Preston public supply. It issues from bedding planes at the base of the New Richmond sandstone and the top of the Oneota dolomite. It is only 2 feet above the level of the river and was formerly subject to overflow, but is now protected by cement walls. The water is collected in a cement cistern built down to the rock. The yield is said to be 250 gallons a minute, of which only about 30 gallons is required for the public supply. The flow is constant and independent of seasons. The water has but little permanent hardness and will not form much scale if heated before being admitted to boilers. Two analyses are given in the table.

Rushford.—The first public supply for Rushford was installed about 1887, the water being obtained from a well sunk on the side of the bluff above the village. This well was used for a number of years, but, because of the expense of pumping, a new well 553 feet deep was sunk in 1901 on low ground in the center of the village, and flowing water was obtained. The flow shows certain puzzling fluctuations. When the barometric pressure is low, and usually in the spring, it discharges out of a pipe 1½ feet above the ground, but at other times the flow stops. The changes are irregular, however, and may have some other cause besides variations in barometric pressure.

Chatfield.—The village of Chatfield, which extends into Olmsted County, has a system of public waterworks deriving its supplies from wells sunk to the Jordan sandstone. Private wells drilled to depths of 65 to 100 feet procure an adequate supply.

Harmony.—The public supply at Harmony comes from a well 220 feet deep, which ends in the St. Peter sandstone. The water is reported to stand 130 feet below the surface. It is used largely for domestic purposes.

Wykoff.—The public supply at Wykoff is derived from a well 600 feet deep, which has been pumped at the rate of 180 gallons a minute.

The water is reported to stand 300 feet below the surface. It is used by most of the people for domestic purposes.

Fountain.—The first deep well in the vicinity of Fountain is said to have been sunk by William Herman. Its success showed the possibilities of deep wells, and accordingly others were drilled by private persons and by the municipality. The first village well was originally 6 inches in diameter and 376 feet deep, but later it was sunk to a depth of 585 feet and now obtains a good supply, the water rising within 340 feet of the surface. A street well was sunk to a depth of 376 feet and was pumped by a windmill and later by a gasoline engine, but it finally failed. A new village well, sunk in 1906 to a depth of 608 feet, obtains water at depths of 90 feet and 370 feet and at the bottom. The records of the two deep wells are as follows:

Section of the village wells at Fountain.

[Authorities: Old well, W. G. Banks; new well, O. H. Case.]

	Old well.		New well.	
	Thickness.	Depth.	Thickness.	Depth.
	Feet.	*Feet.*	*Feet.*	*Feet.*
Soil and clay	20	20	10	10
Galena, Decorah, and Platteville:				
Limestone	155	175	160	170
Blue shale	45	220	....	....
Limestone and shale	30	250	....	....
Green shale and limestone	....	....	30	200
St. Peter sandstone	90	340	90	290
Shakopee dolomite	30	370	85	375
New Richmond sandstone	40	410	35	410
Oneota dolomite	180	590	190	600
Jordan sandstone (entered).				

The large springs from which Fountain derives its name are a mile or more northwest of the village and issue at a level 147 feet lower than the general level of the village. The water comes in large volume from solution crevices in the limestone immediately above the shales (see the above sections). At one time it was lifted by a ram to the village, but the springs were abandoned because of the muddiness of the water after storms, evidently due to the earth entering the underground passages through the sinks in the vicinity. Since these sink holes are often made the receptacles of refuse, the waters are liable to pollution, and the village did well to abandon its supply.

Mabel.—The public supply at Mabel is here drawn from a well 140 feet deep, in which the water rises within 40 feet of the surface. A majority of the people use private wells.

Canton.—In the village of Canton there is a well 240 feet deep. The stock yards are supplied from a well reported to be 318 feet deep. These wells apparently derive their water from the New Richmond and Jordan sandstones, respectively.

SUMMARY AND ANALYSES.

The most reliable supplies in Fillmore County are derived from the deep sandstone formations. The water from these beds stands at a level far below the upland surface, but rises nearly to the level of the deepest valleys and near Rushford produces flows. Many satisfactory wells for farm and domestic supplies are obtained from the surface deposits and from the rock formations near the surface. These wells have an advantage over those going to the deep sandstones both in depth and in head. The waters from all the horizons utilized are similar in chemical composition. They contain rather large amounts of calcium and magnesium and the bicarbonate radicle, but little other mineral matter.

Mineral analyses of water in Fillmore County.

[Analyses in parts per million.]

	Root River.			Springs.				
	1.	2.	3.	4.	5.	6.	7.	8.
Depth . . . feet	......	......	......	......	......	......	......	......
Calcium (Ca)	60	74	62	83	73	60	78	79
Magnesium (Mg)	20	21	20	26	24	21	25	18
Sodium and potassium (Na+K)	6.5	7.5	9.5	10	3.7	4.5	11	4.1
Bicarbonate radicle (HCO_3)	290	334	303	385	318	251	240	314
Sulphate radicle (SO_4)	7.2	10	8	16	16	93	38	8.1
Chlorine (Cl)	.6	1.0	1.6	.8	24	2	....	25
Total solids	242	278	257	326	286	248	272	286

	St. Peter and New Richmond sandstones.										Jordan sandstone.	
	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.
Depth . . . feet	23	15	30	45	12	60	190	96	318	389	585	600
Calcium (Ca)	113	74	67	61	185	68	90	85	88	79	82	76
Magnesium (Mg)	22	28	28	21	49	24	32	30	30	24	33	23
Sodium and potassium (Na+K)	32	4.3	.....	2	52	7.1	12	2	9	6.5	3.8	6.1
Bicarbonate radicle (HCO_3)	476	341	295	286	511	304	460	406	415	350	342	334
Sulphate radicle (SO_4)	47	26	38	10	196	28	5.9	4	6.5	20	23	22
Chlorine (Cl)	.8	67	.....	3	108	6.1	4.5	3	9.1	1.2	1.1	4
Total solids	456	312	310	241	845	295	389	327	352	305	301	296

1. Water from Root River at Lanesboro. October, 1892.
2. Water from Root River at Lanesboro. 1903.
3. Water from Root River at Preston. October, 1892.
4. Spring at Lanesboro. August, 1903.
5. Spring at Lanesboro. December, 1906.
6. Spring at Spring Valley. October, 1906.
7. Spring at Preston. December, 1899.
8. Spring at Preston. 1906.
9. Chicago, Milwaukee and St. Paul Railway well at Rushford. November, 1892.
10. Chicago, Milwaukee and St. Paul Railway well at Spring Valley. August, 1888.
11. Chicago, Milwaukee and St. Paul Railway well at Spring Valley. December, 1899.
12. Chicago, Milwaukee and St. Paul Railway well at Mabel. January, 1889.
13. Chicago, Milwaukee and St. Paul Railway well at Preston. Sept. 1892.
14. Chicago, Milwaukee and St. Paul Railway well at Mabel. September, 1892.
15. Chicago, Milwaukee and St. Paul Railway well at Canton. September, 1892.
16. Village well at Harmony. January, 1889.
17. Well at the stock yards in Canton. December, 1888.
18. Chicago, Milwaukee and St. Paul Railway well at Fountain. December, 1895.
19. Village well at Fountain. December, 1890.
20. Village well at Fountain. February, 1907.

Analyses 5, 6, and 8 were made for the United States Geological Survey by H. S. Spaulding; all the others were furnished by G. N. Prentiss, chemist Chicago, Milwaukee and St. Paul Railway Company.

FREEBORN COUNTY.

By C. W. Hall and M. L. Fuller.

SURFACE FEATURES.

Freeborn County lies upon the plateau that forms the southeastern portion of the State. Its topography is very simple. The extremes of altitude are between about 1,150 feet above sea level in the northwestern corner and about 1,350 feet on the morainic summits in the central portion. Its average altitude is not less than 1,250 feet. Two well-defined belts of morainic mounds extend from north to south across the county, one of them through the eastern part and the other and larger belt through the west-central part. Owing to the irregular surface caused by the deposition of these belts, a number of lakes have been formed which lie in the depressions and mark the ground-water level in this part of the county. Along the eastern and western borders and on the smooth stretch between the morainic districts the land is relatively level and has an altitude between 1,150 and 1,250 feet, with very little variation.

The streams which carry off the surface drainage of the county flow partly southward across Iowa to Mississippi River and partly northwestward across Faribault and Waseca counties into Minnesota River. The west-central morainic belt forms the divide that separates these waters. There are no streams of considerable size within the county and many hundred square miles show no definite drainage valley.

SURFACE DEPOSITS.

The glacial drift varies from 75 to more than 200 feet in thickness. Along the eastern border of the county wells indicate a thickness of 100 feet, which increases gradually westward and northward to more than 200 feet, the last-named thickness being reported near Hartland and near Clarks Grove. The two broad north-south morainic belts are composed of diversified material, including very characteristic drift masses of bowldery gravel and sand, extensive stretches of stratified gravels and sands, and not uncommonly an excellent brick clay, quite free from the bowlders so common in the ordinary drift. Water abounds in these morainic accumulations, but owing to the diversified character of the material the supply is far from uniform.

Modified drift constitutes the surficial deposit of the level tracts between the morainic ridges. The stratified character of this material is frequently seen in the dug wells, which are 10 to 50 feet deep. Much of the material is in the form of a lake deposit, but doubtless it was mostly formed as an outwash from the melting ice and accumulating moraines.

CRETACEOUS DEPOSITS (?).

The presence of Cretaceous rocks has repeatedly been announced for Freeborn County,[a] but a review of the records shown by the wells reported fails to make clear the presence of deposits of this period. Fragments of "coal" or wood in advanced stages of transformation to coal have frequently been dug up, but nowhere has there been reported a deposit that may positively be referred to Cretaceous age. In Blue Earth and other counties, particularly Chisago, interglacial peat beds have been discovered; fragments of wood may come from these, and the fragments of lignite or "coal" may easily have been brought in the glacial drift from the counties lying farther west, where such deposits are known to occur.

PALEOZOIC FORMATIONS.

The limestone referred to the Devonian is an extension westward of the formation seen at the surface at and near Austin. It occurs beneath about one-half of the county, with its greatest thickness in the southeastern corner. Associated with it is a belt of water-bearing sandstone which may also belong to the Devonian or may prove to be an arenaceous layer of the earlier period represented by the Galena, Decorah, and Platteville formations. Good supplies of water have been drawn from this limestone through a number of wells drilled into it in the southeastern part of the county.

Beneath the drift in the northwestern quarter of the county occurs the buff magnesian Galena limestone, underlain by a thin bed of Decorah shale and 25 or 30 feet of Platteville limestone. The total thickness of these formations, as indicated by the Freeborn well, appears to be more than 300 feet. Little or no water is found in the shale, but in general the limestones will yield enough for domestic and farm purposes and occasionally, where the upper surface is broken and fissured, enough for industrial and small public supplies.

The St. Peter sandstone underlies the Platteville limestone throughout the county and is generally 600 to 700 feet below the surface. Its thickness is believed to be about 140 feet, and it is usually saturated with water under considerable pressure, the supplies entering the wells freely and affording quantities usually sufficient for all purposes.

Beneath the St. Peter sandstone is a succession of limestones, sandstones, and shales, reaching a depth of many hundred feet. All the sandstones, except those of the red clastic series, contain large amounts of water which would be yielded to deep wells penetrating them. In general, however, the supplies are no greater than those from the St. Peter, and hence there has been usually no advantage in sinking to them.

[a] Ann. Rept. Geol. and Nat. Hist. Survey Minnesota, 1874; Final Rept., vol. 1, 1882, pp. 382-385, etc.

UNDERGROUND WATER CONDITIONS.

Wells.—Owing to the fact that the entire surface of the county is covered with drift, rarely less than 100 and at many points more than 200 feet thick, by far the greater number of the wells obtain their supplies from this material, though many have also been sunk to the underlying rock formations. The wells may be grouped in four general classes—1) shallow wells in glacial drift, (2) deeper wells in drift, (3) wells sunk to the glacial-subglacial contact zone, and (4) wells entering the Paleozoic rocks.

The wells of the first class seldom exceed 30 feet in depth and obtain their water from thin, gravelly layers in the upper portion of the drift. The water at this horizon is more liable to pollution from the surface seepage than any of the deeper supplies, and it often fails in dry seasons. For both these reasons this source of water is generally less desirable than the deeper formations.

Most wells of the second class are 25 to 75 feet deep and penetrate a considerable thickness of yellow and blue drift. They obtain their supplies from interbedded gravelly layers at varying depths. Being of the tightly cased tubular type and carried through impervious clays, these wells generally are freer from danger of contamination than those in the first class. The water is commonly harder but more palatable than that of the shallow wells. In some places, however, where much ancient and slowly decomposing organic material occurs in the drift, the waters may taste strongly of iron and sulphur derived from the lignite, black clay, etc.

The third class of wells—those entering the materials of difficult stratigraphic assignment between the drift and the underlying hard rock—commonly obtain abundant water. The supply is, however, very often of the ferruginous or sulphurous character described above. Not uncommonly wells sunk into the upper layers of the Paleozoic limestones gather their waters from this contact zone. In such wells the limestone serves as a reservoir for collecting supplies.

Most of the wells of the fourth class obtain their water from the formations lying only a short distance below the glacial drift. Thus near the northeastern corner a number are supplied from the Devonian sandstone. But the deeper wells pass through the upper formations and reach the St. Peter or sandstones at still lower levels.

Flowing areas.—Flowing wells are found in the lowlands about Geneva, Albert Lea, and Glenville, in Riceland Township, and elsewhere. The water is obtained in part from the base of the drift and in part from the upper portion of the underlying Paleozoic formations. The head appears to come from the adjacent moraines.

Springs.—The surface of Freeborn County is in general undissected and springs are accordingly scarce. Nevertheless, a considerable number of small springs issue along the streams and at the foot of the morainal hills, where they are used for stock purposes.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Albert Lea.—The public supply at Albert Lea is used by approximately one-half the people, and it is estimated that 200,000 gallons of water are consumed daily. The supply is obtained from two drilled wells. One is 448 feet deep and ends in the Galena; the other is 660 feet deep and reaches the St. Peter sandstone. The water is under sufficient head to rise to the surface, and the maximum yield is very large. It is reported that the wells under test have yielded at the rate of 1,000 gallons a minute.

Alden.—The well that furnishes the public supply at Alden is 215 feet deep and ends in the Galena. About one-fourth of the people use the water from this well, and nearly 20,000 gallons are consumed daily.

Hartland.—The public waterworks in the village of Hartland are supplied from a well that ends in the Galena limestone at a depth of about 300 feet.

Emmons.—The waterworks at Emmons are supplied by a drilled well 160 feet deep. Virtually all the people depend on private wells.

SUMMARY AND ANALYSES.

The glacial drift furnishes the most accessible and largely utilized source of water supply in Freeborn County. Several strong water-bearing beds, however, lie at greater depths and afford a large reserve that can be tapped by deep wells anywhere within the limits of the county.

Mineral analyses of water in Freeborn County.

[Analyses in parts per million.]

	Glacial drift.			St. Peter sandstone.	
	1.	2.	3.	4.	5.
Depth ... feet	14	18	20	660	643
Calcium (Ca)	151	98	116	100	99
Magnesium (Mg)	42	26	33	30	30
Sodium and potassium (Na+K)	19	33	16	22	12
Bicarbonate radicle (HCO_3)	398	445	394	496	455
Sulphate radicle (SO_4)	164	52	98	18	27
Chlorine (Cl)	65	....	25	1.5	....
Total solids	639	435	486	423	....

1. Chicago, Milwaukee and St. Paul Railway well at Albert Lea. 1897.
2. Chicago, Rock Island and Pacific Railway well at Albert Lea.
3. Chicago, Milwaukee and St. Paul Railway well at Albert Lea (former supply). 1892.
4. City well at Albert Lea. 1892.
5. Minneapolis and St. Louis Railroad well at Albert Lea. 1903.

GOODHUE COUNTY.

By C. W. Hall and M. L. Fuller.

SURFACE FEATURES.

Like other counties bordering on Mississippi River Goodhue County has a surface consisting of relatively level upland tracts separated by the deep valleys of the numerous tributaries of that stream. These upland areas, which are a part of a once continuous plateau, range in elevation from 1,000 feet above sea level in the north to 1,100 feet in the center, and 1,150 feet in the south, where they stand 450 feet or more above the Mississippi. They preserve the flat or gently rolling aspect characteristic of the original plateau surface, and are also marked here and there by sudden variations of level where the rocks change in hardness. The highest elevations are in the areas of the harder and more resistant Galena and Platteville limestones. The irregularities of the uplands are subdued in the east by a coating of loess, and in the west by the glacial drift.

The county is crossed in its northern part by Cannon River. The bed of this stream is 250 to 300 feet below the uplands. Along the south side of the county the north branch of Zumbro River has eroded a channel 100 to 150 feet deep. Besides these there are numerous short tributaries of the Mississippi occupying ravines or valleys, which in their lower portions may be so much as 400 feet below the adjacent uplands. Except a few of these ravines, the valleys of Goodhue County are not canyon-like, and the streams are so numerous that the upland tracts are generally small.

Along Cannon River, and also along the Mississippi, both above and below the mouth of the Cannon, are found series of terraces, some of which are of considerable extent. They represent the action of the waters from the glaciers that once occupied the region and bear evidence of some interesting features in the glacial and post-glacial history of the State.

SURFACE DEPOSITS.

The surface deposits of Goodhue County include alluvium, terrace gravels, loess, and glacial drift.

The alluvium, consisting of stratified, loamy gravel, sand, and silt deposited by the streams, has an unknown thickness, but probably is at most 150 feet thick. Considerable amounts of water, derived from rainfall, from downward percolation from the streams, and from leakage from the hillsides, occur in the pores of the deposit and are available to wells of moderate depth in amounts sufficient for domestic, farm, or small industrial purposes. Along Mississippi River within this county are some of the most notable alluvial beds the State affords.

Owing to recent erosion by the streams their ancient flood plains are now seen only as narrow shelves or terraces. Water is readily absorbed by the gravels and the sands of these terraces, but because of their exposed position this water is quickly drained away; hence the terraces are not generally satisfactory sources of supply unless the wells penetrate to a point below the level of the adjacent streams.

The loess is a yellow unstratified silt reaching 15 feet or more in thickness. It is found mainly on the flat-crested ridges between the streams, being elsewhere largely removed by subsequent erosion. Owing to the thinness of the deposit it is seldom a source of water supply, but is important because it absorbs quickly the water falling on its surface and feeds it to the underlying rock.

The glacial drift of Goodhue County is in some places 50 to 100 feet thick and is predominantly of the clayey type, weathered to a yellow color for 10 to 20 feet below the surface. Locally it is somewhat gravelly, especially at its base, thus affording good facilities for the storage of water. The drift-covered area occupies a strip several miles long from the northern point of the county southwestward to a point south of Dennison, where its boundary turns southeastward, passing near Zumbrota and Pine Island.

Much discussion has been aroused by certain beds of clay found in the central portion of Goodhue County, the best-known exposure of which is in T. 112 N., R. 15 W. It is a fine blue clay of uniform texture and of so excellent a quality that it is used in a large manufactory of tile and earthenware at Red Wing. It has all the characters of the Cretaceous as known in identified localities and has accordingly been considered to be of Cretaceous age. Inspection of the beds, made possible by quarrying operations, has shown, however, that glacial gravels lie beneath the clay, and this situation leads to the conviction that the material, though derived from Cretaceous beds elsewhere, is stratigraphically a mass of glacial drift.[a]

ROCK FORMATIONS.

Rocks are exposed in the bluffs along Mississippi River and its larger tributaries in practically continuous outcrops across the county. On the crest of the ridges between the streams, however, rock rarely shows at the surface because of the mantle of loess. Farther west the rock formations are still more deeply buried by glacial drift.

The Galena, Decorah, and Platteville formations, with a thickness varying from 50 to 75 feet, occur beneath the highest lands in the southwestern part of the county, but are of little value as a source of water.

[a] Sardeson, F. W., The so-called Cretaceous deposits in southeastern Minnesota: Jour. Geology, vol. 6, 1898, pp. 679-691.

The St. Peter sandstone is about 150 feet thick and outcrops along the rim of the uplands bordering the Cannon and Mississippi river valleys. In the eastern part of the county it underlies the upland flats between the streams, from which it passes beneath the glacial deposits to the west, appearing at the surface only in deep valleys. Where deeply buried it carries considerable water and affords good supplies to wells that pass through the overlying drift and limestone, but along its outcrops its supplies are much smaller, owing to the escape of the water into the adjacent valleys.

The Shakopee dolomite, which is about 25 to 40 feet thick, outcrops along the edge of the bluffs of Cannon and Mississippi rivers and their tributaries. Its contact with the overlying St. Peter affords a notable spring line. Certain sandy layers afford a little water, but its significance is in its relation to the two sandstones between which it lies.

The New Richmond sandstone is about 30 feet thick and outcrops between the Shakopee and Oneota dolomites in the river bluffs. It carries considerable water and at some distance from the valleys may furnish supplementary supplies of importance. Beneath the drift area, however, it is of slight importance as a water bearer, because the St. Peter, which also is here under cover, furnishes more copious supplies.

The Oneota dolomite is similar to the Shakopee in all its rock characters but reaches a thickness of 150 feet in its outcrops along Mississippi and Cannon rivers. It carries some water in joints and bedding planes, but the yield is much less than from the overlying New Richmond sandstone, and hence it is of little importance as a source of supplies. Wells starting in the Oneota should be carried through it to the Jordan sandstone.

The Jordan sandstone is about 90 feet thick, outcropping in the lower bluffs of the deepest valleys in the eastern part of the county. From its outcrop it dips slightly southwestward, underlying the entire county in that direction. Near its outcrop it will furnish only small supplies, but on the uplands, at a distance from the valleys, it will yield large supplies of good quality to deep wells.

The St. Lawrence formation consists of shale and dolomite with some sandstone and green sand, the whole having a thickness of about 140 feet. It occurs in the lower portions of the bluffs and beneath the alluvium of the Mississippi Valley and its large tributaries. It carries a little water, especially in its sandy layers, but because of the compact texture of the formation as a whole the volume is much less than in the overlying Jordan or in the underlying Dresbach sandstone, and hence it is rarely to be considered as a source of supply.

The Dresbach is a white to gray mica-bearing sandstone with some shale. It is about 85 feet thick and lies entirely below the level of Mississippi River. It carries large amounts of water in its porous, sandy layers, and its supplies are available to deep wells at all points in the county. The water is under considerable artesian pressure and will rise to the level of the Mississippi flood plain or slightly higher.

The shales which underlie the Dresbach sandstone are present throughout the county and will yield large supplies of water. In the Mississippi River valley the water is usually under sufficient head to flow at the surface. Beneath these shales occurs the red clastic series, consisting of a succession of red sandstones, quartzites, and shales, the total thickness of which varies more than that of any stratified formation of southeastern Minnesota. This variation is probably due to the uneven granite surface upon which the rocks were laid. Experience has shown that when these red rocks are reached little additional water may be expected, and the water which they do contain is very hard and rich in sodium chloride.

Granite has been reported at Red Wing at a depth of a little more than 200 feet, but this report has not been verified.

UNDERGROUND WATER CONDITIONS.

Head of the water.—In the southwestern portion of the county the water stands but little below the upland surface, many shallow wells being only 15 to 30 feet deep, but toward Mississippi and Cannon rivers the ground-water table gradually drops and adjusts itself to the drainage level of the deep valleys.

Along the entire length of Mississippi and Cannon rivers and many tributary streams in this county flows of good volume are obtained from the Dresbach sandstone. This artesian supply has been utilized constantly since 1881, and the demands upon it have steadily increased, not only in Red Wing but at various places throughout the length of the valley; as a result the flow has been slowly diminishing.

Quality of the water.—So far as has been determined by the investigation the water from all horizons is hard but wholesome. The water from the red clastic series is especially hard and high in chlorine content.

Springs.—Numerous springs occur along the contact zone of the several Paleozoic formations and afford copious supplies of wholesome water for dairying and locally for power. These springs flow from different horizons in different parts of the county. In the high area near the southwestern corner the top of the Galena limestone affords an excellent base along which the water makes its way within the glacial drift, loess, and residuary material that together make up the surface covering. The top of the Shakopee affords another horizon of springs where the supplies are collected from the extensive St. Peter sandstone. From the highest exposures of the Shakopee to the lowest Oneota there are no well-defined spring horizons, but at the bottom of the Jordan sandstone there is another spring zone of notable proportions, the underlying shaly beds of the St. Lawrence formation giving the necessary floor along which the waters of the sandstone creep to the valleys.[a]

WATER SUPPLIES FOR CITIES AND VILLAGES.

Red Wing.—The lower portion of the city of Red Wing is built on the Mississippi flood plain, which is more than a mile in greatest width. The water supply from the alluvium is copious, but because of seepage from higher ground it has become so contaminated that it is unsafe for human use. The underlying rock, which yields large supplies of water, is reached at depths varying up to 130 feet.

At Red Wing and in its immediate vicinity the artesian zones are heavily drawn upon. The first flowing well was drilled for the Chicago, Milwaukee and St. Paul Railway Company. It reached a depth of 500 feet, passing through the shales of the St. Lawrence formation, the Dresbach sandstone, and underlying shales, and penetrating the red rock. Water rose under a pressure of 40 pounds per square inch at the surface and maintained an excellent supply until the casing became corroded and the well clogged. A second well drilled for the railway company yielded equally good supplies. Among other firms utilizing artesian waters are the following: Simmons Milling Company, G. A. Carlson, Lagrange Milling Company, Red Wing Malting Company, Minnesota Malting Company, Red Wing Brewing Company, Minnesota Stoneware Company, Red Wing Gas Company, and Chicago Great Western Railway Company. There are also two flowing wells at the State Training School, 2 miles from the city. The strongest well at present is probably that of the Chicago Great Western Railway Company, the water from which rose 28 feet above the surface. The flows of some of the wells have been very large. In the Chicago, Milwaukee and St. Paul Railway well, for example, W. E. Swan, the driller, reported the original flow at 800 gallons a minute and the head at 75 feet above the surface. The first flow was struck at 191 feet, and the yield increased until the red rock was reached. Formerly the flowing wells were used without pumping, but at present some of them are pumped. The diminished

[a] Winchell, N. H., Final Rept. Geol. and Nat. Hist. Survey Minnesota, vol. 2, 1885, pp. 20, 21.

yield is due to local interference from the drilling of many wells in the same vicinity and, in some of the older wells, to the corroding of the casing. Analyses of the water from several of the flowing wells are given in the accompanying table.

The following record of the strata underlying Red Wing is compiled from drillers' notes and data published by the Geological Survey of Minnesota:

General well section at Red Wing.[a]

	Thickness.	Depth.
	Feet.	*Feet.*
Jordan sandstone [b]	70	....
St. Lawrence formation:		
Sandy shale	10	35
Blue shale	50	85
Sandstone	10	95
Blue shale	30	125
Alternating sandstone and limestone	45	170
Dresbach sandstone and underlying shales:		
White sandstone	50	220
Shale and shaly sandstone	250	470
Red shale, etc	9	479
Granite (entered).		

[a] Winchell, N. H., Thirteenth Ann. Rept. Geol. and Nat. Hist. Survey Minnesota, 1884, pp. 57-58.
[b] This formation and the upper layers of the St. Lawrence occur only in wells located in the upper portion of the city.

The public supply is taken from Mississippi River. Although originally intended for fire protection, it has become generally installed in the business part of the city for ordinary use. The residence districts still use shallow wells and cisterns to a large extent. Without filtration the river water is not fit for domestic supplies because of the large communities located upon the banks farther upstream. Likewise the water afforded by shallow wells is here, as everywhere, soon polluted. In order to have a safe supply, it is necessary to utilize deep artesian waters or else install an efficient plant for filtering the river water. The following table shows the mineral quality of the water from the various sources:

Composition of water at Red Wing.

	Mississippi River.	Shallow wells.	Deep wells.
Hardness:			
Temporary	6.2	8.7	5.6
Permanent	5.2	5.5	3.3
	11.4	12.1	9.2
Residue:			
Fixed	147.2	512.8	208.0
Volatile	52.0	180.3	67.3
	199.2	693.1	275.3

Cannon Falls.—The public supply at Cannon Falls is derived from a flowing well which is 270 feet deep and taps the Jordan sandstone. The following is the approximate stratigraphic section for the vicinity of Cannon Falls:

General section of deep wells at Cannon Falls.

	Thickness.	Depth.
	Feet.	*Feet.*
Platteville limestone (on tops of surrounding hills)	25	25
St. Peter sandstone	150	175
Shakopee dolomite	35	210
New Richmond sandstone	8	218
Oneota dolomite	150	368
Jordan sandstone	80	448

Kenyon.—The public supply for the village of Kenyon is obtained from a shallow well in the weathered and fissured limestone. The first strong water-bearing formation beneath this locality is the St. Peter sandstone, which lies immediately under the Platteville limestone, at a depth of not more than 125 feet. Approximately 200 feet below the bottom of the St. Peter the top of the Jordan sandstone, the second great water-bearing formation of this region, will be reached.

Zumbrota.—The public supply at Zumbrota is obtained from a well 210 feet deep. Most of the people use shallow private wells.

Pine Island.—The public supply at Pine Island is derived from a well 156 feet deep, which has been tested at 100 gallons a minute. This water is used by about two-thirds of the people of the village.

Goodhue.—The public supply at Goodhue is derived from a well 10 inches in diameter and 275 feet deep, which has been tested at 300 gallons a minute. The water is used by nearly all the people for domestic purposes.

SUMMARY AND ANALYSES.

Several sandstone formations will yield large and permanent supplies of moderately hard water in Goodhue County. In the deepest valleys flows are obtained from the Dresbach sandstone and underlying beds, but on the uplands the water from the lowest horizons stands far below the surface. The red clastic series should never be penetrated, as it will furnish only meager amounts of highly mineralized water.

Mineral analyses of water in Goodhue County.

[Analyses in parts per million.]

	Springs.		St. Peter and New Richmond sandstone.			Jordan sandstone.	
	1.	2.	3.	4.	5.	6.	7.
Depth ....feet..	......	......	18	30	40	270	210
Silica (SiO_2)	30	11	14	20	......	15	21
Iron and aluminum oxides ($F_2O_3+Al_2O_3$)	19	2	......	1.7	8.4	7	2.9
Iron (Fe)	......	......	.15	......	......	......	......
Calcium (Ca)	97	96	79	116	76	72	74
Magnesium (Mg)	28	27	27	28	23	26	32
Sodium and potassium (Na+K)	20	13	16	18	5.2	7.4	4
Bicarbonate radicle (HCO_3)	442	292	322	296	308	343	313
Sulphate radicle (SO_4)	26	24	52	100	34	24	23
Chlorine (Cl)	6	18	18	33	4.8	1.0	1.5
Nitrate radicle (NO_3)	......	......	2.3	......	......	......	......
Total solids	447	337	544	514	303	306	277

	Dresbach sandstone and underlying shales.								
	8.	9.	10.	11.	12.	13.	14.	15.	16.
Depth ....feet..	225	300	325	......	450	450	450	450	1,018
Silica (SiO_2)	9.0	3.6	2.2	9.5	......	4.2	6.0	10	......
Iron and aluminum oxides ($F_2O_3+Al_2O_3$)	......	17	.2	......	2.5	......	6.6	......	9.9
Iron (Fe)	1.6	......	......	1.5	......	......	......	.6	......
Calcium (Ca)	62	66	147	62	54	132	64	52	61
Magnesium (Mg)	17	30	25	18	23	43	29	14	37
Sodium and potassium (Na+K)	22	46	.7	29	74	281	72	57	9.0
Bicarbonate radicle (HCO_3)	326	275	491	310	319	464	306	264	370
Sulphate radicle (SO_4)	18	74	65	21	6.5	240	40	22	10
Chlorine (Cl)	5.0	61	1.0	28	88	343	101	60	6.7
Nitrate radicle (NO_3)	Trace.	......	......	Trace.	......	......	......	Trace.	......
Total solids	312	434	483	331	406	1,277	471	361	315

1. Spring at the bed of Cannon River at Cannon Falls. 1902.
2. Spring at Vasa. 1902.
3. Experimental well at Red Wing, situated on opposite side of Chicago, Milwaukee and St. Paul Railway tracks from the pumping station.
4. Village well at Kenyon. November 23, 1906.
5. Railway well at Cannon Falls. December 1, 1882.
6. City well at Cannon Falls. November 23, 1906.
7. Village well at Zumbrota. November 19, 1906.
8. Artesian well at the St. James Hotel in Red Wing.
9. Artesian well of the J. H. Rich Sewerpipe Company at Red Wing. June 11, 1896.
10. Minnesota Stoneware Company well at Red Wing. January 28, 1896.
11. Artesian well at the Red Wing brewery.
12. Railway well at Red Wing. 1891.
13. Well at the poor farm near Red Wing. 1902.
14. Artesian well of the Red Wing Sewerpipe Company. May 11, 1898.
15. Artesian well at the Chicago, Milwaukee and St. Paul Railway station, Red Wing.
16. Well at the state training school in Red Wing. 1899.

Analyses 4, 6, and 7 were made for the United States Geological Survey by H. S. Spaulding. Analyses 3, 8, 11, and 15 were made by M. G. Roberts, chemist Minnesota state board of health. Analyses 1, 2, and 13 were made by J. P. Magnusson, chemist University of Minnesota. Analyses 5 and 12 were furnished by G. N. Prentiss, chemist Chicago, Milwaukee and St. Paul Railway Company. Analyses 9 and 14 were furnished by Edgar & Carr, chemists. Analysis 10 was furnished by the Dearborn Drug and Chemical Company, Chicago. Analysis 16 was furnished by C. F. Sidener, chemist University of Minnesota.

HENNEPIN COUNTY.

By C. W. Hall.

SURFACE FEATURES.

The upland surface of Hennepin County consists chiefly of moraines, which form a series of irregular hills alternating with sharp depressions generally occupied by marshes, sloughs, and lakes. Minnetonka, the largest of the lakes, is more than 10 miles long and has 221 miles of shore line, so that in this respect it is one of the most remarkable lakes in the country. Southeast of Crow River, in the northeastern part of the county, there is a considerable area of relatively flat land in which few lakes occur.

Minnesota River, which borders the county on the south, has a broad valley cut into the upland to a depth of 150 or 200 feet. The Mississippi, which forms most of the eastern boundary, has a valley of more youthful aspect. Above Minneapolis it flows through a narrow and shallow trench, but in the heart of the city it descends the Falls of St. Anthony, and thence to Fort Snelling at the southeastern extremity of the county, where it is joined by the Minnesota, flowing through a deep but narrow gorge which has been excavated in post-glacial times by the recession of the falls.

SURFACE DEPOSITS.

Alluvium representing the flood-plain deposits of the present streams occupies the bottom of the valleys of Minnesota and Mississippi rivers, and to a less extent the valleys of some of the larger tributaries. It contains abundant water, but owing to the presence of considerable silt does not give up its water as freely as do the more porous gravels of the drift deposits.

The outwash and terrace deposits consist of sand grading into gravel at the base, the whole attaining 50 feet or more in greatest thickness. The outwash deposits form a broad belt along the Mississippi from Dayton to the vicinity of Minneapolis; the terrace deposits are found chiefly within the latter city and on the elevated terraces along Minnesota River. The surfaces of both outwash and terrace gravels are generally comparatively flat, but certain undulations appear upon them representing channels of old streams by which they were deposited in the Pleistocene epoch. Except near the eroded margins, the supplies of water which they furnish are generally sufficient for domestic and farm purposes.

The glacial drift occurs over the greater part of the county. The surficial layer is largely of the gravelly type, especially in the north near the Mississippi. Over most of the county the drift is of a grayish-blue color, which is due to its derivation from the Ordovician and

Cretaceous shales farther northwest. In the southeastern part of the county, however, a considerable amount of red material occurs, doubtless brought from the Lake Superior region far to the northeast. The thickness of the deposits varies, but probably averages 100 to 120 feet, or even more, and in a number of wells in the Lake Minnetonka region reaches a maximum of more than 200 feet. Considerable water exists in the interbedded gravel layers, and this is the source of supply for most of the farm and domestic wells throughout the southern and western portions of the county. At Minneapolis the drift waters have, however, become greatly reduced because of the heavy demands which hundreds of wells make upon them.

In the correlation of well records from different parts of the county it has become obvious that along certain lines the drift is much deeper than elsewhere, thus plainly marking the position of preglacial or interglacial stream channels. One of these buried valleys lies within the city of Minneapolis and extends from a point near the Mississippi in the north part of the city westward and southwestward through a chain of lakes toward Minnesota River. Its presence and general course can easily be followed by the well sections reported from this vicinity. Another buried channel is suggested beneath Minnetonka, where the drift is more than 200 feet in depth and the rocks occur at a less depth on either side.

ROCK FORMATIONS.

The Decorah shale is represented by a total thickness not exceeding 30 feet, and the Platteville limestone by an upper layer of impure limestone 10 feet thick, a middle layer of shaly limestone 5 feet thick, and a lower layer of argillaceous limestone 15 feet thick. The Decorah shale is present at only a few localities, the most important of which is on the west side of the Mississippi, about 2 miles west of the Falls of St. Anthony.

The Platteville limestone occurs in the elevated land in the northern and northeastern portions of Minneapolis and south of that city to Minnesota River, constituting a flat, thin belt several miles long and of undetermined width. This is the rock over which the water flows at the Falls of St. Anthony. It contains some underground water in the joints, bedding planes, and solution passages, but the amounts are too small to be taken into account as a source of supply.

The St. Peter sandstone, where not eroded, ranges from 150 to 175 feet in thickness. According to well drillings it is characterized by a number of shale partings in the lower third of the formation. It outcrops in the bluff of the Mississippi below the Falls of St. Anthony, and occurs beneath the limestone at the falls. West of Minneapolis it forms a subglacial belt extending from the Mississippi to the Minnesota, but the exact position of its boundaries can not be indicated, on account of the deep covering of drift. The formation contains large amounts of water, especially in the portions away from the river and beneath the bed of the stream. Near the river the water of the upper part is largely removed owing to drainage into the deep valley. The lower part of the formation, beneath the shale, is everywhere water bearing, and, although much depleted by the large number of wells that have been sunk to it, still affords supplies to numerous wells in Minneapolis and the vicinity.

The Shakopee dolomite is the lowest of the formations that outcrop in the county. It lies beneath the surface deposits in a north-south belt across the central portion but is everywhere deeply covered with drift and carries but little water.

The new Richmond sandstone here consists merely of a series of sandy lenses occurring at somewhat different horizons in the limestone. Probably in more than one-half the wells of Hennepin County it was not detected by the driller. Where it exists it will supplement the supplies from the other sandstones, although it does not hold as much water proportionately as the St. Peter or Jordan, owing to the presence of the limy cement which partly fills its pores and to its lenticular distribution.

The Oneota dolomite reaches a thickness of 100 feet or more. It underlies Minneapolis and the rest of the eastern part of the county, but is seldom utilized as a source of water supply.

The Jordan sandstone is 80 to 100 feet thick. In the northern part of the county it lies beneath thick deposits of drift and in the neighborhood of Lake Minnetonka it occurs in the preglacial valleys. Like the other formations, it dips eastward, and numerous wells prove its existence in the eastern two-thirds of the county. It is penetrated by the deep wells in Minneapolis and forms a strong water horizon.

The St. Lawrence formation, according to the recent investigations of Prof. F. W. Sardeson, consists of two layers of dolomite, one forming the upper part of the formation and the other its bottom, between which is interpolated a series of green and blue shales associated with considerable sandstone. There is some water within the formation, but it is too much loaded with mineral salts to be satisfactory for either drinking or commercial supplies, as was proved by two wells which were drilled into it within the city of Minneapolis.

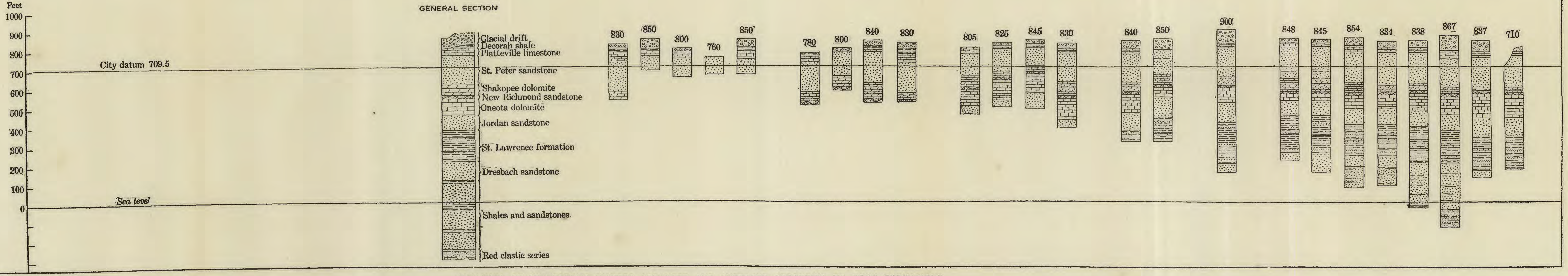
The Dresbach sandstone and underlying shales are found in every well within this county that reaches lower than the St. Lawrence. These formations constitute a strong water zone.

The red clastic series occurs in great thickness beneath Hennepin County, as was proved in drilling the well at Lakewood Cemetery in Minneapolis. This well, which reached a depth of 2,150 feet, passed through at least 1,140 feet of these beds and penetrated the

PARTS PER MILLION	RIVER				LAKE			GLACIAL DRIFT				SPRINGS						
	1	2	3	AV.	4	5	AV.	6	7	8	AV.	9	10	11	12	13	14	AV.
Silica (SiO_2)	13.	17.	14.	14.				21.	21.	21.	21.	18.	18.	28.	11.	17.	21.	19.
Oxides of iron and aluminum ($Fe_2O_3 + Al_2O_3$)								1.2	1.9				1.6	1.6	.4	2.	1.5	1.4
Calcium (Ca)	44.	42.	61.	49.	28.	29.	28.	37.	52.	32.	47.	68.	68.	70.	93.	84.	65.	75.
Magnesium (Mg)	16.	12.	17.	15.	8.	10.	9.2	11.	14.	7.9	11.	26.	26.	23.	27.	21.	26.	25.
Sodium and potassium (Na + K)	2.3	4.1	10.	5.5	3.	4.3	3.6	13.	24.	13.	17.	3.4	3.1	7.4	55.	7.5	5.5	14.
Bicarbonate radicle (HCO_3)	211.	195.	270.	225.	126.	149.	137.	141.	228.	122.	164.	330.	336.	340.	286.	328.	338.	325.
Sulphate radicle (SO_4)	4.7	5.	7.8	5.8	.0	.5	.2	40.	24.	27.	31.	10.	10.	7.1	2.	22.	.5	5.3
Chlorine (Cl)	1.7	1.9	11.	4.9	.7	.9	.8	7.1	21.	8.6	12.	.5	.5	1.		14.	.4	
Total solids	293.	277.	256.	275.	153.	128.	140.	201.	271.	170.	214.	293.	294.	306.	329.	331.	293.	308.

PARTS PER MILLION	ST. PETER						NEW RICHMOND					JORDAN.				
	15	16	17	18	19	AV.	20	21	22	23	AV.	24	25	26	27	AV.
Silica (SiO_2)	11.	19.	15.	6.	17.	14.	15.	25.	16.	4.	15.	18.	14.		17.	16.
Oxides of iron and aluminum ($Fe_2O_3 + Al_2O_3$)	2.	1.5	2.7	.7	1.7	1.7	3.	1.8				6.5	3.4		3.4	4.4
Calcium (Ca)	47.	69.	76.	64.	62.	64.	54.	77.	69.	71.	68.	77.	90.	68.	84.	80.
Magnesium (Mg)	37.	26.	28.	24.	26.	28.	29.	31.	27.	29.	29.	26.	36.	29.	31.	30.
Sodium and potassium (Na + K)	5.7	1.3	7.6	9.2	4.2	5.6	6.4	3.9	16.	17.	11.	13.	9.6		5.7	9.4
Bicarbonate radicle (HCO_3)	236.	273.	360.	297.	318.	297.	321.	390.	378.	352.	360.	346.	459.	354.	453.	405.
Sulphate radicle (SO_4)	77.	12.	14.	24.	4.	26.	5.	4.8		17.		20.	14.		2.	12.
Chlorine (Cl)	7.3	2.	1.2	7.1	3.6	4.2	2.5	2.5	7.1	18.	7.7	18.	2.	3.	2.	6.2
Total solids	304.	404.	504.	281.	276.	354.	273.	341.	322.	330.	316.	342.	392.	289.	375.	350.

PARTS PER MILLION	ST. LAWRENCE			DRESBACH, ETC										
	28	29	AV.	30	31	32	33	34	35	36	37	38	39	AV.
Silica (SiO_2)	4.7	23.	14.	20.	22.	14.	12.	14.	.8	15.	19.		1.5	13.
Oxides of iron and aluminum ($Fe_2O_3 + Al_2O_3$)	10.	.7	5.3	.2	3.7	3.9	1.8	1.9	12.	1.2	1.3		4.9	3.4
Calcium (Ca)	137.	77.	107.	52.	78.	88.	96.	79.	92.	65.	63.	80.	60.	75.
Magnesium (Mg)	41.	24.	32.	37.	28.	30.	31.	29.	33.	27.	24.	25.	27.	29.
Sodium and potassium (Na + K)	22.	16.	19.	4.5	2.	22.	5.9	2.5	5.9	3.5	2.6	14.	2.2	6.5
Bicarbonate radicle (HCO_3)	433.	252.	342.	346.	379.	419.	401.	386.	531.	330.	285.	325.	374.	378.
Sulphate radicle (SO_4)	153.	98.	125.		5.6	7.	32.	7.8	19.	5.9	20.	67.		21.
Chlorine (Cl)	32.	12.	22.	6.9	1.		1.8	1.	4.7	1.	4.		Tr.	2.5
Total solids	614.	376.	495.	292.	326.	371.	374.	331.	380.	281.	275.	347.	300.	328.



ANALYSES OF MINNEAPOLIS WATERS ARRANGED AND AVERAGED ACCORDING TO ROCK FORMATIONS.

By C. W. Hall.

1. Mississippi River above Minneapolis. Analysis Mar. 13, 1882, by J. A. Dodge.
2. Mississippi River below Minneapolis. Analysis Mar. 13, 1882, by J. A. Dodge.
3. Mississippi River at Minneapolis. Analysis Jan. 21, 1902, by G. M. Davidson.
4. Lake Minnetonka. Analysis May 2, 1883, by W. A. Noyes.
5. Lake Minnetonka. Analysis June 4, 1896, by C. W. Drew.
6. Well of Republic Elevator Company. Analysis Oct. 5, 1897, by Edgar & Mariner.
7. Well of Standard Elevator Company. Analysis Nov. 25, 1899, by Edgar & Carr.
8. Well of Acme Cooperative Barrel Company. Analysis Dec. 5, 1895, by Edgar & Mariner.
9. Inglewood spring water. Analysis in 1883, by W. A. Noyes.
10. Inglewood spring water. Analysis Jan. 21, 1886, by C. F. Sidener.
11. Glenwood spring water. Analysis February, 1885, by J. A. Dodge.
12. St. Anthony Falls mineral spring water. Analysis in 1877, by S. D. Hayes.
13. Spring on campus of University of Minnesota. Analysis in 1884, by C. F. Sidener.
14. Great Medicine spring water. Analysis Nov. 29, 1892, by C. F. Sidener.
15. Well of J. S. Lane, 625 Eighth avenue SE. Analysis Jan. 10, 1905, by G. B. Frankforter.
16. Well of A. Dickenson, Twenty-fourth avenue SE. Analysis in 1905, by A. D. Meeds.
17. Well at Pillsbury A mill. Analysis in 1894, by C. W. Drew.
18. Well at U. S. Soldiers' Home. Analysis June 14, 1897, by Edgar & Mariner.
19. Well of E. S. Woodworth Elevator Company. Analysis Dec. 15, 1897, by Edgar & Mariner.
20. Well of General Electric Company. Analysis in 1894, by C. W. Drew.
21. Well of Chicago, St. Paul, Minneapolis, and Omaha Railway Company. Analysis July 26, 1904, by G. M. Davidson.
22. Well of Baltimore Packing Company. Analysis Dec. 21, 1897, by Edgar & Mariner.
23. Well of O. W. Kassube. Analysis Feb. 6, 1896, by Edgar & Mariner.
24. Well of Minneapolis Brewing Company. Analysis May 12, 1900, by G. M. Davidson.
25. Well of Northern Pacific Railway Company at roundhouse. Analysis November, 1901, by G. M. Davidson.
26. Well of Northern Pacific Railway Company at Northtown Junction. Analysis May, 1900, by G. M. Davidson.
27. Well of Janney Semple Hill & Co. Analysis Apr. 26, 1906, by C. F. Sidener.
28. Well at Zier Building, Fourth avenue and Ninth street. Analyst: C. W. Drew.
29. Well of Minneapolis, St. Paul and Sault Ste. Marie Railway Company. Analyst: C. W. Drew.
30. Well of Interior Elevator Company. Analysis Jan. 6, 1896, by Edgar & Mariner.
31. Well at Minneapolis Knitting Works. Analysis Jan. 9, 1907, by A. D. Meeds.
32. Well at West Hotel. Analysis August, 1885, by J. A. Dodge.
33. Well at Boston Block. Analyst: C. W. Drew.
34. Well at Donaldson Building. Analysis Dec. 31, 1906, by A. D. Meeds.
35. Well at Guaranty Loan Building. Analysis in 1894, by C. W. Drew.
36. Well on campus of University of Minnesota. Analysis Feb. 7, 1907, by A. D. Meeds.
37. Well at power house, Nicollet and Thirty-first streets. Analysis Feb. 20, 1907, by A. D. Meeds.
38. Well at Chicago, Milwaukee and St. Paul Railway shops. Analysis Sept. 28, 1900, by G. N. Prentiss.
39. Well at Meeker Island, Lock No. 2. Analysis Apr. 21, 1899, by Edgar & Carr.

granitic rock. The red series carries a little water, but its yield is utterly insignificant when compared with the abundant supplies that can always be found in the overlying formations.

SOURCES OF WATER.

The sources of water utilized in Hennepin County are varied, depending on the situation, the purpose for which water is desired, the quantity required, and other factors.

Lakes.—In this county, probably more than in any other of southern Minnesota, the lakes have been utilized for water supplies. This is due to the large population in the cities of Minneapolis and St. Paul, which draws on the surrounding country for food of every description. Many of the market gardens are located beside the lakes, and the crops are freely watered from the supplies which they afford. Around the larger lakes, particularly Lake Minnetonka, Christmas Lake, and Medicine Lake, the villas, lawns, and gardens are all watered from pipes leading from the lakes.

Streams.—There is scarcely a stream in the county that is not drawn on heavily for water supplies. Indeed, many of them have practically disappeared within the last generation through the demands for water to use upon the adjacent land, and the lakes which are intimately associated with them in the drainage of the county are consequently becoming notably smaller.

Springs.—From the Falls of St. Anthony down the gorge of Mississippi River to Fort Snelling and thence up Minnesota River to the west line of the county numerous springs issue from the valley walls. The geologic structure determining their occurrence is very simple. The Paleozoic rocks beneath the glacial drift are the floor on which the waters entering the drift flow until their outlet is reached. In other parts of the county, especially from the falls northeastward along the Mississippi to Dayton, and thence along Crow River to the west line of Greenwood Township, there are many excellent springs, but they are neither so large nor so numerous as those along the Mississippi-Minnesota stretch above mentioned. In the interior of the county are also many springs, due largely to the morainic character of the glacial drift. They are utilized extensively as a source of water supply, but within the cities and villages they are liable to contamination and should not generally be used for drinking purposes. In the southwestern part of Minneapolis is a series of springs that feed several lakes. This series includes the Glenwood-Inglewood springs, which provide a large amount of drinking water for the city and which are situated along a slope that forms one side of the preglacial valley now occupied by Bassetts Creek. The Paleozoic rocks are here covered by a gray bowlder clay, upon which lies a red bowlder clay. Between these two beds of clay issue the springs. Analyses of several spring waters will be found in Plate X.

The glacial drift.—The glacial drift is the principal source of water supply for the people of the county. Everywhere wells are sunk into this material, and the water stands so near the surface that it is obtained with the greatest ease. Owing to the contamination of the water, however, this supply is fast falling into disuse in the thickly populated parts of the county.

The sandstones.—There are three strong water-bearing sandstones in the county, the St. Peter, the Jordan, and the Dresbach. The St. Peter is first reached in drilling, and is therefore heavily drawn on. The Jordan is sufficiently coarse and porous to allow the water to percolate through it with great freedom, and hence affords copious supplies. The Dresbach sandstone carries a large supply of water. The approximate depths to these zones can be ascertained by referring to Plate X.

HEAD OF THE WATER.

In the Minnesota Valley along its entire stretch bordering this county, in the Mississippi Gorge below the Falls of St. Anthony, and in the Mississippi River valley in the northern part of the county, the water from the deeper beds will rise above the surface and flowing wells can be obtained. On the upland surface at Minneapolis and elsewhere, however, the water from all horizons remains a short distance below the surface and must be pumped.

QUALITY OF THE WATER.

The mineral composition of the water from the various sources mentioned above is graphically shown in Plate X. It will be seen that the analyses here given indicate no notable differences in the composition of the waters from the three chief water zones—the St. Peter, Jordan, and Dresbach sandstones. The water from all three is moderately mineralized, the principal dissolved constituents being the bicarbonate radicle, calcium, and magnesium, which produce some scale in boilers and render the water hard. Much of this scale can be removed by heating the water before admitting it into the boilers, and the same process will reduce its hardness or soap-consuming property. The water from the St. Lawrence formation, and without doubt that from the Shakopee and Oneota dolomites and the red clastic series, is harder than that from the three principal sandstones. The water from the glacial drift (including the springs that issue from the drift) varies considerably, but, according to the analyses given, has a slightly lower average hardness than the sandstone waters. The water from the river also contains considerable quantities of calcium and magnesium and of the bicarbonate radicle, but its average hardness is less than that of the underground waters.

MINNEAPOLIS PUBLIC SUPPLY.

The Minneapolis public water supply is taken from Mississippi River. In early days fire protection was needed for the mills erected around the Falls of St. Anthony and for the groups of stores and shops built along the banks of the stream. The river was drawn on to procure water for this purpose and ever since has furnished the public supply. Some years ago the pumping stations at the Falls of St. Anthony were closed by the city water department and a larger pumping station was erected 3 miles or more up the river, where there was no danger of sewage contamination from the city. Later the east-side pumping station was erected.

The pollution of the river water is the most serious objection to its use as a city supply. The basin of the Mississippi above the pumping stations contains about 20,000 square miles and is the home of 300,000 to 400,000 people, of whom approximately 75,000 live in cities and villages located on the banks of the river. Under these conditions it is practically impossible to prevent the pollution of the stream and its accompanying serious risk to the health of all citizens making use of the water. Moreover, the immense number of logs coming down the river annually, the contamination from sawdust, and the pollution incident to the residence on the river of hundreds of men engaged in the lumbering industries lead to continual risk in the use of the water.

The investigations of the Minneapolis water department have led to the recommendation of settling reservoirs and a sand filtration plant, by which the matter in suspension, and especially the organic content of the water, could be removed. The expense of such a system, which would amount practically to $1,500,000, led the water department to proceed only to the establishment of the settling reservoirs. A filtration plant would cost approximately $1,000,000.

Meanwhile the question has been raised whether the waters stored in the sandstone formations would not furnish a more satisfactory source. In a comparison of the two prospective sources of supply, several factors must be considered, the most important of which may be enumerated as follows: (1) The quantity available, (2) the sanitary quality, (3) the mineral quality, (4) the cost of installation, and (5) the cost of operation.

The last-named factor, the cost of supplying the water after the plant is installed, resolves itself chiefly, so far as the underground source is concerned, into a question of the head of the water—that is, the height to which the water will be lifted by artesian pressure and the distance it must be lifted artificially in order to bring it to the surface. The head will depend in large measure on the quantity of water available, and hence these two factors must be considered together.

The general problem of the yield and head of underground water involves three more specific problems—(1) the total quantity of water now stored in the rock formations, (2) the rate at which new supplies of water will be furnished to the rock formations from which the water is withdrawn by pumping, and (3) the resistance that the rock offers to the transmission of water. The volume of water in the formations underlying Minneapolis is without doubt very large, and the potential annual accession from the rainfall is also great. The crucial question, however, pertains to the resistance of the rock to the transmission of water. As no precise data are at hand in regard to the porosity and size of grain of the various sandstones, no definite statements can be made as to the rate at which the rocks will conduct water under a given pressure gradient. Nevertheless, rough calculations have been made in which maximum and minimum values for the porosity and size of grain have been used, and these calculations indicate, with favorable assumptions, that if the quantity of water required for the Minneapolis public supply were pumped from wells, even though these wells were distributed over a considerable area and should draw from all the principal water zones, the water level in the wells would be materially lowered. As only a moderate lowering of the water level would greatly increase the cost of pumping, it is evident that a system depending on underground supplies should not be installed without first conducting a careful series of experiments on the water-yielding capacity of the available formations.

The mineral quality of the various waters has already been discussed; the sanitary problems involve so many issues beyond the proper scope of this report that they can not be considered here.

HOUSTON COUNTY.

By C. W. Hall and M. L. Fuller.

SURFACE FEATURES.

The upland surface of Houston County is a much dissected plateau 1,150 to 1,300 feet above sea level and more than 500 feet above the valley of Mississippi River. Where the upland surface remains the topography is relatively level, but in the vicinity of the streams it is extremely rugged. The sink holes due to the caving of the subterranean drainage channels are a common feature, and in some places their linear arrangement is very noticeable. A thin covering of loess subdues irregularities and helps to make the upland surface more nearly level.

SURFACE DEPOSITS.

There is little or no glacial drift in this county, the only covering for the rocks being the residuum resulting from their decay and the mantle of yellow silt or loess, the whole rarely more than 25 feet thick. In the early days many shallow wells were sunk into the loess and residuum, but it was found that the supplies from this source were small and uncertain.

In the valleys of Mississippi River and its tributaries there are alluvial deposits which vary in thickness from a few feet to nearly 200 feet, the usual range being between 50 and 100 feet. Water occurs everywhere in these deposits, but because of the clay silt present it is yielded rather slowly in many wells. In the gravel fan at the mouth of Root River, opposite La Crosse, the materials are coarser than elsewhere, and larger supplies should be obtained at this point than elsewhere. In general the yield is smaller than that from the underlying rocks.

There are many terraces along the sides of the Mississippi River valley. They extend up the tributary valleys and form an important economic as well as an interesting topographic feature. Owing to the leakage on the exposed valley sides wells must be sunk about to the level of the flood plain before permanent water supplies can be obtained.

ROCK FORMATIONS.

Rock outcrops occur everywhere along the cliffs of the valleys of the Mississippi and its tributaries, affording abundant opportunity for the determination of the character and thickness of the successive beds. The rock formations outcropping at the surface are all Paleozoic.

The green Decorah shale is represented by a thickness of 25 feet, and is underlain by a massive bed of Platteville limestone, averaging 15 feet in thickness. Because of resistance to erosion, together with geologic position, these formations constitute the highest land in the county, capping the high areas in the southwestern corner. They yield small supplies to shallow wells, but are of little value as a source of water. Some springs occur at the margins of their areas, but most of the water sinks through the crevices of the formations into the underlying sandstone.

The St. Peter sandstone here is about 80 feet thick, or only one-half the thickness of the same formation in Hennepin County. It occurs beneath the Platteville limestone in the southwestern part of the county and underlies a large area of the uplands south of Root River. Although cemented by iron and somewhat resistant in places, a condition due to surface alteration, it does not generally give rise to rock exposures, the outcrop area commonly being flat and covered with grass and trees. It yields moderate supplies of water to shallow wells, but owing to the free escape of its water to the adjoining lowlands it does not afford amounts sufficient for industrial or public supplies.

The Shakopee dolomite is about 75 feet thick, occurring beneath the uplands above the river valleys. It carries some water in joints, bedding planes, and solution passages, and gives rise to a number of springs, but it does not generally afford supplies adequate even for domestic and farm purposes.

The New Richmond sandstone, which ranges up to 35 feet in thickness, is exposed beneath the Shakopee in the uplands several hundred feet above the stream. It affords little water along its outcrops, but where it is covered by younger rocks, as in the southwestern portion of the county, it may furnish supplies of considerable importance to moderately deep wells, though generally the amounts will prove insufficient for industrial or public supplies.

The Oneota dolomite, which is approximately 150 feet thick, outcrops in the upper portion of the cliffs bordering Mississippi and Root rivers and their tributaries and forms conspicuous bluffs and pinnacles. The upper portion is often broken and characterized by the presence of chert and other concretions. It contains some water in joints, bedding planes, and solution passages. Along the borders of the valley springs of considerable importance issue from this formation, a few yielding sufficient quantities for industrial or public supplies and even for water power.

The Jordan sandstone, a coarse buff sandstone about 100 feet thick, outcrops below the Oneota in the cliffs bordering Mississippi and Root rivers. In the greater part of the county it yields abundantly, the public supplies for several villages being derived from it. Near the outcrops, however, the yield is greatly reduced because of the escape of the water into adjacent valleys.

The St. Lawrence formation consists of green and gray calcareous shales with some green sand and occasional sandstone layers, having a total thickness of about 175 feet. It outcrops in the lower portions of the cliffs of the Mississippi and underlies the bottom of Root River and the lower portions of its tributaries to the western border of the county. It contains considerable water in the sandy layers and is said to yield flows at a few localities in the valleys. It has, however, little value as a water zone, its yield being materially less than that from the overlying Jordan or the underlying Dresbach sandstone.

The Dresbach sandstone is a massive, crumbling sandstone about 60 feet thick, with occasional cemented layers. It outcrops along the cliffs of the Mississippi and beneath the alluvium of Root River. Its base is approximately at the level of the Chicago, Milwaukee and St. Paul Railway along the Mississippi. It is a strong water-bearing formation, and in the valley of Root River yields abundantly, the water being used for industrial and public supplies. Beneath the upland it contains large quantities of water, but there is generally no advantage in sinking to it, as the supplies are not materially larger than those from the Jordan except near an outcrop of the latter.

Underlying the Dresbach sandstone are several hundred feet of shale and sandstone, which lie almost entirely below the level of the flood plain of the Mississippi and are encountered only in deep wells. The upper portion consists of blue and green shale and the lower of porous sandstone. The shale furnishes an impervious cap, which confines the water in the sandstone, thus giving rise to splendid flows from the sandstone in the valleys of Mississippi and Root rivers. The yield is generally sufficient for all purposes, including industrial and public supplies.

Beneath the last-mentioned sandstone are the red shales, sandstones, and quartzites of the red clastic series, which rests upon the granitic rock. Neither the red clastic series nor the granite will yield much water. Following is the section of an artesian well drilled in 1878 in the village of Brownsville for the Chicago, Milwaukee and St. Paul Railway Company. The granite was here encountered at about 70 feet above sea level.

Well section at Brownsville.

[Authority, W. E. Swan, driller.]

	Thickness.	Depth.
	Feet.	*Feet.*
Alluvium:		
Blue clay	40	40
Basal Cambrian:		
Limestone	25	65
Blue shale	60	125
Green shale	70	195
Sandstone (probably including some of the Algonkian (?) red clastic series)	375	570
Granite (entered 20 feet).		

UNDERGROUND WATER CONDITIONS.

Head of the water.—Flowing wells can be obtained in the valleys of Mississippi and Root rivers throughout their entire extent in this county and also in the lower courses of the tributary streams (Pl. IV). On the upland the water in the deep wells remains several hundred feet below the surface. For example, in the village well at Caledonia it is reported to stand about 250 feet and in the village well at Spring Grove about 300 feet below the surface.

Quality of the water.—The water from all horizons is moderately mineralized, the principal constituents being calcium, magnesium, and the bicarbonate radicle. (See the accompanying table of analyses and Pl. V.) A wide variation in the waters of this county in normal chlorine content was noted by H. C. Carel [a] in his investigations several years ago. A general statement summarized from these reports is to the effect that the deep-lying water-bearing strata are

[a] Eighteenth Rept. Minnesota State Board of Health, 1899-1900, pp. 241-260; Nineteenth Rept., 1901-2, p. 346-356.

much more heavily loaded with chlorine than the shallower beds. At Houston in 1900 there were 28 artesian wells, ranging in depth between 230 and 310 feet, all obtaining their water from sandstones lower than the Dresbach. The shallowest of these wells yielded the least chlorine, 44.2 parts per million; the deepest yielded 187.2 parts per million. On the higher ground around Houston, where the supplies are drawn from the Jordan, the New Richmond, and even from so high a formation as the St. Peter, the amount of chlorine is appreciably less. The average chlorine content of springs flowing from these formations is, for the county, only 4.6 parts per million. As a summary of Carel's investigations the following figures have been compiled from the large amount of material gathered by him:

Average chlorine content of underground waters.

	Parts per million.
Springs (several formations)	4.6
Shallow wells	2.8
Jordan sandstone	9.4
Dresbach sandstone	13
Lower sandstone	9.5
Red clastic series	76

Springs.—There are springs along the base of the cliffs at numerous points, the waters draining freely from the rocks wherever they are cut by deep valleys. In the vicinity of Hokah many springs rise from the base of the Jordan sandstone. Several miles west of Hokah is Stimpson Spring, which was long a favorite resort and which is reported to issue from above an impervious limestone as a stream of considerable size. When the county was first settled there were many gristmills operated by water power, and streams issuing from springs were frequently utilized. Winnebago Creek, Pine Creek, Thompson Creek, Money Creek, Beaver Creek, Crooked Creek, and Crystal Creek are all examples.[a]

WATER SUPPLY FOR CITIES AND VILLAGES.

Caledonia.—The village of Caledonia and the farms adjacent have reported a number of wells ranging from 250 to 312 feet in depth, in some of which the water stands more than 250 feet below the surface. A generalized section of these wells is given below.

General section at Caledonia.

	Thickness.	Depth.
	Feet.	*Feet.*
Loam clay and bottom of St. Peter sandstone	70	70
Shakopee dolomite	40	110
New Richmond sandstone	10	120
Oneota dolomite	150	270
Jordan sandstone (entered 40 feet).		

[a] Winchell, N. H., Final Rept. Geol. and Nat. Hist. Survey Minnesota, vol. 1, 1882, p. 208.

The public supply is obtained from a well 320 feet deep. Two analyses of the water are given in the table (p. 210). About 3 miles from Caledonia there is a spring which for many years was used by the Chicago, Milwaukee and St. Paul Railway Company for locomotive supplies. An analysis of water from this spring is also given in the table.

Houston.—The village of Houston lies in the valley of Root River, which here apparently flows over a bed of the St. Lawrence formation. In the valley flowing wells are obtained from the Dresbach and lower sandstones. The public waterworks are supplied from a well 6 inches in diameter and 302 feet deep, which has been pumped at the rate of 130 gallons a minute. The water rises 12 feet above the surface, or about 960 feet above sea level. All the people depend on private supplies.

Spring Grove.—The village of Spring Grove is situated in the highest portion of the county, where the Platteville limestone occurs. The public waterworks are supplied from a well 396 feet deep, but many of the private wells are shallow. The water in the deep wells stands far below the surface.

Hokah.—Along the valley of Root River in the vicinity of Hokah there are flowing wells with considerable head. In several wells where the situation is favorable the natural head of water is used to operate hydraulic rams that lift the water to levels to which it would not otherwise rise. At Hokah this inexpensive and convenient method of pumping is employed at the village waterworks. Ordinarily this device raises sufficient water, but a gasoline engine can be used in case of shortage. The village well is 544 feet deep, the water rising 18 feet above the surface or 692 feet above sea level. The yield exceeds present needs, though in the past there has been some difficulty owing to the loss of water either through a leak in the casing or through the uncased portion of the sandstone. An analysis of the water is given in the table. The public supply is used by about one-half the people and about 5,000 gallons is consumed daily.

SUMMARY AND ANALYSES.

The three strongest water-bearing formations are the Jordan, Dresbach, and basal Cambrian sandstones. On the upland they lie at depths of several hundred feet and the water stands far below the surface. In the deepest valleys they occur at or near the surface, and where not exposed by erosion give rise to flows. The basal Cambrian sandstone is best protected from erosion and is therefore the best artesian zone. The water from all sources is moderately hard.

Mineral analyses of water in Houston County.

[Analyses in parts per million.]

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Depth.......feet..	......	......	18	25	110	299	300	320	320	544
Silica (SiO_2)......	......	......	......	......	......	......	......	......	16	9.2
Iron (Fe)......	......	......	......	......	3.9	......	1.7	5.3	2.7	2.9
Calcium (Ca)......	61	49	102	59	137	69	64	62	70	76
Magnesium (Mg)......	21	28	31	34	15	31	24	28	31	29
Sodium and potassium (Na+K).	9.3	6.3	30	......	13	3.3	56	11	11	6.7
Bicarbonate radicle (HCO_3)......	326	264	389	331	435	335	279	327	256	343
Sulphate radicle (SO_4)......	5	3.4	61	4.6	24	27	50	......	12	28
Chlorine (Cl)......	1.3	23	47	......	34	4.2	71	18	30	4
Total solids......	267	246	466	280	441	300	404	286	322	279

1. Spring at Caledonia used by the Chicago, Milwaukee and St. Paul Railway Company. 1892.
2. Spring at Hokah used by the Chicago, Milwaukee and St. Paul Railway Company. 1892.
3. Chicago, Milwaukee and St. Paul Railway well at Houston. October, 1892.
4. Chicago, Milwaukee and St. Paul Railway well at River Junction. June, 1900.
5. Chicago, Milwaukee and St. Paul Railway well at Spring Grove. July, 1892.
6. Chicago, Milwaukee and St. Paul Railway artesian well at River Junction. April, 1902.
7. Chicago, Milwaukee and St. Paul Railway well at Houston. May, 1895.
8. Village well at Caledonia. July, 1894.
9. Village well at Caledonia. November, 1906.
10. Village well at Hokah. November, 1906.

Analyses 1 to 8, inclusive, were furnished by G. N. Prentiss, chemist Chicago, Milwaukee and St. Paul Railway Company. Analyses 9 and 10 were made for the United States Geological Snrvey by H. S. Spaulding.

JACKSON COUNTY.

By O. E. Meinzer.

SURFACE FEATURES.

In general the surface of Jackson County slopes very gradually from the southwestern corner, which is nearly 1,600 feet above sea level, to the northeastern, where the altitude is about 1,300 feet. The surface constitutes a nearly level and poorly drained upland prairie covered with lakes, ponds, and swamps. This nearly level surface is, however, interrupted by two prominent physical features. One of these is a morainic belt which has a more irregular topography and a higher general altitude than the surrounding prairie and runs with a north-south trend through the middle tier of townships, also occupying the southwestern corner of the county. The other is the valley of Des Moines River, which is a postglacial gorge between 100 and 150 feet deep. This gorge is a rather striking feature in a region otherwise so little affected by erosion, but its extreme youth is apparent from the fact that it has only a few short tributaries and drains only a narrow strip of land on either side. In the geologic future the system of tributaries will become greatly extended and the sluggish streams on the undissected uplands will be captured by Des Moines River.

Heron Lake, the largest lake in southwestern Minnesota, is entirely within this county. It seems to lie in the nearly obliterated valley of an ancient stream which once flowed southeastward along the line of Lake Yankton, Lake Shetek, Heron Lake, and Spirit Lake.[a]

[a] Upham, Warren, Final Rept. Geol. and Nat. Hist. Survey Minnesota, vol. 1, 1882, p. 507.

SURFACE DEPOSITS.

Description.—The glacial drift forms a mantle which everywhere covers the older formations and averages between 200 and 300 feet in thickness. At several points south of this county the thickness revealed by drilling was somewhat less than 300 feet; in the southern half of the county many wells end in drift at 200 to 300 feet below the surface, and several apparently at still greater depths; in the northeastern and north-central parts underlying formations have been reached at 250 to 300 feet. In some localities in the northwestern part, however, the drift is relatively thin, owing to the presence of a buried quartzite ridge. Thus in the vicinity of Okabena the rock has been reached at depths of about 150 feet, in the village of Heron Lake at 110 and 195 feet, and at points just across the Nobles County line at 100 and 120 feet, although the average thickness in the northwestern part is greater than these figures would indicate.

The following section, to a depth of 350 feet, is typical of the drift. It is the log of a well drilled near Jackson, on the farm of H. W. Miller, NE. ¼ sec. 30, T. 102 N., R. 34 W.

Well section near Jackson.

[Authority, Gilbert Nourse, driller, Jackson.]

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow bowlder clay	25	25
Blue bowlder clay	175	200
Yellow bowlder clay	15	215
White sand	5	220
Blue clay (bowlders at 300 feet)	130	350
Yellow clay	5	355
"Light green" clay ("greasy," contains pebbles)	5	360
Fine sand	8	368

Yield of water.—Seams of sand and gravel thick enough and coarse enough to yield adequate supplies are found at some depth in nearly every locality. The 10-inch village well at Lakefield and the 8-inch village well at Alpha serve as examples. The former, which terminates in a thick gravel layer 190 feet below the surface, has been pumped for eight hours continuously at the rate of 175 gallons a minute; the latter, 96 feet deep, has been tested for two hours at 100 gallons a minute. The alluvial deposits in the valley of Des Moines River often provide large quantities of water from very shallow depths.

Head of the water.—In a region having a relatively low altitude there is usually not much difference in the head of the water from different depths, that from all horizons coming near the surface. The eastern part of Martin County affords a good example of this condition.

On the other hand, in an area of relatively high altitude, where the water has many opportunities to percolate to lower levels, there is likely to be an important difference in the head from the various horizons in the same locality, the water frequently coming nearer the surface in the shallow than in the deep wells. Jackson County, and especially the morainic belt occupying the central part, offers a good illustration of this second condition. Thus, at Lakefield there is a gravelly bed at a depth of 80 or 90 feet from which the water rises within about 10 feet of the surface, and another at 180 feet from which it rises only within about 100 feet of the surface; in the deepest wells of this region the water frequently remains still farther below the surface.

Near Des Moines River the head is lowered by seepage into the valley, as is shown by the many springs along the valley sides.

Quality of the water.—The waters from the glacial drift are represented in the accompanying table (p. 216) by analyses 2 to 7. They all contain considerable quantities of calcium and magnesium, together with large amounts of sulphates, for which reason they have a great permanent hardness and will deposit hard scale in boilers. The water from the alluvium in the Des Moines Valley is only moderately hard and hence is better adapted for use in boilers. It is represented by analysis 1 in the table.

CRETACEOUS SYSTEM.

Description.—In this county and in all the adjoining counties strata of shale and sandstone believed to be of Cretaceous age have been encountered by the drill immediately beneath the drift. It is therefore probable that they underlie much of this county, though everywhere deeply buried. In some localities in the northwestern part, however, they are absent. Plate IX shows the approximate sections of several wells that enter the Cretaceous rocks. According to S. J. Moe, of Lakefield, a well on the farm of A. L. Bradley, SW. ¼ sec. 35, T. 103 N., R. 36 W., east of Lakefield, is about 500 feet deep, passing through nearly 200 feet of shale and ending in sand.

Yield of water.—In all but the northwestern part of the county formations of sand or sandstone will probably be found at depths ranging from about 250 to 500 feet. These will generally furnish copious supplies of water, but the unconsolidated sand will cause trouble in some wells if not skillfully handled.

Head of the water.—On the upland prairies the water from deep sources will remain at depths of 100 to 250 feet. In the valley of Des Moines River it will of course rise nearer the surface, but flows can nowhere be expected. Windom, Minn., and Estherville, Iowa, are both situated in this valley, the former being just north of the Jackson County line and the latter several miles south. In neither city can flows be obtained from the Cretaceous. The water seems to rise to about 1,250 feet above sea level in the northern part of the county and to somewhat less than 1,200 feet in the southern, while the valley of Des Moines River is more than 1,300 feet above sea level at the northern boundary and more than 1,250 feet at the southern.

Quality of the water.—Analysis 8 in the accompanying table represents Cretaceous water. It is high in calcium, magnesium, and sulphates, and is therefore a hard water and poor for boiler purposes.

PALEOZOIC FORMATIONS.

At Lake Park, Iowa, a few miles south of this county, a well was drilled for the railway company to a depth of 804 feet. Stratified formations, chiefly shale, sand, and sandstone, seem to make up about 550 feet of this depth. The upper portion is supposed to be Cretaceous in age, but the lower probably belongs to some Paleozoic formation. This well was tested with a large steam pump. The water is said to stand nearly 300 feet below the surface, or about 1,200 feet above sea level. It is so hard that it is not used by the railway company.

SIOUX QUARTZITE.

In most of this county the Sioux quartzite or "red rock" lies many hundreds of feet below the surface, but in the northwestern part it is sometimes encountered at depths of 100 to 200 feet. The well data which have been assembled show that a completely buried quartzite ridge extends with a northwest-southeast trend through parts of Murray, Nobles, and Jackson counties (Pl. III). This ridge is separated by a deep depression from the quartzite area in Pipestone and Rock counties, and also apparently from that in Cottonwood County. It is smaller than these areas and does not rise so high. In Pipestone County the rock rises to more than 1,700 feet above sea level, and in Cottonwood County to about 1,500 feet; the extreme altitude reached in this area, so far as is known, is about 1,370 feet. In preglacial times it formed a low ridge, and in pre-Cretaceous times it must have stood up conspicuously above the surrounding country. At present it is entirely concealed beneath Cretaceous and glacial deposits. No quartzite wells were reported east of Heron Lake nor south of Okabena station.

The Sioux quartzite will invariably yield some water if the drilling is carried deep enough, the water coming from the joints and less firmly cemented portions. The railway well at Heron Lake, whose section is given on Plate IX, is 6 inches in diameter at the bottom and was tested at 90 gallons a minute. The head and quality of the water from the quartzite are similar to that of the overlying formation.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Jackson.—The village of Jackson is situated upon the banks of Des Moines River which has here cut a valley about 100 feet deep. On the west side of the river there is a narrow flood plain and a series of four terraces standing at levels 15, 40, 60, and 80 feet higher. The valley is carved out of the glacial drift, and the flood plain and terraces are covered with deposits of alluvium.

The public supply is pumped from a well 26 feet in diameter and 20 feet deep, cased with brick and mortar. It is located at the north end of the village on the flood plain near the river and terminates in alluvial gravel. In July, 1907, the water stood about 10 feet below the surface and was lowered about 3 feet when the well was pumped for two or three hours at the rate of about 300 gallons a minute. In times of severe drought, however, the yield is so much reduced that the well can be emptied in a short time. An analysis of the water is given in the table. About 600 people are supplied and 50,000 gallons of water is consumed daily.

About two-thirds of the inhabitants use water from private wells, which are bored or dug into the alluvial gravels and are very shallow. These gravels are saturated with water and usually yield generous supplies, but the probability of pollution is great, especially on the lower levels. The Chicago, Milwaukee and St. Paul Railway Company uses water from the river.

Lakefield.—The glacial drift is deep at Lakefield, and the underlying formations have never been reached in drilling. There are porous water-bearing deposits (1) near the surface, (2) at a depth of 100 feet or less, and (3) at a depth of about 185 feet. The following is the approximate section of the upper 190 feet:

Well section at Lakefield.

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow bowlder clay	15	15
Gravel	10	25
Yellow bowlder clay	10	35
Blue bowlder clay (frequently sand at about 100 feet)	140	175
Sand and gravel	15	190
Blue bowlder clay.		

The public supply comes from a drilled well, which has already been described. About 200 people use the water, and the daily consumption amounts to approximately 25,000 gallons. The mill well is 180 feet deep and taps the same zone that furnishes the public supply. The water from both is hard but is probably as good for boiler purposes as can be obtained. Several analyses are given in the table. About 80 per cent of the people depend on private wells, most of which end in the yellow clay or gravelly seams near the surface, but some of which penetrate to the beds of sand at depths of 100 feet or less.

Heron Lake.—All the people of Heron Lake are supplied from private wells; there are no public waterworks. Most of the data in regard to the railway well, whose section is shown on Plate XV, have already been given. The fact should be added, however, that the 25-foot bed of sand and gravel at the base of the drift was tested and found to yield about 65 gallons a minute from an 8-inch hole.

Alpha.—The village of Alpha lies upon a nearly level drift-covered plain. The public waterworks are supplied from a drilled well that has already been described. An analysis of the water is given in the table. All the people use water from private wells, most of which are shallow and yield moderate and uncertain supplies. There are, however, a few private drilled wells that are deeper and more satisfactory.

FARM WATER SUPPLIES.

By far the greater number of the farms are supplied by bored wells 1 to 3 feet in diameter and cased with wood or tile. Some end in the surficial yellow clay or gravel, but many pass through blue bowlder clay and tap seams of sand and gravel at depths commonly ranging between 50 and 100 feet. The shallow wells are liable to furnish only small and uncertain supplies, but the deeper ones yield much more copiously.

There are also a few drilled wells scattered through the county, most abundant in the northern part. They have a wide range in depth. Some are less than 100 feet deep and terminate in the same beds as the bored wells, but others have been sunk farther; a number of farm wells more than 300 feet deep are reported. Several extend to the Cretaceous strata, and a very few in the northern part penetrate the quartzite.

The most desirable type for farm purposes is the 6-inch drilled well finished with an open end. It is more permanent, yields more water, and is better protected from pollution than the bored type. Two-inch wells should not be drilled in this county, for they require screens, which become cemented by minerals precipitated from the water. If a screen must be put into a 6-inch well it should be considerably smaller than the diameter of the casing, so that it can be removed readily when it becomes incrusted. Wells of moderate depth are preferable to very deep ones because the water is likely to rise nearer the surface and to be less highly mineralized.

SUMMARY AND ANALYSES.

The sand and gravel beds lying at moderate depths are the most satisfactory source of water. They are generally superior to the very shallow sources (1) in yield of water, (2) in permanence of supply, and (3) in freedom from pollution; and to the deeper drift deposits (1) in the height to which the water will rise, and (2) in its mineral quality. However, where an adequate supply is not obtained at a moderate depth there need be no hesitation in drilling farther.

Deep sandstone zones that would yield abundantly no doubt occur in most of the county, but probably nothing would be gained by sinking to them. Two important questions are always asked in regard to the lower formations: (1) Will they give rise to flows? and (2) Will they supply softer water than the shallower beds? These questions may be answered for this county somewhat as follows: Flowing wells can not be obtained from deep horizons, and on the upland the water will always stand far below the surface. In regard to soft water the answer is less certain. No soft-water beds have thus far been discovered in this county, but there is a possibility that they exist. The probabilities in the case are set forth in the discussion of this subject in the report on Cottonwood County (pp. 157–158).

Mineral analyses of water in Jackson County.

[Analyses in parts per million.]

	Alluvium.	Glacial drift.						Cretaceous.	Sioux quartzite.	
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Depth ....feet..	20	96	140	185	180	190	180	292	217	217
Diameter of well ....inches..	312	8	24	6	2	10	8 and 6	2	6	8
Silica (SiO_2)	25	23	.....	.....	31	11	.....	14	29	27
Iron (Fe)	2.5	2.5	.....	.....	2.7	2.8	.....	2.5	.....	.....
Aluminum (Al)	8.7	2.3	.....	.....	.....	.....	.....	.....	.....	.....
Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	.....	.....	3	5	8	6	.....	11	10	.17
Calcium (Ca)	69	117	162	220	98	119	159	158	130	277
Magnesium (Mg)	29	39	44	81	48	42	45	57	149	82
Sodium and potassium (Na+K)	54	62	23	99	72	33	10	43	276	134
Carbonate radicle (CO_3)	.0	.0	.....	.....	.0	.0	.....	.0	.....	.....
Bicarbonate radicle (HCO_3)	381	444	260	444	464	461	462	459	692	489
Sulphate radicle (SO_4)	88	142	403	697	199	145	217	346	886	877
Chlorine (Cl)	4	55	3	6	3	3	1.6	3	33	8
Nitrate radicle (NO_3)	3.5	2	.....	.....	.0	.0	.....	.0	.....	.....
Total solids	483	671	766	1,326	692	593	662	845	1,855	1,807

1. Village well at Jackson. July 24, 1907.
2. Village well at Alpha. July 24, 1907.
3. Well at Okabena. October 18, 1895.
4. Well at Prairie Junction. August 30, 1895.
5. Mill well at Lakefield. July 20, 1907.
6. Village well at Lakefield. July 20, 1907.
7. Village well at Lakefield. July 8, 1902.
8. Well on the farm of Arthur Johnson, 5 miles south of Windom. July 19, 1907.
9. Railway well at Heron Lake. September 19, 1900.
10. Railway well at Heron Lake. November 22, 1902.

Analyses 1, 2, 5, 6, and 8 were made for the United States Geological Survey by H. A. Whittaker, chemist Minnesota state board of health. Analyses 3, 4, and 7 were furnished by G. N. Prentiss, chemist Chicago, Milwaukee and St. Paul Railway Company. Analyses 9 and 10 were furnished by G. M. Davidson, chemist Chicago, St. Paul, Minneapolis and Omaha Railway Company.

KANDIYOHI COUNTY.

By O. E. MEINZER.

SURFACE FEATURES.

Kandiyohi County has three distinct types of topography and can accordingly be divided into as many physiographic provinces[a]—(1) the irregular morainic region north and east of Willmar, (2) the area of gently rolling prairie south and west of that city, and (3) the level sandy plain in the northeastern part of the county. All three provinces are poorly drained and contain some lakes, but in the first named the lakes are most abundant.

SURFACE DEPOSITS.

Description.—The surface deposits consist almost entirely of glacial drift, which comprises bowlder clay and beds of sand and gravel. There is no outcrop of older rock and in only a very few places have the underlying formations been disclosed in drilling. Throughout a large portion of the county the drift averages not less than 300 feet in thickness. At Willmar drilling has been carried to a depth of 280 feet; in sec. 6, T. 119 N., R. 34 W., to a depth of 298 feet; in sec. 22, T. 121 N., R. 36 W., to a depth of 303 feet; in sec. 20, T. 121 N., R. 35 W., to a depth of 318 feet; and in sec. 7, T. 120 N., R. 35 W., to a depth of 337 feet, apparently without reaching the bottom of the drift sheet in any case. In the southwest the drift is generally between 200 and 300 feet thick, and in the northeastern part it is also commonly less than 300 feet and is locally thin.

The following section shows the material penetrated by the two railway wells at Willmar, all of it probably consisting of glacial drift:

Well section at Willmar.

[Authority, A. H. Hageland, chief engineer Great Northern Railway Company.]

	Thickness.	Depth.
	Feet.	*Feet.*
Clay	26	26
Gravel	6	32
Clay	42	74
Gravel	22	96
Quicksand	2	98
"Hardpan"	65	163
Dry sand	11	174
"Hardpan"	15	189
Clay and quicksand	10	199
Clay	13	212
Gravel	3	215
Clay	14	229
Sand (water)	18	247
Gravel (water)	21	268

[a] Upham, Warren, Final Rept. Geol. and Nat. Hist. Survey Minnesota, vol. 2, 1885, pl. 40.

Yield of water.—The beds of sand and gravel are the water-bearing portions of the drift. In the northeast, where these are spread out over the surface, copious supplies can be obtained at slight depths. In the irregular morainic area there are also abundant deposits of water-bearing sand and gravel, but they are intermingled with the bowlder clay in the most complicated manner. In the gently undulating province the drift consists more largely of clay; yet in nearly every locality water will be found at some level. As a rule the deepest beds are the most persistent and contribute the largest and most permanent supplies of water, but the structure of the drift is so essentially irregular that every such rule has exceptions.

In the vicinity of Willmar three rather distinct water zones are recognized. These are represented in the section of the Willmar railway wells given above by (1) the clay and gravel near the surface, (2) the bed of gravel between the depths of 74 and 96 feet, and (3) the sand and gravel deposit below 229 feet. The railway wells are 10 inches in diameter and are supplied from the lowest of the three zones. One of them was tested with the following results: [a]

(1) Before pumping: Water stood at 10 feet below the surface.

(2) After pumping at the rate of 157 gallons per minute for six hours continuously: Water stood 13 feet below the surface.

(3) After pumping at the same rate for nineteen hours continuously: Water stood 14½ feet below the surface.

(4) After pumping at the same rate for thirty hours continuously: Water stood 14½ feet below the surface.

(5) Five minutes after pumping was stopped: Water had again risen to its normal level of 10 feet below the surface.

The 8-inch city well at Willmar, which also extends to the deepest of these zones, has been pumped for four hours continuously at the rate of 500 gallons a minute.

Head of the water.—On account of the surface irregularities there is considerable difference in the head of the water. In most localities it rises near the surface, and at the base of the high morainal ridge flows can frequently be obtained.

There is a group of flowing wells in Lake Andrew Township (T. 121 N., R. 35 W.) and such wells could no doubt be obtained in other localities. At Willmar the water from both the deep zones comes virtually to the surface, or slightly higher than the level of Foot Lake.

Quality of the water.—The three analyses given in the accompanying table (p. 221) represent the three types of water found in this county—(1) the water from the sandy deposits at the surface, which is moderately hard; (2) the water from the upper portions of the glacial drift (not including No. 1), which is very hard and in which the great quantities of calcium present are largely associated with the sulphate

[a] Furnished by A. H. Hageland, chief engineer Great Northern Railway Company.

radicle, thus producing much hard scale in boilers; and (3) the water from the lower portion of the drift, which is only moderately hard and contains relatively small amounts of the sulphate radicle.

CRETACEOUS SYSTEM.

Very little is known of the formations beneath the drift. A thin bed of the Cretaceous, composed chiefly of shale, is without doubt present in some parts of the county, but is not in others. The following data bear on this subject: (1) Twenty feet of blue shale were penetrated in drilling 2 miles south of Raymond; (2) shale and sandstone have been discovered in a number of wells in Swift and Chippewa counties to the west; (3) shales have been encountered at Renville, Olivia, and Bird Island, which are 7 or 8 miles south of this county; and (4) Cretaceous rocks, in which fossils belonging to the Benton epoch have been identified,[a] are exposed about 10 miles beyond the northeastern extremity of this county.

No successful wells ending in Cretaceous rocks have been reported. Where these rocks are present they may consist entirely of impervious beds, which would not furnish water, and they are probably nowhere of value as a water-bearing formation.

ARCHEAN ROCKS.

So far as is known, granite has never been struck in this county, though in a number of places drilling has gone to a depth of more than 300 feet. However, there can be no doubt that it lies generally within a few hundred feet of the surface. The following data throw light on this subject: (1) At Benson, 17 miles west of this county, granite was entered at a depth of about 400 feet; (2) along Minnesota River, about 14 miles southwest, it is exposed at the surface; (3) at Renville, Olivia, Bird Island, and Hector, 7 to 10 miles south, it has been found at depths of 325 to 450 feet; (4) at Grove City, 4 miles east, it was encountered at a depth of several hundred feet; (5) at a few points not more than 10 miles east it was discovered at depths of less than 300 feet; and (6) in a number of localities 15 to 25 miles north and northeast it comes to the surface.

The granite will not supply water, and no water-bearing formation exists below it.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Willmar.—The stratigraphic section and water zones below Willmar have already been discussed. The upper beds yield very hard water and the lowest provide a softer supply. (See the analyses in the

[a] Kloos, J. M., A Cretaceous basin in the Sauk Valley, Minnesota: Am. Jour. Sci., ser. 3, vol. 3, 1872, pp. 17-26.

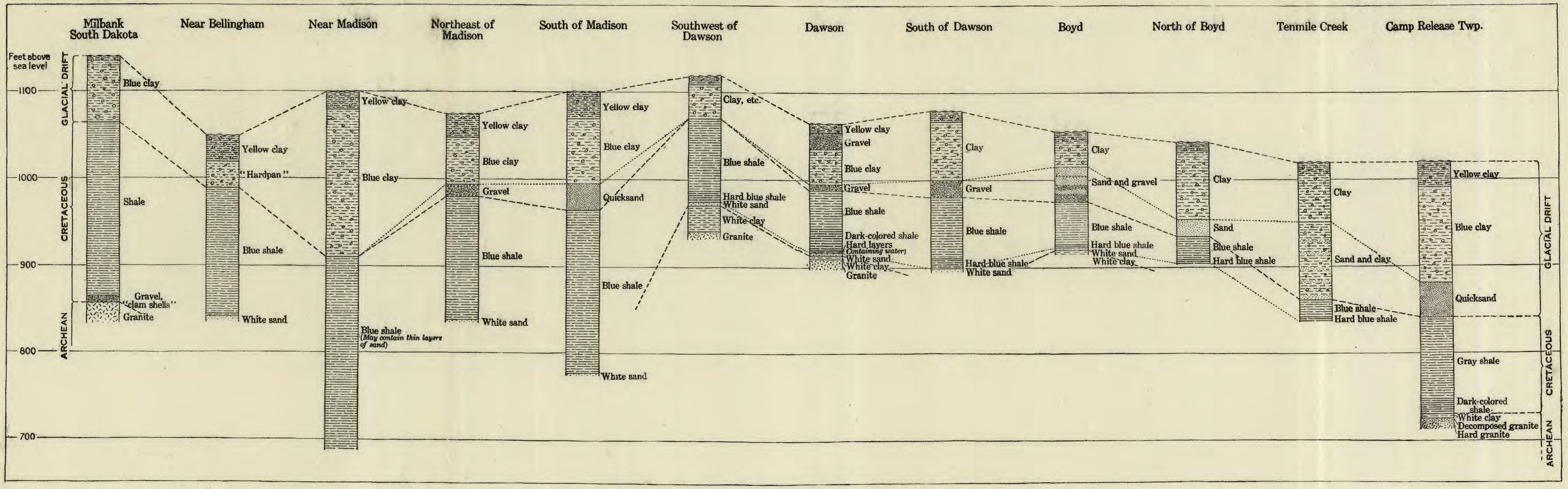
table.) The water from all depths rises nearly to the surface. The public supply is taken from a well 8 inches in diameter and 273 feet deep, ending with a screen in the same thick deposit of sand as the railway wells described above. About 1,200 people use this water, and 100,000 gallons is consumed daily. Perhaps 70 per cent of the inhabitants are supplied from private wells, of which most are bored or dug into yellow clay or gravelly seams near the surface and yield small quantities of hard water, but a few are drilled to a depth of about 100 feet and yield more generously. The well at the flouring mill, which is about 100 feet deep, has been abandoned because the water is too hard for boiler purposes.

Atwater.—In the village of Atwater sand and gravel deposits near the surface furnish the entire water supply. An unsuccessful well drilled for the municipality passed through beds of sand at about 250 and 400 feet in depth, but although these were water bearing the well was finished in them with difficulty. The public supply is drawn from four wells 3 inches in diameter and about 35 feet deep. They are provided with screens and are pumped by suction at about 75 gallons a minute. The water is only moderately hard, as is shown by the analysis given in the table below. About 95 per cent of the people use water from private wells, which are bored or driven into the surficial layers of sand, and the railway company is likewise supplied from a shallow well.

New London.—The domestic supply in the village of New London is obtained chiefly from driven wells. The public waterworks draw from the lake, and surface water is generally used for industrial purposes.

FARM WATER SUPPLIES.

Three types of wells are in use in this county—(1) driven, (2) bored or dug, and (3) drilled. The driven wells are confined to the localities in which a bed of sand or gravel lies at the surface. In the large area in the northeastern part of the county where this condition prevails, nearly all the wells are driven. They are shallow and inexpensive and usually afford liberal supplies of only moderately hard water. The bored and dug wells are also shallow and do not generally reach the blue clay. Many of them furnish only small quantities of water and fail entirely in dry years, but some yield more abundantly. Most of the farm wells, especially in the morainic area, are bored or dug. Drilled wells, for the most part 2 inches in diameter, are found in nearly all parts of the county, but are most abundant in Arctander Township (T. 121 N., R. 36 W.). They vary greatly in depth, probably averaging not much more than 100 feet. They provide ample supplies in localities where the bored wells fail. As the deep drift layers contain the softest water, there would be an advantage in drilling to them.



GEOLOGIC SECTIONS IN LAC QUI PARLE COUNTY.

By O. E. Meinzer.

Milbank, S. Dak.—Given by N. H. Winchell, in Fourteenth Ann. Rept. Geol. and Nat. Hist. Survey Minnesota, 1885, p. 14, on authority of J. W. Williams.

Near Bellingham.—Well on farm of Hiram Graff, NW. ¼ sec. 12, T. 119 N., R. 45 W.

Near Madison.—Unsuccessful well on farm of Jens Jacobson, SE. ¼ sec. 1, T. 118 N., R. 45 W.; approximate.

Northeast of Madison.—Well 4 miles northeast of Madison. This section and the two preceding are given on the authority of Ole Bjorgan, driller, Madison.

South of Madison.—Well on farm of L. P. Satre, NE. ¼ sec. 16, T. 117 N., R. 44 W.

Southwest of Dawson.—Well on farm of J. J. Windingstaad, SE. ¼ sec. 14, T. 116 N., R. 44 W.

Dawson.—Generalized section south of river at Dawson.

South of Dawson.—Well on farm of E. A. Throndrud, SW. ¼ sec. 8, T. 116 N., R. 43 W.

Boyd.—W. Swenson's well.

North of Boyd.—Well on farm of A. Olerud, SW. ¼ sec. 10, T. 116 N., R. 42 W.

Tenmile Creek.—Well on farm of O. E. Husby, NE. ¼ sec. 36, T. 117 N., R. 42 W. This section and the six immediately preceding are given chiefly on the authority of Nicholas Danielson, driller, Dawson.

Camp Release Township.—Well on farm of John M. Hanson, NE. ¼ sec. 33, T. 117 N., R. 41 W. Authority, J. M. Haubris, driller, Montevideo.

Most of the altitudes are only approximately known.

SUMMARY AND ANALYSES.

In every part of the county the granite probably lies within a few hundred feet of the surface, and deep-water zones therefore do not exist. The glacial drift is, however, several hundred feet thick and contains an abundance of water. In general, the best boiler supplies come from the lower portions of the drift.

Mineral analyses of water in Kandiyohi County.

[Analyses in parts per million.]

	Surface deposits.		
	1. Surface sand and gravel.	2. Upper portion of glacial drift.	3. Lower portion of glacial drift.
Diameter of well ... inches	3	36	8
Depth ... feet	35	30	272
Silica (SiO_2)	29	34	8.4
Iron (Fe)	0	.2	2
Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	2	4	3.2
Calcium (Ca)	88	224	65
Magnesium (Mg)	36	76	35
Sodium and potassium (Na+K)	7	10	61
Carbonate radicle (CO_3)	.0	.0	.0
Bicarbonate radicle (HCO_3)	346	454	454
Sulphate radicle (SO_4)	42	227	56
Chlorine (Cl)	35	148	4
Nitrate radicle (NO_3)	5	50	.0
Total solids	421	1,012	464

1. Village wells in Atwater. September 23, 1907.
2. Well of Nels Anderson at Willmar. September 24, 1907.
3. City well at Willmar. September 24, 1907.

The above analyses were made for the United States Geological Survey by H. A. Whittaker, chemist Minnesota state board of health.

LAC QUI PARLE COUNTY.

By O. E. Meinzer.

SURFACE FEATURES.

Most of the surface of Lac qui Parle County consists of a plain which slopes very gradually toward the northeast, descending from about 1,200 to 1,000 feet above sea level. This plain is interrupted on the northeast by the valley of Minnesota River, which has here been cut to depths of 100 to 150 feet, and on the southwest by the Coteau des Prairies (Dakota Hills) which lies about 500 feet above the plain. A low morainal ridge crosses the southwestern part of the county with a trend roughly parallel to the margin of the Coteau.

The flatness of the plain, which occupies most of this county and extends southward into Yellow Medicine, Lyon, and Redwood counties, stands in decided contrast to the gentle undulations of the Coteau, with its numerous lakes. This difference is explained by Warren Upham as follows:[a]

When the ice sheet, dissolved by a warmer climate, was retreating northeastward across Lac qui Parle County, the waters of its melting were carried to the southeast

[a] Final Rept. Geol. and Nat. Hist. Survey Minnesota, vol. 1, 1882, p. 622.

along the margin of the ice, which was a barrier preventing their flow in the direction of the present drainage. * * * A glacial lake * * * was formed in the Minnesota basin along the front of the ice and reached from Faribault and Blue Earth counties to Big Stone Lake. * * * By this submergence the drift in Lac qui Parle County and upon a large part of the Minnesota basin farther southeast was spread more evenly and many of its hollows that would have held small lakes were filled. * * * During the somewhat later recession of the ice across Big Stone County, free drainage could take place from its border, and the drift presents a more undulating and rolling surface, dotted by many little lakes.

J. E. Todd explains in essentially the same manner the very similar topography of the so-called James River valley in South Dakota on the west side of the Coteau des Prairies.[a]

Several streams flow northeastward across Lac qui Parle County. They occupy shallow valleys until as they approach Minnesota River they descend rapidly to its level. They have few tributaries and leave large areas without any well-defined drainage system.

SURFACE DEPOSITS.

Description.—The glacial drift consists of bowlder clay with associated deposits of sand and gravel. A thick accumulation of gravel commonly lies at the base, as is shown by the sections given in Plate XI. Such a basal gravel is commonly found in other counties, but is especially well developed in this region. Because of the irregular surface upon which the drift rests, its thickness varies greatly within short distances. Throughout most of the county the thickness is between 100 and 200 feet; but in much of the south central part it is less than 100 feet, and 2½ miles south of the county line the underlying rock comes to the surface; north of Dawson and between Dawson and Madison the average thickness is more than 200 feet, and the same is true in the southwestern corner of the county (Pl. II). The Minnesota Valley has been excavated virtually out of the drift, and consequently the underlying rocks are here generally near the surface and in a few localities they form outcrops.

Yield, head, and quality of the water.—Supplies adequate for ordinary purposes can be obtained in most places from the deposits of sand and gravel in the drift, but where the drift sheet is thin it does not invariably contain a satisfactory water-bearing bed. Throughout most of the county the water rises nearly but not quite to the surface, but within several miles of the Minnesota Valley the head is lowered by leakage, which manifests itself in numerous springs on the valley side. South of Marietta there are a number of flowing wells which derive their head from the high land to the west. They are not accurately located on the map showing underground water conditions (Pl. II). All the water from the glacial drift is hard.

[a] Todd, J. E., The moraines of southeastern South Dakota: Bull. U. S. Geol. Survey No. 158, 1899, p. 124.

CRETACEOUS SYSTEM.

Description.—The Cretaceous rocks include (1) soft, uniform gray-blue shale, or "soapstone," (2) darker and harder shale, and (3) thin beds of unconsolidated white quartz sand. The shale predominates greatly, the only stratum of sand generally being a thin layer at the base of the series, even this being absent in some places. The hardest shale is in most places found next the sand.

The Cretaceous rocks are present throughout most of the county, but generally not in the vicinity of Minnesota River, nor that of Lac qui Parle River as far upstream as Dawson, nor in the extreme south central part. Owing to their uneven upper and lower surfaces, the thickness varies, reaching in this county at least 225 feet. The sections given in Plate XI represent the series in its typical development.

Yield of water.—In drilling in this county any one of the following three conditions may be encountered: (1) The Cretaceous may be absent, the drill passing directly from the glacial drift into the granitic rocks; (2) shale or "soapstone" may alone be present, in which case the rocks will contribute no water; (3) the Cretaceous may be present and include a layer of sand, which, even if it is thin, may afford liberal supplies. Because the Cretaceous is so irregular in distribution and thickness it is impossible to predict the exact localities in which it will be found as a water-bearing deposit. All except two or three of the sections shown in Plate XI represent successful wells, most of them capable of yielding copiously. The following table gives the data in regard to these wells:

Typical wells in the Cretaceous, Lac qui Parle County.[a]

Owner and location.	Depth to water-bearing stratum.	Thickness of water-bearing stratum.	Yield.	Head.
	Feet.	*Feet.*		*Feet below surface.*
Hiram Graff, NW. ¼ sec. 12, T. 119 N., R. 45 W	207	8	Ample	40
Well 4 miles northeast of Madison	237	(?)	...do	40
Lars Roise, SE. ¼ sec. 16, T. 118 N., R. 44 W.[b]	200	Thin.	...do	17
L. P. Satre, NE. ¼ sec. 16, T. 117 N., R. 44 W	325	2	...do	60
J. J. Windingstaad, SE. ¼ sec. 14, T. 116 N., R. 44 W	150	(?)	...do	19
Dawson village well [c]	148	1½	100 gallons (?)	16
E. A. Throndrud, SW. ¼ sec. 8, T. 116 N., R. 43 W	185	(?)	Ample	70
Ole Husby, NE. ¼ sec. 36, T. 117 N., R. 42 W	185	(?)	...do	25
N. Swenson, in village of Boyd	135	½	Moderate	16
A. Olerud, SW. ¼ sec. 10, T. 116 N., R. 42 W	142	Thin.	Ample	22

[a] The water from all these wells is soft.
[b] Section not shown in Pl. XI.
[c] The analysis of this water is given on page 224.

Head of the water.—The head is virtually the same as that of wells in the deeper drift zones, the water in most places rising nearly but not quite to the surface. The range in the wells given in the above table is 16 to 70 feet below the surface. At Madison the Cretaceous water rises to about 1,080 feet above sea level, at Dawson to 1,050 feet, and at Boyd to 1,040 feet.

Quality of the water.—The water from the Cretaceous strata is soft but contains large quantities of sodium, the sulphate radicle, and chlorine. The following analysis is typical, except that in some localities there is a much higher content of chlorine. At Madison, for example, the water is perceptibly saline.

Mineral analysis of Cretaceous water. [a]

	Parts per million.
Silica (SiO_2)	11.4
Iron and aluminum oxides ($Al_2O_3+Fe_2O_3$)	3.6
Calcium (Ca)	10
Magnesium (Mg)	7.5
Sodium and potassium (Na+K)	248
Carbonate radicle (CO_3)	0
Bicarbonate radicle (HCO_3)	483
Sulphate radicle (SO_4)	136
Chlorine (Cl)	27
Nitrate radicle (NO_3)	0

ARCHEAN ROCKS.

Granite outcrops at a number of points in the valley of Minnesota River and in a small area 2½ miles south of the county line. It has also been discovered in drilling in nearly every part of the county. As its surface is not regular, it is found at different levels, but in most localities it lies at a depth of several hundred feet. It is nearest the present surface in the region bordering the Minnesota and in the eastern and south central sections of the county. At Dawson it has been encountered at a depth of 155 feet; near Marietta, at 345 feet; and at Milbank, S. Dak., at 283 feet.

Where the granite was protected from glacial erosion by overlying formations the upper part is decayed and is locally veneered by a white clay, which is often wrongly called "marl," but in fact is the leached decomposition product of the granite, though in some places it has been transported and redeposited by water.

The granite is not water bearing, except that rarely an adequate supply is derived from gritty parts of the white clay or other decomposed rock. In the well of John Hanson, the section of which is given in Plate XI, drilling was carried to a depth of 298 feet and entered solid granite without finding water. A charge of dynamite was then exploded, after which the well yielded generously. However, in most wells this procedure would not be successful.

[a] East village well at Dawson. Sample collected August 29, 1907. Analyst, H. A. Whittaker, chemist Minnesota State Board of Health.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Madison.—Madison has no public supply. The water zones may be classified as follows:

1. Surficial yellow clay and sand, utilized chiefly by bored wells 30 to 40 feet deep. At present this zone furnishes most of the supply. The water is hard.

2. Seams of sand and gravel in the glacial drift, tapped by drilled wells commonly between 100 and 160 feet deep. This water is also hard.

3. Strata of Cretaceous sand, reached by drilled wells at a depth of about 300 feet, but not yet used much. The water is soft but saline.

Dawson.—The underground water conditions are not the same in different parts of the village of Dawson. On the south side of the river the Cretaceous intervenes between the basal granite and the glacial drift, which is here less than 100 feet deep. At the bottom of the Cretaceous is a thin layer of white quartz sand, which affords soft water (Pl. XI). On the north side of the river the drift appears to be fully 200 feet deep and to rest directly on the granite, the soft-water zone being absent.

The waterworks, which were completed in 1908, are supplied by two wells south of the river, both of which are about 148 feet deep, and end in the soft-water stratum. The village authorities have reported that the two wells have been pumped at the rate of about 160 gallons a minute for twelve hours continuously. The water is soft but contains rather large quantities of alkali sulphates and chlorides, as is shown by the analysis given above. It will be employed largely for all purposes, its softness recommending it for domestic use. Several other soft-water wells have been drilled on the south side, one of which supplies the creamery. Most of the private wells are bored and end in yellow clay or gravel at depths of 30 or 40 feet, yielding small quantities of hard water. There are a few drilled wells which tap the deeper layers of sand and gravel in the drift and also furnish hard water. The well at the mill is an example of this type.

Boyd.—In the well of N. Swenson, the section of which is given in Plate XI, the Cretaceous shale is encountered at a depth of 80 feet, and the white clay, which presages granite, at 130 feet. At other points the glacial drift is known to be deeper. The Swenson well ends in a 6-inch layer of Cretaceous sand and provides a small quantity of soft water, while the well of A. Olerud, which is just north of the village and no doubt reaches the same horizon, affords a larger amount of the same kind of water. It has not been determined how extensively soft water could be obtained.

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The glacial drift here contains an uncommon proportion of sand and gravel (Pl. XI). The 8-inch well which supplies the public waterworks is 62 feet deep and draws from this source. The water rises within about 5 feet of the surface, and according to J. M. Haubris, the driller, of Montevideo, pumping at the rate of 80 gallons a minute for fifteen hours continuously lowered this level only 4 inches. The water is hard and is at present used almost exclusively for fire protection. The mill is supplied by a well 120 feet deep, which yields an abundant supply of hard water. Most of the private wells are dug or bored into yellow clay or gravel and many are not more than 20 or 30 feet deep.

Bellingham.—The domestic supplies at Bellingham are derived chiefly from private wells 20 to 100 feet deep. The public waterworks are also provided with a well, the water being used to a moderate extent for various purposes. The soft-water well of Mr. Hiram Graff, the description of which is given above, points to the possibility that soft water can be obtained in Bellingham.

FARM WATER SUPPLIES.

There are two principal types of farm wells—bored and drilled. The former are relatively shallow and many of them have not adequate or permanent supplies; the latter are deeper and generally more satisfactory and reliable. By far the greater number stop in glacial drift and yield hard water, but those which tap Cretaceous strata and afford soft water are widely distributed. Many farms now have hard water where a soft-water supply could be procured by drilling a little deeper. Two-inch wells terminating in the drift must be provided with screens, which are liable to become clogged in a few years. Wells of larger diameter are therefore more satisfactory and economical for farm purposes.

SUMMARY.

As granite that is not water-bearing lies everywhere within a few hundred feet of the surface, deep drilling should never be undertaken in this county. After the white clay (which generally lies above the granite) has been entered the chances of finding water are very poor, and whenever hard granite is reached drilling should be discontinued.

The two sources of underground water consist of (1) sand and gravel deposits interbedded with the bowlder clay and (2) layers of sand below shale ("soapstone"). The former nearly always yields plenty of water; the latter is more uncertain but frequently furnishes adequate supplies. The former contains hard water, the latter generally soft.

In this region drilling for soft water is to be encouraged, for although there is no certainty that it will be found, the conditions in most parts of the county are favorable to success. Moreover, the experiment is not expensive. If soft water exists at all, it will be reached only a short distance below the hard-water horizons; and the "soapstone," through which it is necessary to pass, is very readily penetrated. If no soft water is found, the casing can usually be withdrawn.

On the other hand, drilling for flowing wells in this county is to be discouraged. Although the water usually rises near the surface, no flows can be obtained except in a few small areas where they are derived from shallow layers. Hence all attempts to obtain flows by deep drilling must be considered a waste of money.

LESUEUR COUNTY.

By C. W. Hall and M. L. Fuller.

SURFACE FEATURES.

The upland surface of Lesueur County ranges in height from about 900 feet above sea level near Minnesota River to nearly 1,100 feet in the central and eastern portions of the county. The general level of the plateau is broken by two irregular morainal ridges. One of these, standing 50 to 75 feet above the adjoining plain, extends along the eastern end of the county, lying for 1 to 5 miles of its width in Lesueur County and for the remainder in Rice County to the east. The other ridge, which is of similar character, is only 3 or 4 miles wide and extends from the southeast corner of the county diagonally across the southern townships to Minnesota River near St. Peter.

Both the ridges and the general plateau surface, which is undulating or gently rolling, are dotted with lakes, some of which are several miles long. The stream valleys are those of the Minnesota and its tributaries and that of Cannon River in the southeastern corner. The Minnesota River valley lies 100 to 200 feet below the adjacent uplands, but the valleys of the remaining streams, except the lower portions of those entering the Minnesota, are not deep nor characterized by steep sides. Along the east side of the Minnesota, within its flood plain, there is a strip of low alluvial deposits from one-eighth to one-half mile in width. Above this at Kasota and Ottawa are terraces 1 or 2 miles wide and underlain by the Shakopee dolomite, described below. Near Kasota and Lesueur there are two of the so-called prairies, representing flat terrace surfaces standing 100 feet or more above Minnesota River. The Lesueur prairie is more than 4 miles wide. Back of these terraces the land rises in a sort of bluff to the upland level, which is generally 50 to 100 feet higher. Along upper Cannon River there are gravel terraces formed by the streams during the glacial period.

SURFACE DEPOSITS.

Lesueur County is everywhere deeply drift covered except along the Minnesota Valley, and even here the rock projects through the alluvium. The surface deposits include alluvium, terrace sands, and unmodified glacial drift.

The glacial drift consists of pebbly clay with bowlders and intermingled sandy or gravelly layers, the sand and gravel being especially abundant in the moraines. Between the morainal districts stratified outwash deposits have been laid down. The drift attains its greatest development on the uplands near Minnesota River, where it is locally more than 200 feet thick. Water is found in considerable amounts in the various sandy and gravelly layers and is available to wells of moderate depth, enough usually being obtained to supply large industries as well as households and farms.

The alluvium consists of loamy sands and gravels deposited in the principal valleys, at some places to a depth of perhaps 100 feet or more. It usually affords supplies sufficient for domestic and farm purposes.

The terrace sands and gravels are similar to those of the alluvium except that less silt is present. In the Minnesota Valley they lie about 100 feet above the present stream, having been deposited by the river flowing at the level indicated and left in their present situation on terraces by the subsequent erosion of the stream. Their thickness is generally 20 to 30 feet; beneath them the wells penetrate the unmodified drift. Water is readily absorbed by the porous materials and is commonly abundant in the portions remote from the streams, affording supplies for domestic, farm, and small industrial purposes. Near the valleys the water escapes by percolation to the lower land and many wells fail to obtain the necessary supplies until the underlying rocks are reached.

PALEOZOIC FORMATIONS.

The Galena and Platteville limestones have not been seen at the surface but have been encountered in wells and probably underlie several square miles of the highland on the eastern border of the county.

The St. Peter sandstone, like the overlying Galena and Platteville limestones, has not been seen at the surface but has been found in wells at a number of points, as at Elysian and Waterville. It is 100 feet thick and more and underlies the Platteville and the drift in the southeastern portion of the county. The volume of water which it yields is generally considerable, being sufficient for farm and industrial purposes and for the public supplies of small cities. The water does not occur under great pressure.

The Prairie du Chien group is represented by the pink to buff Shakopee and Oneota dolomites, which outcrop at Kasota and other points along the Minnesota River and underlie the drift throughout the western half of the county. Their water supply is limited to the creviced portions and the interbedded lenses of sandstone. On the valley border, where the water escapes readily, the supply lies at a considerable depth. In such localities wells must go below drainage levels to procure adequate amounts of water. On the uplands the supplies are larger and are obtained at a higher level. The best supply probably comes from a sandy bed in the upper part of the group, supposed to be the representative of the New Richmond sandstone of the counties along the Mississippi.

The Jordan sandstone, which is about 90 feet thick, outcrops along the Minnesota and dips eastward beneath the uplands underlying the entire county. It can be reached anywhere in the region by moderately deep wells and will usually afford supplies adequate for all purposes, the water being under sufficient pressure to cause it to enter the wells freely.

Beneath the Jordan sandstone there are about 150 feet of shale and limestone, not water bearing, known as the St. Lawrence formation. Beneath these lies the Dresbach sandstone, a water-bearing bed 50 to 100 feet thick and similar to the Jordan. Its yield, however, is usually no greater than that of the Jordan and there is therefore no advantage in drilling to it, unless the supplies of the Jordan should be locally exhausted by heavy withdrawals. Below the Dresbach there are several hundred feet of shales and water-bearing sandstone beds, below which lie, in turn, the red clastic series and the granite, neither of which is important as a water bearer.

UNDERGROUND WATER CONDITIONS.

Wells.—The wells of Lesueur County fall into five clearly defined groups: The first includes the shallow wells of the drift-covered uplands, the second the deep upland wells obtaining their supplies from the drift, the third the upland wells entering the rock, the fourth the shallow valley wells ending in alluvium, and the fifth the deep artesian wells of the valleys.

The first group, comprising the shallow wells of the upland, are commonly of the dug or bored types. Water is obtained from sandy or gravelly layers of the drift, but the supplies reached are usually small and are liable to fail in dry seasons. The water, too, is not of the best quality. For these reasons the deeper drilled wells are to be preferred. The wells of the second group obtain their supplies from the water-bearing beds yielding good supplies, which are generally found before the rock is struck. The deeper upland wells comprising the third group enter the rock, obtaining their supplies from the St. Peter sandstone, the creviced and sandy portions of the Prairie du Chien group, or the Jordan sandstone. Ample supplies are generally obtained. In the valleys the shallow wells which make up the fourth group are commonly of the driven type and are sunk from 20 to 40 feet into the alluvium. They are especially abundant along the Minnesota. The supplies are usually rather small and of unsatisfactory quality. For large supplies in the valleys recourse is had to deep-drilled wells (the fifth group) which penetrate to the Dresbach and underlying sandstones. From these water is obtained in large volumes and under sufficient head to lift it 75 feet above the river in places.

Head of the water.—In view of the differences in surface altitude found in this county, the head relative to the surface must vary within comparatively wide limits. Ordinarily the shallow drift wells on the uplands find the ground-water level but a few feet below the surface, whereas the deeper drift supplies and the water from the rock formations stand at a lower level, the head usually becoming progressively lower as greater depths are reached. But in the Minnesota Valley, which is several hundred feet below the uplands, the water from the rock formations will rise above the surface without rising any higher above sea level than elsewhere in the county. In the city well at Lesueur, which is 668 feet deep, the water rises 18 feet above the surface, or 778 feet above sea level. In the well at Lesueur Center, 340 feet deep (extending 52 feet below the surface at Lesueur), the water rises within 180 feet of the surface, or 898 feet above sea level. In other words, the water at Lesueur Center is lifted 90 feet above the level to which it will rise in the flowing well at Lesueur.

Springs.—Springs are very numerous where the Minnesota and its tributaries have cut their valleys into the drift. The water of the drift escapes from the sandy layers at many points and affords supplies to numerous farms. The largest springs occur where the limestone rises above the valley level and outcrops in the bluffs. This rock serves to collect and concentrate the water from the overlying drift and thus affords a plane along which the water makes its way from the underground supplies to the surface.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Lesueur.—The 8-inch flowing well which furnishes the public supply for Lesueur is the deepest well in the county. It penetrates far into the Dresbach sandstone and underlying shales, as is shown by the following section:

Well section at Lesueur.

	Thickness.	Depth.
	Feet.	*Feet.*
Alluvium and drift	176	176
St. Lawrence formation (shale and dolomite)	100	276
Dresbach sandstone and underlying shale	392	668

When this well is pumped at the rate of 400 gallons a minute the water is lowered 15 feet below the surface. About one-half the people use the public supply, and approximately 40,000 gallons is consumed daily. An analysis of the water is given in the table on page 232.

Waterville.—Waterville has a system of public waterworks supplied from an 8-inch well 185 feet deep, which probably ends in glacial drift. About 10,000 gallons is consumed daily.

Montgomery.—The glacial drift in the locality of Montgomery is about 175 feet thick and rests on strata of limestone and sandstone, which are penetrated by a few of the deepest wells. The following is the section of the well drilled in 1904 for the Minneapolis and St. Louis Railroad Company:

Well section at Montgomery.

[Authority, chief engineer Minneapolis and St. Louis Railroad Company.]

	Thickness.	Depth.
	Feet.	*Feet.*
Clay and "hardpan" (glacial drift)	175	175
Limestone (probably Oneota)	27	202
Loose sandstone (probably Jordan)	18	220
Hard sandstone (probably Jordan)	32	252

The public supply is derived from a 10-inch well which is 213 feet deep. At least one-half of the people use the water, and about 25,000 gallons is consumed daily. Several analyses of water from this village are given in the table.

Lesueur Center.—The well that supplies the public waterworks of Lesueur Center is 340 feet deep. Only a small amount of water is used, as most of the people depend on private wells.

Elysian.—The village of Elysian has a well 287 feet deep, which apparently taps the St. Peter sandstone. Only a small proportion of the people use the public supply.

Kilkenny.—The waterworks at Kilkenny are supplied from a well 250 feet deep, which derives its water from the St. Peter sandstone.

SUMMARY AND ANALYSES.

Underlying this region are several sandstones, all of which yield water generously. In the valley of the Minnesota they give rise to flowing wells, but on the uplands no flows can be obtained from rock formations at any depth, for the head of water is lowest in the deep wells. However, the water from the sandstones is not so highly charged with iron as that from the drift and in this respect is distinctly preferable.

Mineral analyses of water in Lesueur County.

[Analyses in parts per million.]

	Glacial drift.			Preglacial rock formations.								
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
Depth ....feet..	......	50	185(?)	195	344	340(?)	273	273	273	315	140	668
Silica (SiO_2)...........	19	25	25	4.8	10	......	......	......	......	......	6.6	7.8
Calcium (Ca)...........	50	80	54	70	110	76	119	90	168	80	114	55
Magnesium (Mg).......	23	30	31	14	36	36	44	39	......	32	40	21
Sodium and potassium (Na+K).............	135	7.6	9.6	61	42	74	......	59	1.2	22	90	42
Bicarbonate radicle (HCO_3).............	448	340	321	287	468	518	518	510	453	437	545	270
Sulphate radicle (SO_4)..	61	52	11	73	64	67	15	85	48	18	98	48
Chlorine (Cl)...........	3.7	1.3	3.4	14	2.7	2.7	9.1	6.0	1.6	1.7	70	29
Total solids............	618	363	294	487	578	512	624	531	442	369	687	366

1. Follert's spring in sec. 14, T. 111 N., R. 26 W. 1902.
2. Chicago, St. Paul, Minneapolis and Omaha Railway well at Lesueur. 1901.
3. City well at Waterville. September, 1897.
4. Montgomery Brewing Company well at Montgomery. May, 1905.
5. Well at the New Prague Flouring Mill at New Prague. November, 1906.
6. City well at Montgomery. December, 1901.
7. Minneapolis and St. Louis Railroad well at Montgomery. November, 1901.
8. Minneapolis and St. Louis Railroad well at Montgomery. December, 1901.
9. Minneapolis and St. Louis Railroad well at Montgomery. 1892.
10. H. H. Flower's creamery well at Cleveland. 1901.
11. Chicago and Northwestern Railway well at Kasota.
12. City well at Lesueur. 1901.

Analysis 1 was made by J. P. Magnusson; analysis 3 by C. W. Drew; analysis 4 by the School of Brewers; and analysis 5 by H. S. Spaulding. Analyses 2, 11, and 12 were furnished by G. M. Davidson, chemist Chicago and Northwestern Railway Company; analyses 6 and 10 by G. N. Prentiss, chemist Chicago, Milwaukee and St. Paul Railway Company; and analyses 7, 8, and 9 by the Minneapolis and St. Louis Railroad Company.

LINCOLN COUNTY.

By O. E. Meinzer.

SURFACE FEATURES.

Lincoln is a prairie county, most of which lies on the coteau more than 1,700 feet above sea level. In the northeast, however, the surface slopes down to the lowland plain bordering the Minnesota Valley, and in this slope descends about 500 feet within a few miles (Pls. I and V). The coteau abounds in lakes and swamps and has a very imperfect drainage, but the slope has become incised by numerous ravines, some of which are deep enough to be fed by permanent springs. These ravines will gradually be cut down and their heads will slowly encroach on the upland prairie, until in the distant future all of Lincoln County will be dissected into hills and valleys, and the lakes and swamps will have disappeared.

The county is crossed by two morainal ridges that run parallel to each other with a northwest-southeast trend (Pl. II). Both can be traced northwestward into South Dakota and southeastward through Minnesota into Iowa. They stand higher than the surrounding prairie and have a more irregular relief. The crest of the outer (or more southwesterly) ridge rises nearly 2,000 feet above sea level. It is interrupted by several remarkable gaps evidently formed by streams in the last glacial epoch.[a]

[a] Upham, Warren, Final Rept. Geol. and Nat. Hist. Survey Minnesota, vol. 1, 1882, p. 603.

SURFACE DEPOSITS.

DESCRIPTION.

On the coteau the glacial drift is very thick, but it thins out in the direction of the lowland plain, and in the extreme northeastern corner the North Branch of Yellow Medicine River has cut through it and exposed a sandstone formation.

As has just been stated, the coteau forms a relatively even plateau about 500 feet above the lowland plain, the slope from one level to the other being well defined and relatively abrupt. The large features of the topography (the coteau, slope, and lowland plain) are the same as they were at the close of the Pleistocene epoch, only minor characters being due to more recent erosion. The question at once arises: To what extent is the coteau of preglacial origin, and in how far has it been formed by deposits of drift?

It has been the general opinion that in this region the older formations lie at a higher level than farther northeast and that the greater thickness of the drift accounts for only a small part of the 500 feet of increase in altitude. This was the view of the Minnesota Survey geologists, Warren Upham's statement on this point being as follows:[a]

> Till, or the unstratified bowlder clay, deposited by the ice of the glacial period, forms a thick sheet, probably averaging a hundred feet in depth upon the surface of all this district (Lyon, Lincoln, and Yellow Medicine counties). * * *
>
> Though no exposures of strata older than the drift have been found upon the Coteau des Prairies in this district and northwestward, the underlying formations are believed to rise here much higher than on either side, in the basins of the Minnesota, Big Sioux, and James rivers. The altitude of the coteau is doubtless thus caused by the greater height of the formations, probably Cretaceous, upon which these drift deposits lie, rather than by extraordinary thickness of the drift beyond that which it commonly has throughout southwestern Minnesota. The depth that is added to the general drift sheet by the accumulations of the terminal moraines does not appear to average more than 50 to 75 feet. Upon the Coteau des Prairies the knolls and hillocks of the morainic belts rise 20 to 50 and rarely 75 or 100 feet above the adjoining hollows; and the thickness which they add to the drift sheet appears to be from 50 to 150 feet.

At the time this statement was made there were no deep wells in the region, the deepest one reported in Lincoln County being 94 feet. Hence there was no direct evidence as to the thickness of the drift. Knowledge is still very imperfect, but a number of rather deep drillings made in recent years indicate that Mr. Upham's statement will require some modification. It still seems altogether probable that the elevation of the coteau is to large extent caused by older formations (though as yet there is no proof of this in Minnesota); but the well data at hand show that the average thickness of the drift is here much greater than on the adjacent lowland plain, and

[a] Final Rept. Geol. and Nat. Hist. Survey Minnesota, vol. 1, 1882, p. 601.

that so far as this county is concerned a considerable part of the higher elevation results from this greater thickness. The well records also seem to indicate that the present margin of the coteau is determined by the deposits of drift, and that locally the underlying formations are no higher above sea level beneath the coteau than beneath the lowland plain.

The following table, showing the altitude of the top of the Cretaceous (or the bottom of the drift) on the plain near the foot of the coteau, is introduced here for comparison with similar data to be given for Lincoln County.

Altitude above sea level of the surface upon which the glacial drift rests, for specified points, at the foot of the coteau.

	Feet.
Tracy	1,235
Amiret	1,200
Marshall	1,125
Ghent	1,200
Minneota	1,155
Canby	1,140

All the drillers at Marshall assert positively that they have never encountered anything on the coteau or the upper part of the slope but sand, gravel, and ordinary pebbly clay, though on the lower part of the slope and on the lowland plain they constantly drill into "soapstone," which is the name they apply to the Cretaceous shale. They all differentiate between "soapstone" and the blue clay of the drift which contains pebbles and bowlders. Near Russell (Lyon County), on the farm of T. Thompson, NE. ¼ sec. 30, T. 110 N., R. 42 W., the following well section is reported:

Well section near Russell (Lyon County).

	Thickness.	Depth.
	Feet.	*Feet.*
Gravel, sand, and blue clay	280	280
Blue clay	80	360
Sandy blue clay	15	375
Sand	15	390

This well was sunk by Adair Brothers, of Marshall, who drill chiefly in the Cretaceous on the lowland plain, but who report that nothing in the nature of "soapstone" was reached at this place. If the entire section consists of glacial drift, the surface of the underlying formations is here less than 1,200 feet above sea level.

At Tyler the following section is reported for the old village well, the thickness of the various beds being only approximately correct.

Well section at Tyler.

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow clay	40	40
Blue clay	70	110
Quicksand	20	130
Blue clay	100	230
Yellow clay and gravel	100	330
Blue clay	170	500
Hard layer	5	505
Blue clay	45	550
Gravel	8	558

This well was drilled by Oxholm Brothers, of Arco, who also sunk the well at the former county poor farm (4 miles north and 1 mile east of Lake Benton) to a depth of 560 feet and several other wells in the county to depths of about 500 feet. These men have drilled in shale in South Dakota and hence distinguish between that material and the blue clay of the glacial drift. They state emphatically that they have never encountered shale in Lincoln County. They also report bowlders, generally more or less decayed, between depths of 300 and 500 feet. If the above section consists entirely of drift, the surface of the underlying formations is here not more than 1,190 feet above sea level.

The railway well at Tyler reached a depth of 575 feet. In reporting this well the representative of the railway company states that "all material penetrated is characteristic glacial deposit." If this is true, the older formations at this point do not rise more than 1,175 feet above the sea.

The following section is given for the unsuccessful well at Ivanhoe:

Well section at Ivanhoe.

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow clay	53	53
Red sand	23	76
Blue clay	29	105
Yellow clay	150	255
Sand	93	348
Shale	10	358
Blue clay (contains pebbles and bowlders)	77	435
Conglomerate	1	436
Soil ("perfectly black")	3	439
Yellow clay	11	450
Blue clay (entered)	37	487

If the beds here passed through are all drift, as they appear to be, the underlying surface is not more than 1,260 feet above sea level.

The testimony of all the drillers in Lincoln County is to the effect that the glacial drift is very deep and that the Cretaceous shale or "soapstone" is never penetrated. Three other deep wells have been drilled in the county—at Ivanhoe, Tyler, and Lake Benton—but no reliable section could be obtained. In the western part of Murray County the drift is also reported to be very thick, but no drillings were saved from the deep wells. At Wilmont, in Nobles County, a coarse gravel containing pebbles that show glacial striæ occurs at a depth of 348 feet.

It is notable that the valley of Minnesota River, the margin of the coteau, and the three morainal ridges (two in this county and one farther northeast) are all parallel. It seems probable (1) that before the Pleistocene epoch the territory now occupied by the coteau was in general a relatively high area; (2) that this preexisting highland modified the course of the ice tongue of the last and probably those of earlier glacial invasions; (3) that this ice tongue acted much like a valley glacier, scouring its channel and forming thick deposits at its margin; and (4) that the thickest accumulation of drift occurs near the edge of the coteau and in preexisting valleys of the region.

On the west side of the Coteau des Prairies (in South Dakota) where the upland descends to the so-called James River valley, the topographic features of coteau, slope, and "valley" are strikingly similar to those on the eastern, and the history of the two sides is probably similar. On both sides ice tongues are believed to have acted in much the same way and to have been followed by temporary lakes which smoothed out the lowland surface. On both sides also postglacial erosion has been most active on the slope.

YIELD OF WATER.

The sand and gravel deposits of the glacial drift are usually water bearing. The 6-inch village well at Tyler, which is 230 feet deep, has been tested at 35 gallons a minute, and the 6-inch railway well at the same place, which is 575 feet deep, at 88 gallons a minute. Generally, however, supplies adequate for ordinary purposes can be procured at more moderate depths.

HEAD OF THE WATER.

Flowing wells are found in the valley of North Branch of Yellow Medicine River in the northeastern corner of the county. It is possible that an occasional flow may also be obtained in other localities near the foot of the moraines, but there is no important artesian basin. As a rule, the water stands near the surface in shallow wells and far below the surface in the deepest wells. However, in the deep railway well at Lake Benton, which is situated in a gap in the outer moraine, the water rose nearly to the surface.

QUALITY OF THE WATER.

The water from the glacial drift is all hard. Most of it is extremely hard and highly mineralized and is very poor for boiler purposes. The analyses in the accompanying table seem to show that the least mineralized water is that from very shallow wells, and this is probably true, though the samples represented are too localized to warrant any general conclusion. The water from the deep well drilled at Lake Benton for the railway company (analysis 10 in the table, on p. 239) is also less mineralized than the average drift water, but nothing is known as to the source of this sample except the depth of the well.

UNDERLYING FORMATIONS.

Description.—Sandstone supposed to belong to the Cretaceous system is exposed in the valley of North Branch of Yellow Medicine River,[a] and other outcrops occur in Lyon County. This is probably the same sandstone that lies above the principal shale or "soapstone" beds at Canby, Minneota, and Marshall. The Cretaceous of Lyon County, known to attain a thickness of nearly 500 feet, is believed to extend below the drift of Lincoln County and to be continuous with the thicker formations farther west. (See the discussion of the Cretaceous in the report on Lyon County.) About 7 miles west of Minneota there lies beneath the drift a 40-foot bed of limestone which, if report is to be trusted, probably lies stratigraphically above the outcropping sandstone.

In the vicinity of Elkton, 1 mile west of the state line, the Sioux quartzite has been encountered at depths of 200 feet and less, and in one well in the southeastern part of this county (sec. 30, T. 109 N., R. 44 W.) hard rock that may belong to the same formation was struck at a depth of 450 feet. In the north the Archean granite occurs immediately below the Cretaceous.

Yield, head, and quality of water.—As very little is known from direct evidence in regard to the Cretaceous of this region, the reader is referred to the report on Lyon County. Throughout most of Lincoln County the water from the sandstones would remain at depths of several hundred feet. In the northeastern corner the altitude is low enough so that it would rise nearly or quite to the surface, but the principal water-bearing bed, elsewhere in the county, is not present here, the granite being found in its stead. In general, the Cretaceous water is even harder than that from the drift, but certain soft-water zones have been discovered in Lyon and other counties.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Lake Benton.—The outer moraine crosses the region about Lake Benton, and the village lies in a unique gap in the moraine, caused by a stream that once flowed southwestward. The glacial drift is known to be very thick. The well which furnishes the public supply

[a] Upham, Warren, Final Rept. Geol. and Nat. Hist. Survey Minnesota, vol. 1, 1882, pp. 598 and 599.

is 12 feet in diameter and was sunk to a depth of 16 feet, chiefly through sand and gravel. It is cased with brick and admits water at all levels. In the summer of 1907 the lake had risen almost to the top of the well, which was nearly full of water. The well has been tested at 400 gallons a minute and is reported to yield an ample supply even in dry years. The water is hard, as is shown by the analysis given in the table below. It is used by about 250 people, the average daily consumption amounting approximately to 7,500 gallons. Most of the private wells are of the dug or bored variety and are shallow, but there are also a few drilled wells, most of which are less than 100 feet deep.

Tyler.—The glacial drift is very thick near Tyler, as is shown by the section on page 235. The public supply is derived from a well 6 and 8 inches in diameter and 230 feet deep, which has a brass screen at the bottom. The water rises within 70 feet of the surface, or 1,680 feet above sea level. When the well was completed, in 1906, it was pumped for about twenty hours continuously at the rate of 35 gallons a minute. The water is very hard and contains much iron, which is oxidized and precipitated when exposed to the air. It is utilized for various purposes, but seems to be avoided for drinking and cooking because of its iron content. Shallow private wells are in general use. The mill and creamery are supplied from drilled wells that yield very hard water. An analysis of the water from the creamery well is given in the table.

Ivanhoe.—The public waterworks in the village of Ivanhoe are supplied from a 10-inch well that is finished with a screen at a depth of 315 feet, the water being reported to rise within about 100 feet of the surface. Most of the private wells are sunk into yellow clay and are shallow, but there are a few deeper drilled wells. The stratigraphic section, to a depth of 487 feet, has been given on page 235.

Hendricks.—The well that furnishes the public supply for Hendricks is 16 feet in diameter and 16 feet deep and ends in sand and gravel below a layer of clay. Perhaps 75 people use the water, and on an average 3,000 gallons is consumed daily. Most of the inhabitants rely on shallow private wells.

FARM WATER SUPPLIES.

There are two principal types of farm wells—bored and drilled. The former are shallow and terminate in yellow clay or are somewhat deeper and reach sand and gravel beds beneath a layer of blue clay. Their depth averages less than 50 feet and is rarely as much as 100 feet. Wells of the latter type range from less than 100 feet to nearly 500 feet in depth, the great majority being between 100 and 200 feet. The most satisfactory type for farm purposes is the 6-inch drilled well.

SUMMARY AND ANALYSES.

Throughout most of the county strata of sandstone, which would afford large quantities of water, are believed to exist, but they lie at considerable depths and the water would generally stand several hundred feet below the surface and be extremely hard. Soft-water zones containing adequate supplies may occur, but they are easily passed through unnoticed in drilling. If any further prospecting for soft water is undertaken, the careful methods described in the chapter on problems relating to wells (pp. 95–96) must be followed or failure will be almost certain. The sandstone may give place to granite in the northern and to quartzite in the extreme southern part of the county. In the northeastern corner, where the altitude is low, such sandstone strata as do exist will be encountered relatively near the surface, and the water will rise almost or quite to the surface.

The Sioux quartzite should not be penetrated unless no other source of supply is available. The granite should never be entered, because it is not water bearing.

Mineral analyses of water in Lincoln County.

[Analysis in parts per million.]

	Surface sand and gravel.						Glacial drift.			(?)
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Depth ...feet..	10	16	20	21	24	24	140	575	585	569
Diameter of well ...inches..	24	144	2	1¼	72	1¼	2	10,8,6	2	4½
Silica (SiO_2)...	45	1	28	26	29	21	26	42	31	27
Iron and aluminum oxides (Fe_2O_3 + Al_2O_3)...	4.8	26	2.06	......	1.6	24	......	5	3.5	1.7
Calcium (Ca)...	99	146	186	207	180	130	407	318	311	121
Magnesium (Mg)...	27	45	55	63	58	30	97	127	103	47
Sodium and potassium (Na+K)...	54	30	31	34	32	6	238	309	198	25
Bicarbonate radicle (HCO_3)...	216	403	534	403	573	422	956	941	724	410
Sulphate radicle (SO_4)...	284	286	279	469	255	99	1,091	1,147	976	198
Chlorine (Cl)...	3	2	20	20	16	9	7	15	15	6
Total solids...	623	735	863	1,016	855	527	2,337	2,427	1,994	628

1. Well on the shore of Lake Hendricks, at Hendricks. June 22, 1900.
2. Village well at Lake Benton. December 8, 1893.
3. A test well at Lake Benton. June, 1891.
4. A driven well at Lake Benton. November 29, 1898.
5. Well at Lake Benton. July 20, 1891.
6. A driven well at Lake Benton. June 10, 1902.
7. Creamery well at Tyler. January 31, 1900.
8. Railway well at Tyler. January 22, 1901.
9. Railway well at Tyler. December, 1899.
10. Railway well at Lake Benton. June 30, 1892.

The above analyses were furnished by G. M. Davidson, chemist Chicago and Northwestern Railway Company.

LYON COUNTY.

By O. E. Meinzer.

SURFACE FEATURES.

The topographic features of Lyon County are unique. As the map shows (Pl. I), the surface descends from about 1,750 feet above sea level in the southwestern corner to about 1,075 feet in the northeastern corner. But the grade is not uniform. As far as the 1,500-foot contour the descent is slight, thence for some miles it is relatively rapid, and below the 1,200-foot contour it is very gradual. The county is thus divided into three physiographic provinces—the upland plain, the slope, and the lowland plain.

The upland plain occupies the southwestern corner and forms a part of the Coteau des Prairies, which extends westward into South Dakota. It is crossed by a moraine, and in some parts is hilly, though generally only gently undulating. It is poorly drained and contains many lakes and swamps. The only stream of any consequence is Redwood River, which rises in Pipestone County and flows northeastward across Lyon County.

The slope from the upland to the lowland is not precipitous. It is not a cliff or escarpment, but only a gradual descent. Nevertheless, the gradient is sufficient for the surface waters to erode actively, and consequently this tract has become dissected by numerous ravines and valleys, all of which run northeastward toward the lowland plain. The largest have been cut deep enough to tap the upper zones of underground water and are now fed by springs. Extensive stream capture is destined to take place in this region before the drainage, which is still extremely youthful, shall have become adjusted.

The lowland plain of this county is a part of a much larger expanse lying between the coteau and Minnesota River. It is very flat and quite featureless. It is crossed by Yellow Medicine, Redwood, and Cottonwood rivers, which descend from the coteau and here occupy shallow valleys with but few tributaries, thus leaving the general surface of the plain poorly drained.

SURFACE DEPOSITS.

Description.—The glacial drift, which is a mixture of clay, sand, and gravel, ranges in thickness from a thin veneer to perhaps more than 400 feet. It is most attenuated in that portion of the lowland plain that lies next the slope from the coteau. Here the average depth is less than 50 feet, and in a few places streams have cut down to the underlying formations. Toward the northeast it thickens gradually, in some localities on the lowland plain attaining a depth of 100 feet; toward the southwest it thickens greatly and rapidly, within a few miles reaching a depth of several hundred feet.

At Taunton, Minneota, Ghent, Marshall, Heckman, and Dudley the average thickness is less than 50 feet; in the country surrounding Green Valley it is between 50 and 100 feet; in the locality of Cottonwood, about 100 feet; at Amiret, about 80 feet; and in the vicinity of Tracy, between 100 and 200 feet. Three miles northeast of Lynd (SW. ¼ sec. 19, T. 111 N., R. 41 W.) underlying shale was found at 155 feet; but wells in this village reach 125 feet, and a well near Russell 390 feet, apparently without passing out of the drift, the average thickness of which on the coteau is probably more than 300 feet. (Pl. II.)

Yield of water.—On the lowland plain in the northeastern part of the county the drift is too thin to be a reliable source of water, and in some localities it contains no water-bearing bed; but on the upland plain in the southwest it is deep and includes thick seams of sand and gravel, which afford abundant and permanent supplies.

Head of the water.—There are a few small areas of flowing wells supplied from the drift. Many of these wells are just outside of the Cretaceous flowing area and are located in the valleys on the slope (Pl. IV). Generally, however, these valleys have been cut so deep that they have tapped the water-bearing seams and allow the water to escape through springs, thus destroying artesian conditions.

Flowing wells from the drift have been reported as follows: (1) A group of very shallow wells about 5 miles southwest of Minneota, on secs. 16, 17, 20, and 21 in T. 112 N., R. 43 W.; (2) a well 66 feet deep on the farm of H. Kuhling, NE. ¼ sec. 6, T. 111 N., R. 42 W.; (3) a well 89 feet deep on the farm of Sobinskie Brothers, SW. ¼ sec. 36, T. 110 N., R. 41 W.; and (4) a well 85 feet deep 3 miles north of Tracy, on the farm of O. Pierce, NE. ¼ sec. 2, T. 109 N., R. 40 W. No doubt there are other small areas in which flows could be obtained.

Quality of the water.—The water is very hard and very poorly adapted for use in boilers. In some wells, especially on the lowland plain, it is too rich in magnesium, alkali, and sulphates to be satisfactory for drinking and culinary purposes.

CRETACEOUS SYSTEM.

DESCRIPTION.

The series of shales and sandstones shown in Plate XII has been penetrated in an indefinite number of wells in all parts of Lyon County except the southwestern, where the drift is very deep. Although there is no direct fossil evidence as to the age of these rocks, there can be no reasonable doubt that they constitute the eastward extension of the Upper Cretaceous of South Dakota. Their geographic position and lithologic character and the head and mineral composition of the water all indicate this.

As far as is known the upper surface of the Cretaceous has no great irregularities. A line drawn from the southeastern to the northwestern corner of the county would represent approximately its 1,200-foot contour. Thus at Tracy its altitude is about 1,235 feet; at Amiret, 1,200 feet; at Marshall, 1,125 feet; and at Minneota, 1,155 feet. From the 1,200-foot contour it descends gradually toward the northeast, reaching about 1,000 feet in the northeastern corner. Less is known about the Cretaceous surface in the southwestern part, but it certainly does not rise as much as the present surface of the land. In the sections given in Plate XII the Cretaceous ranges from 125 to 455 feet in thickness, but the extreme range is somewhat greater. In the northern and especially the northeastern part its thickness is least, the granite coming near the surface; in the central and southern parts it is commonly penetrated to depths of 350 to 450 feet, and the bottom is rarely reached. It probably thickens westward beneath the coteau.

There is so much monotony in the sections of the Cretaceous that it is not possible to correlate them with certainty from well records. The stratigraphic succession at Marshall has been determined most accurately, and many well sections within 5 or 10 miles of that city, especially to the east and southeast, have been correlated with it. The main artesian zone (B in Pl. XII) and the principal soft-water zone (D in Pl. XII) are well recognized there.

YIELD OF WATER.

In the vicinity of Marshall the following water-bearing strata are found: (1) The shallow zone. The section for the first 100 feet below the surface is not constant, but there are several sandy layers which yield abundantly. (2) The soft-water zone. This occurs at a depth of 250 feet and supplies a number of wells, but its yield is so small that were it not for the relative softness of the water, it would not be utilized at all. The soft-water well at the new mill will furnish about 2 gallons a minute with the pump at the bottom of the well. (3) The 300-foot zone. In Marshall a hard impervious layer is encountered at about 300 feet below the surface, or 50 feet below the soft-water zone; but 1 mile east of the city, on the farm of C. H. Middleton (SE. ¼ sec. 3, T. 111 N., R. 41 W.), there was found associated with this hard layer a 6-foot sandstone stratum which gives rise to a flow of 2 or 3 gallons a minute, and near by, on the farm of C. E. Overstrud (NE. ¼ sec. 3, T. 111 N., R. 41 W.), the same hard layer and artesian sandstone stratum were penetrated. These wells show that a layer at one place water bearing may at no great distance be quite impervious, and that small amounts of water are commonly associated with the hard layers so frequently encountered in drilling through the soft shale. (4) The main artesian zone. About 400 feet below the surface occurs the sandstone that supplies most of the flowing wells of the vicinity. In Marshall it furnishes sufficient amounts of water for all ordinary purposes, but at some distance east, southeast, and northeast its yield is very small. (5) The deep zone. The new mill well extends to a depth of 490 feet and is evidently supplied from a lower source than the other artesian wells in the city. It is reported to flow 600 gallons a minute from a 6-inch pipe.

At Minneota the Cretaceous contains the following water-bearing beds: (1) Several layers of sand and sandstone between the depths of 25 and 110 feet. These are probably to be correlated with the shallow zone at Marshall. They yield abundantly. The 6-inch village well, which is supplied from this source, has been pumped continuously for twenty hours at the rate of 30 gallons a minute. (2) A stratum of sand at a depth of 250 feet. This would probably furnish considerable water, though the sand is fine and incoherent.

In the region between Minneota and Ghent the same two zones occur that are given above for Minneota. Near Cottonwood and farther west water is found at a depth of about 100 feet and at 150 feet or more. In the entire northern part of the county the main artesian sandstone is absent and the granite exists in its place.

East of Marshall, in the vicinity of Dudley, there are two principal sources from which the wells draw their water—one at depths ranging from about 160 to 230 feet, and the other at an average depth of about 400 feet. The former corresponds, in a general way, to the soft-water beds at Marshall, and the latter to the main artesian sandstone of that locality. The supply from the former varies, but is usually small; the latter yields copiously in the district west and south of Dudley, but fails entirely farther east and north where the granite is nearer the surface. The shallow deposits of sand found at Marshall do not seem to be represented here.

Partial list of wells that end in the upper water zone in the vicinity of Dudley, showing owner, location, and depth.

	Feet.
J. G. Schultz, SW. ¼ sec. 1, T. 111 N., R. 41 W	230
T. L. Wolf, NE. ¼ sec. 12, T. 111 N., R. 41 W	220
E. De Clerk, NE. ¼ sec. 6, T. 111 N., R. 40 W	212
Margaret Lenerds, ¼ sec. 6, T. 111 N., R. 40 W	190
Chris. Rock, NW. ¼ sec. 5, T. 111 N., R. 40 W	170
C. Schoel, NW. ¼ sec. 4, T. 111 N., R. 40 W	160
B. Snyder, SW. ¼ sec. 4, T. 111 N., R. 40 W	178
W. E. Heagle, NW. ¼ sec. 9, T. 111 N., R. 40 W	190
F. W. Ludwig, SW. ¼ sec. 3, T. 111 N., R. 40 W	166
H. Snyder, NW. ¼ sec. 14, T. 111 N., R. 40 W	190
Benj. Christianson, NE. ¼ sec. 14, T. 111 N., R. 40 W	162
R. Castle, SW. ¼ sec. 14, T. 111 N., R. 40 W	190

Partial list of wells that end in the lower water zone in the vicinity of Dudley, showing owner, location, and depth.

	Feet.
W. H. Baughman, SE. ¼ sec. 12, T. 111 N., R. 41 W	405
Watt Fuller, SW. ¼ sec. 13, T. 111 N., R. 41 W	403
C. W. Snyder, NW. ¼ sec. 29, T. 111 N., R. 40 W	435
J. Ciesielski, NW. ¼ sec. 28, T. 111 N., R. 40 W	425
E. C. Kochrane, SE. ¼ sec. 15, T. 111 N., R. 40 W	356
J. F. Fischer, NE. ¼ sec. 22, T. 111 N., R. 40 W.[a]	345

Near Amiret and in the region east and northeast of that village there are numerous wells ranging from less than 400 to more than 500 feet in depth, and a large proportion of these yield generously. The strata in which they end apparently correspond, in a general way, to the lower artesian sandstones at Marshall, the granite being here deeply buried. At Tracy the best water-bearing bed exists 600 feet below the surface. The 6-inch city well, which extends to this depth, has been pumped for fifteen hours continuously at the rate of 50 gallons a minute.

From the data that have been given, the following provisional correlation of the water-bearing members of the Cretaceous can be made:

(1) Shallow zones—represented by the sandy beds generally less than 100 feet below the surface in the vicinities of Marshall, Ghent, Minneota, Cottonwood, etc.

(2) Intermediate zones—represented by the 250-foot and 300-foot strata in the locality of Marshall, the 250-foot sand layer in the region about Ghent and Minneota, and the upper sources in the vicinity of Dudley.

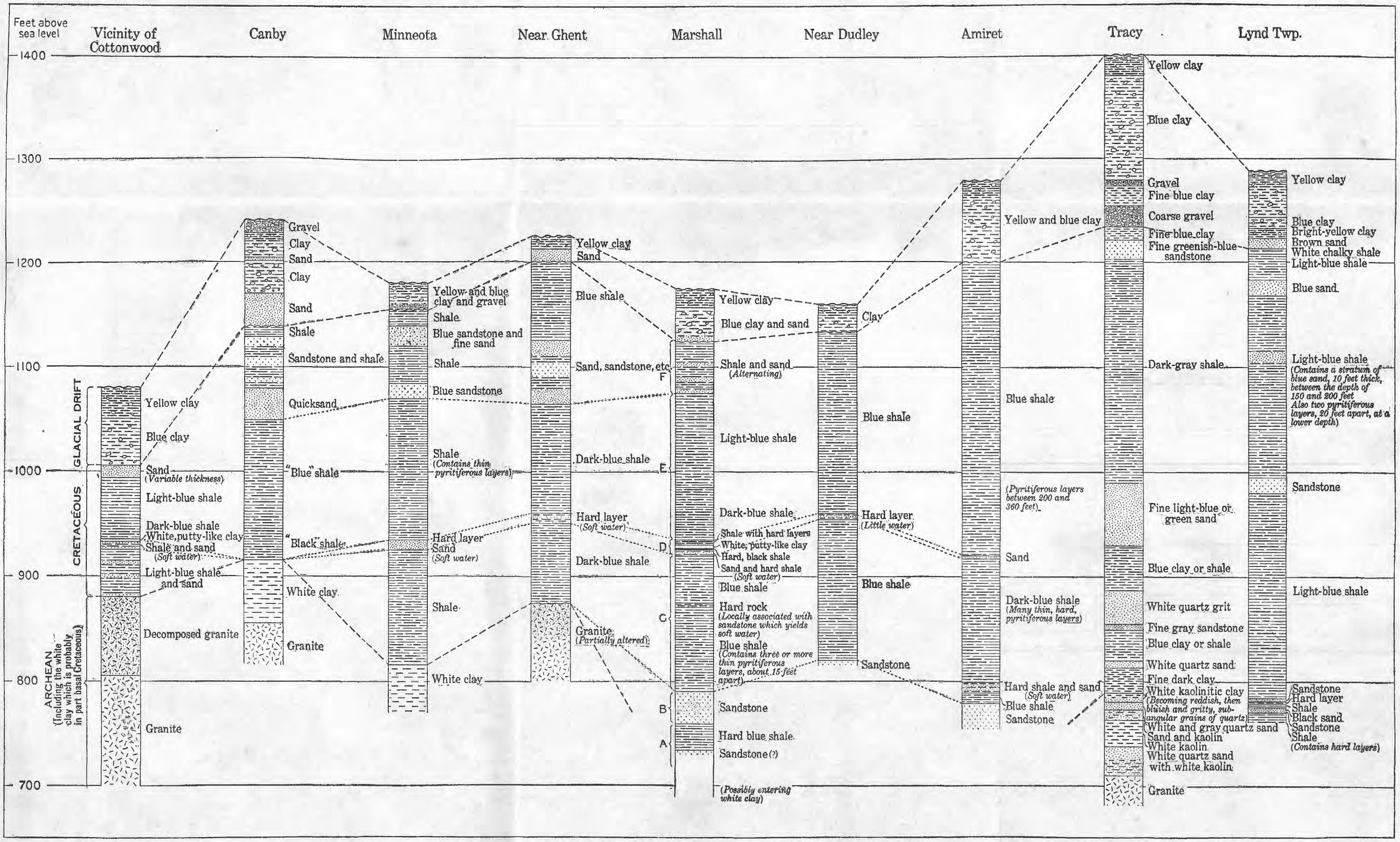
(3) Deep zones—represented by the lower sandstones in the territory including Marshall, Dudley, Amiret, and Tracy.

HEAD OF THE WATER.

The area in which the Cretaceous gives rise to flowing wells lies on the lower portion of the slope from the coteau and on adjacent parts of the lowland plain. It is 6 to 8 miles wide and extends from the vicinity of Ghent southeastward into Redwood County (Pl. IV). With few exceptions, only the deep zones produce flows.

The southwestern margin of the area crosses Lynd and Sodus townships (T. 111 N., R. 42 W., and T. 110 N., R. 41 W.) in a direction nearly due southeast, and then turns more nearly eastward and crosses the southern part of Amiret Township (T. 110 N., R. 40 W.). It lies between the 1,200-foot and 1,300-foot contours. Northwest of Amiret it nearly coincides with the latter, but as it is followed southeastward it gradually descends, leaving the county at an altitude of about 1,250 feet above sea level, and getting down almost to 1,200 feet at Walnut Grove, 6 miles east of the county line. In the F. Mellenthine well, 1 mile south and 6 miles west of Marshall (SW. ¼

[a] The section of this well is given in Pl. XII.



GEOLOGIC SECTIONS IN LYON AND WESTERN YELLOW MEDICINE COUNTIES.

By O. E. Meinzer.

Vicinity of Cottonwood.—Generalized for the vicinity of Cottonwood. The section is somewhat different in different localities.

Canby (Yellow Medicine County).—Deep well drilled for the village; record preserved by village authorities.

Minneota.—The upper 110 feet is generalized. The section below that depth is that of the flowing well belonging to H. A. Rush, as reported by W. A. Crowe, the original owner.

Near Ghent.—Well 3 miles northwest of Ghent, on farm of J. De Cock, NW. ¼ sec. 7, T. 112 N., R. 42 W. The altitude is only approximately known. Data obtained from Adair Brothers, drillers, Marshall.

Marshall.—Generalized from individual sections given by Adair Brothers, S. P. Wheeler, O. W. Martin, and William McColgan, drillers at Marshall. The last 75 feet has been penetrated only in the new mill well, and no accurate data could be obtained. The section of the old mill well was reported by J. E. Todd in Water-Supply Paper U. S. Geol. Survey No. 102, 1903, p. 481. F, Upper shale and sandstone; E, principal shale series (upper portion); D, intermediate sandstone, etc.; C, principal shale series (lower portion); B, main artesian sandstone; A, basal series.

Near Dudley.—Well 3 miles southeast of Dudley, on farm of J. F. Fischer, NE. ¼ sec. 22, T. 111 N., R. 40 W.; approximate. The altitude also is approximate. Authorities, Adair Brothers, drillers, Marshall.

Amiret.—Flowing well at Amiret owned by Webb & McLaughlin; approximate. Authority, O. W. Martin, driller, Marshall.

Tracy.—Deep well drilled at Tracy in the winter of 1885–86. It was reported by Prof. N. H. Winchell (Fourteenth Ann. Rept. Geol. and Nat. Hist. Survey Minnesota, 1885, pp. 351–353) and is probably more accurate than any section since obtained. The well was drilled by Swan & Stacey, and the drillings were examined by Professor Winchell. The description of the strata given on the plate is much abbreviated.

Lynd Township.—Well drilled in 1907, 1 mile south and 6 miles west of Marshall, on the farm of F. Mellenthine, SW. ¼ sec. 9, T. 111 N., R. 42 W. Authority, William McColgan, driller, Marshall.

sec. 9, T. 111 N., R. 42 W.) the water rises slightly above the surface at an altitude of about 1,290 feet; in the well at Amiret it overflows at 1,280 feet; at Tracy it rises to about 1,230 feet; and at Walnut Grove to 1,216 feet.

The northeastern margin is approximately parallel with the southwestern. Starting north of Ghent it passes over Grandview and Fairview townships (T. 112 N., R. 42 W., and T. 112 N., R. 41 W.) to the southeast corner of the latter township. Thence it crosses Clifton Township (T. 111 N., R. 40 W.) diagonally, and leaves the county near the southeast corner of this township.

The southwestern margin of the flowing area is evidently determined by the surface altitude, but another explanation is necessary to account for its limits toward the northeast, for the surface continues to descend in this direction. The failure to obtain flows on the lower ground to the northeast may result from either of two causes, decrease in the artesian pressure or interruption of the artesian zone. It was observed that near the margin the wells commonly give rise only to very small flows, and that in some wells at least this is not due to lack of pressure but rather to the absence of any bed that will yield much water. The well on the farm of T. L. Wolf, NE. ¼ sec. 12, T. 111 N., R. 41 W., will serve as an example. It is located near the northeastern margin, is 520 feet deep, and has a section similar to that of the successful flowing wells immediately to the west and south. At the depth of 410 feet it penetrated a hard and nearly impervious layer which corresponds stratigraphically to the much thicker and more porous sandstone that gives rise to flowing wells farther west and south. This nearly impervious layer yielded only a slight flow, which, however, had a good pressure. Farther northeast no flows are obtained because deep drilling fails to find water-bearing beds. The flowing well at Minneota, whose section is given in Plate XII, is another illustration of this condition. It yields only a few gallons a day, the water escaping drop by drop; yet when the top of the well is closed the confined water exerts considerable pressure, showing that the small yield is not due to a lack of head. Moreover, the water can be pumped down to any level almost instantly. The main artesian zone is evidently absent, and only a minute quantity of water is transmitted by the nearly impervious white formation. In some wells the pressure is slight or the water does not rise to the surface, but a general survey of the conditions has led to the conclusion that the flowing area does not extend farther east and north primarily because of the rise of the granite surface and the consequent interruption of the principal artesian sandstone.

At Marshall the pressure has diminished to a marked extent since the first flowing wells were sunk. The following data are for the main artesian zone.

Decrease in artesian pressure in wells at Marshall.

	Depth of well.	Date of test.	Head above surface.	Head above sea level.
	Feet.		*Feet.*	*Feet.*
Old flouring-mill well[a]	392	1894.	207	1,375
		(b)	161	1,329
M. Guiseke's well[c]	386	1901.	131	1,300
		1906.	70	1,240

[a] Authority, chief engineer Marshall flouring mill.
[b] In U. S. Geol. Survey Water-Supply Paper No. 102, 1903, p. 481, J. E. Todd states that the head is reported to be 161 feet, but gives no date.
[c] Authority, Adair Brothers, drillers, Marshall.

The data given for the city well, which is 410 feet deep, substantially corroborate those given in the above table. In 1895 it had a pressure of 90 pounds to the square inch; that is, the water would have risen 207 feet above the surface, or fully 1,375 feet above sea level, but at present the head is much lower—probably lower than that given for the Guiseke well in 1906.[a]

There are no flowing wells at Tracy, but the head there also has been greatly lowered. In the city well, which is about 600 feet deep, the water is reported to have risen in 1892 to a level about 50 feet below the surface, or 1,360 feet above the sea, whereas in 1907 it was reported to remain 180 feet below the surface, or 1,230 feet above sea level. This shows approximately the same loss of head as at Marshall, and suggests that the decrease of pressure may be a general phenomenon.

In the well at the new flouring mill in Marshall, which reaches a deeper source than the other flowing wells of the city, the pressure at present is 40 pounds to the square inch; that is, the water would rise about 92 feet above the surface, or 1,270 feet above sea level. The 250-foot zone at Marshall yields so little water and has been pumped so hard that the head has been lowered greatly. It once produced flows, and even as late as in 1906 the water in the mill well is reported to have risen, when the well was not pumped for a week, within 16 feet of the surface. A few flowing wells end in the 300-foot stratum.

QUALITY OF THE WATER.

The analyses given in the accompanying table (pp. 251–252) show that in some important respects the Cretaceous waters of this region are similar and in other respects they differ widely. They are all highly mineralized, but they vary greatly in the total amount of mineral matter that they contain. Likewise they are all characterized by a large content of sodium and of sulphates and chlorine, but there is a great difference in the absolute quantities of all these. They differ most radically, however, in their content of calcium and magnesium, and hence in their hardness and scale-forming properties.

[a] Information furnished by Eugene Simmons, superintendent of the public waterworks, Marshall.

The quality of the water from the various Cretaceous strata will be discussed under the heads of shallow zones, intermediate zones, and deep zones.

Shallow zones.—The water from the shallow sources at Marshall is very hard, as well as rich in the alkali sulphates, and that from the strata near the surface at Minneota is similar.

Intermediate zones.—The water that comes from depths intermediate between the shallow and deep zones seems to be relatively soft. The following data bear on this point:

The water from the 250-foot and 300-foot strata at Marshall is soft, as shown by analyses 6, 7, and 8 in the table.

In the J. DeCock well, near Ghent (Pl. XII), the 9-foot stratum that lies at a depth of 265 feet supplies water which is considered soft.

At Minneota the 10-foot layer of sand encountered at a depth of 246 feet in drilling the deep flowing well (Pl. XII) is reported to contain soft water.

In the vicinity of Cottonwood the water from the lower beds—that is, from depths about 150 feet—is said generally to be soft (for example, the old mill well, which was 152 feet deep). In the village well, the water, which is supposed to come from a depth of 175 feet, contains great quantities of common salt (sodium chloride), but is rather soft and not otherwise excessively mineralized.

In the region about Dudley the wells between 160 and 230 feet in depth, given in the list on page 243, all yield water that is considered soft.

At Walnut Grove the village well and other wells between the depths of 150 and 325 feet supply soft water.

Deep zones.—The water from the main artesian sandstone, which occurs at Marshall at a depth of about 400 feet, is extremely hard; it also contains large amounts of sodium and of sulphates and chlorine, and is very corrosive. No unmixed sample could be obtained from the well at the new mill, but its water also seems to be very hard. At Tracy the water from the depth of 600 feet is hard, but in general less highly mineralized than that from the deep sources at Marshall.

It is significant that some of the deepest wells afford soft water, as is shown by analysis 10 in the table. A few of the wells reported to belong to this class are given in the following list:

Partial list of deep "soft-water" wells in Lyon County, showing owner, location, and depth.

	Feet.
T. Jansen, SE. ¼ sec. 17, T. 111 N., R. 41 W	[a] 422
Fred Mellenthine, SW. ¼ sec. 9, T. 111 N., R. 42 W	530
B. Reese, SE. ¼ sec. 3, T. 111 N., R. 42 W	415
F. A. Revard, SW. ¼ sec. 19, T. 111 N., R. 41 W	505
Andrew Silvius, NW. ¼ sec. 6, T. 110 N., R. 41 W	[a] 506
A., J., and E. Van Moer, NW. ¼ sec. 17, T. 110 N., R. 40 W	447
G. T. Walker, SW. ¼ sec. 18, T. 111 N., R. 41 W	[a] 433

[a] Todd, J. E., Water-Supply Paper U. S. Geol. Survey No. 102, p. 481.

PALEOZOIC AND ALGONKIAN ROCKS.

Remnants of Paleozoic strata may exist; but if so, they are deeply buried and have not been recognized.

The Sioux quartzite is certainly absent in most of Lyon County, but may be present in the southwestern part, though there is no evidence of it. Even if present, it is of no value as a source of water.

ARCHEAN ROCKS.

Granite or its decomposition products have been struck in drilling at Cottonwood, Ghent, and Minneota, and elsewhere north of Threemile Creek and Redwood River, as well as at one point near the center of the county[a] (NW. ¼ sec. 6, T. 110 N., R. 41 W.), and at Tracy, in the extreme southern part. The data bearing on the depth of this rock below the surface and its elevation above sea level are shown in Plates III and XII.

In most places where the granite is penetrated it is found to be much altered at the top, commonly being so thoroughly decayed that it is as soft as any clay. The following are some of the indications of granitic residuum which every driller should understand: (1) Clays of brilliant red, yellow, green, white, etc.; (2) silvery flakes of mica; (3) angular, transparent grains of quartz; (4) hard, "glassy" layers alternating with softer material. These last are the quartzose bands of the original gneissic rock. In many localities there is a compact white formation consisting of kaolin or associated minerals derived from the underlying granite. In some places it has a surprising thickness, and contains interbedded seams of grit; such seams prove that it is not there a truly residual product, though resulting from the decomposition of the rock and nearly always lying upon it. (See the Minneota, Canby, and Tracy sections in Pl. XII.)

The granite is not water-bearing, except that rarely small supplies are developed in the upper part.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Marshall.—The underground water conditions in Marshall have been fully described. The public supply is obtained chiefly from a combination dug and drilled well less than 100 feet in total depth. An artesian well 410 feet deep, and also the mill well and the river can be drawn on in case of fire. The combination well is reported to yield about 50,000 gallons a day, and the artesian well will flow at least 30,000 gallons in the same period. The water from the former is preferred to that from the latter because it is somewhat less highly mineralized. Analyses of both are given in the table (pp. 251–252). About 600 people use the public supply and on an average

[a] Todd, J. E., Water-Supply Paper U. S. Geol. Survey No. 102, 1903, p. 481.

approximately 40,000 gallons is consumed daily. About three-fourths of the inhabitants use water from private wells, most of which are less than 100 feet deep. The small supplies from the 250-foot soft-water zone are utilized in boilers and to some extent for culinary purposes. The water from the deep artesian sandstone is ruinous to boilers.

Tracy.—There are in Tracy two principal sources of underground water, the glacial drift at depths of less than 200 feet, and the sandstone stratum at 600 feet. The stratigraphic section is given in Plate XII. The deep well which furnishes the public supply has already been described. The analyses in the table show that its water is hard. About 50,000 gallons is used daily, and approximately 1,800 people are served. The Chicago and Northwestern Railway Company uses water from Lake Sigel for boiler purposes, and most of the people south of the railway are also supplied with this water. The private wells are dug, bored, or drilled, and range from a few feet to about 175 feet in depth, ending in glacial drift. The water in the shallow wells is considered poor.

Minneota.—The entire supply for the village of Minneota comes from depths of less than 125 feet. The public supply is taken from a well 6 inches in diameter and 111 feet deep. It passes through glacial drift and below that through layers of "soapstone," sand, and sandstone, and is finished with an open end in a sandstone stratum. The water rises within 20 feet of the surface, or about 1,165 feet above sea level. About 7,000 gallons is consumed daily. All the wells in the village yield hard water. An analysis of the public supply is given in the table below. Softer water could probably be obtained at a depth of 250 feet (Pl. XII). About 75 per cent of the people use water from private wells, many of which are bored to depths of less than 30 feet and end in glacial drift, but some are drilled into the Cretaceous sandstone.

Cottonwood.—The granitic residuum at Cottonwood lies within 200 feet of the surface and is very thick. The glacial drift is 75 or 100 feet deep. Between the drift and the granitic material are strata of shale and sandstone. The entire population depends upon private supplies. There are only a few wells in the village, but most of the people have cisterns which are filled either with rain water or with water hauled from farm wells. The few private wells are of the dug or bored type and are about 20 to 40 feet deep. It is difficult to get water at shallow depths, but better supplies seem to occur between 100 and 150 feet below the surface. The railway well is 139 feet deep and ends in coarse sand yielding hard water. The creamery well is 160 feet deep and extends into white sand. The old mill well, now abandoned, was 152 feet deep and stopped in sandstone that yielded water reported to be soft. It seems that all these were successful wells. The well which was intended to supply the public waterworks was drilled to a depth of 375 feet, penetrating deep into the granitic rocks. It is cased to 175 feet and is said to get its meager supply from this depth. As the yield is very small and the water contains great quantities of sodium chloride (see the analysis given in the table), it is used only for fire protection. The well will soon be abandoned and water from the lake will be used.

Balaton.—The public supply for the village of Balaton is taken from a well 8 feet in diameter and 27 feet deep. It passes through coarse gravel and is cased with stone. In 1907 the water stood about 13 feet below the surface, and pumping at the rate of 45 gallons a minute lowered it but slightly. It is moderately hard and supplies about 250 people, approximately 10,000 gallons being consumed daily. About one-half of the inhabitants use water from private wells. The dug wells are generally 20 or 30 feet deep and end in a thick bed of outwash gravel, but the drilled wells pass through blue bowlder clay and extend to sand and gravel layers at depths of 100 to 150 feet. The railway well is similar to the village well. The mill and creamery are supplied from drilled wells.

FARM WATER SUPPLIES.

On the lowland plain occupying the northeastern part of the county there are a few shallow bored wells that end in glacial drift, but these are generally unsatisfactory both in the quality and the quantity of the water that they furnish. For this reason by far the greater number of the farms here are supplied by drilled wells that tap the Cretaceous strata. Near the northern margin of the county these are commonly between 100 and 200 feet deep; northeast of Dudley they are generally 200 feet deep or less; in the vicinity of Marshall and thence southeastward between Dudley and Amiret to Redwood County there are many flowing wells between 300 and 500 feet deep, but also numerous shallower drilled wells.

On the upland plain or coteau in the southwestern part of the county the entire farm supply is derived from the glacial drift. Most of the wells are bored and are less than 100 feet deep, but there are also many drilled wells whose average depth is somewhat greater.

On that part of the slope which is included in the Cretaceous flowing area numerous deep wells penetrate the artesian strata, but where flows can not be obtained virtually all the wells end in drift.

SUMMARY AND ANALYSES.

The facts in regard to the underground waters can best be summarized as follows:

Underground water conditions in Lyon County.

Area.	Zones.	Depth.	Yield.	Head.	Quality.
		Feet.			
Northern portion of lowland plain (north of Ghent, Dudley, and Milroy.)	Glacial drift	0 to 100+	None to moderate.	Near surface.	Hard.
	Shallow Cretaceous	25 to 150	Moderate	do	Do.
	Intermediate Cretaceous.	150 to 230	Small to moderate.	do	Rather soft.
Southern portion of lowland plain and slope (approximately coinciding with the Cretaceous flowing area (Pl. IV), between Dudley, Ghent, Lynd, and Tracy.)	Glacial drift	0 to 100	None to moderate.	do	Hard.
	Shallow Cretaceous (absent in east part).	50 to 100	do	do	Do.
	Intermediate Cretaceous.	−200 to 300	Small to moderate.	+ to −125	Soft.
	Deep Cretaceous	300 to 550	Moderate to large.	(+)	Varying, generally hard.
Southwestern portion — the upland plain and that portion of the slope not included in the Cretaceous flowing area. (Southwest of Tracy, Lynd, and Minneota.)	Glacial drift	0 to 300	do	Variable	Hard.
	Cretaceous	300 to 1,000 (?)	do	Low	Varying.

Mineral analyses of water in Lyon County.

[Analyses in parts per million.]

	Glacial drift and top of Cretaceous.					Cretaceous.			
	1.	2.	3.	4.	5.	6.	7.	8.	9.
Depth feet	20	111	80	90	185	250	250	300	312
Diameter of well inches	72	6	48			2	1¼	2	6
Silica (SiO_2)	12	27	24	20	14	3.2	1.2	2.4	12
Iron (Fe)		1.5		3.2		.13	.15	.11	
Aluminum (Al)				10		1.8	2.5	2.1	
Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	.57	3.2			26				6.4
Calcium (Ca)	178	142	207	163	306	31	40	59	17
Magnesium (Mg)	75	70	89	74	95	16	13	20	12
Sodium and potassium (Na+K)	103	205	126	134	248	258	269	524	423
Carbonate radicle (CO_3)		.0		.0		.0	.0	.0	.0
Bicarbonate radicle (HCO_3)	436	380	563	439	1,269	242	268	325	268
Sulphate radicle (SO_4)	559	691	657	604	628	378	291	950	709
Chlorine (Cl)	26	33	6.8	8		52	92	49	23
Nitrate radicle (NO_3)		.0		.0		.0	.0	.0	.0
Total solids	1,167	1,370	1,387	1,230	1,943	836	854	1,793	1,345

	Cretaceous—Continued.								Archean-Cretaceous contact zone.	
	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.
Depth feet	422	390	485(?)	410	430	600	600	592	375(?)	408
Diameter of well inches	1¼		6	8	4½	10 to 6			6 and 8	
Silica (SiO_2)	2.8	22	23	10	11	16	24	8.3	5	16
Iron (Fe)	Tr.		3						2.2	1
Aluminum (Al)	3.4		8							
Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)		.2			2.06	4.4	5	3.8	3.8	3
Calcium (Ca)	22	329	261	209	324	138	139	130	38	89
Magnesium (Mg)	16	97	75	139	99	36	33	33	32	69
Sodium and potassium (Na+K)	536	339	203	415	422	214	182	242	934	611
Carbonate radicle (CO_3)	.0		.0			.0			.0	.0
Bicarbonate radicle (HCO_3)	361	676	420	716	387	283	231	296	85	254
Sulphate radicle (SO_4)	819	1,279	935	1,317	1,679	645	630	689	258	778
Chlorine (Cl)	63	51	40	30	47	39	18	18	1,340	580
Nitrate radicle (NO_3)	.0		.0			.0			Tr.	.0
Total solids	1,663	2,449	1,789	2,473	2,774	1,244	1,150	1,271	2,669	2,274

1. Well at Minneota.
2. Village well at Minneota. August 23, 1907.
3. Well of the Chicago and Northwestern Railway Company at Marshall. May, 1900.
4. City well at Marshall from which the public supply is usually taken. August 12, 1907.
5. Well at Tracy. October 28, 1889.
6. Well at the Marshall Bottling Works. November 12, 1908.
7. Well of H. H. Adair at Marshall. November 12, 1908.
8. Well of C. H. Middleton, near Marshall, in the SE. ¼ sec. 3, T. 111 N., R. 41 W. November 12, 1908.
9. Village well at Walnut Grove (Redwood County).
10. Well of T. Jansen, near Marshall, on the SE. ¼ sec. 17, T. 111 N., R. 41 W. November 12, 1908.
11. Flowing well at the old mill in Marshall. March 6, 1896.
12. City flowing well at Marshall. August 12, 1907.
13. Flowing well at Marshall. April 28, 1902.
14. Flowing well of the Chicago and Northwestern Railway Company at Marshall. February 13, 1903.
15. City well at Tracy. August 13, 1907.
16. City well at Tracy. August 26, 1896.
17. Well at Tracy. March 6, 1891.
18. Village well at Cottonwood. August 21, 1907.
19. Flowing well on the property of W. A. Rush at Minneota. August 23, 1907.

Analyses 2, 4, 6, 7, 8, 9, 10, 12, 15, 18, and 19 were made for the United States Geological Survey by H. A. Whittaker, chemist Minnesota state board of health. Analyses 1, 3, 5, 13, 14, and 17 were furnished by G. M. Davidson, chemist, Chicago and Northwestern Railway Company. Analyses 11 and 16 were furnished by Edgar & Mariner, chemists, Chicago.

McLEOD COUNTY.

By O. E. MEINZER

SURFACE FEATURES.

The surface of McLeod County consists of a gently undulating plain which is covered with many swamps and small lakes. The principal streams are Buffalo Creek and South Branch of Crow River, both of which flow eastward across the county. They occupy shallow valleys and have accomplished but little postglacial erosion.

SURFACE DEPOSITS.

Description.—The glacial drift occurs in all parts of the county and its average thickness is great. Older formations nowhere come to the surface, and they have been reached in only a few wells. In the city well at Glencoe the drift was found to be at least 280 feet thick and possibly 354 feet.[a] At Brownton it has been penetrated to a depth of 304 feet; at Stewart to a depth of 265 and perhaps 320 feet, and on a farm south of Stewart to a depth of 375 feet, without apparently reaching the bottom. In the village of Buffalo Lake, 6 miles west of this county, it was found to be about 340 feet thick. At Hutchinson it has been penetrated to a depth of 230 feet, and in several wells between that city and Brownton to depths of more than 300 feet, without reaching the bottom, and in a well near Lester Prairie the underlying rock was entered 360 feet below the surface.

Yield of water.—The drift yields generous quantities of water, the deepest sand and gravel beds especially furnishing large and permanent supplies. The 10-inch flowing well at the flouring mill in Hutchinson,

[a] This statement is based on the correlations made by Prof. C. W. Hall. A different interpretation is given by Warren Upham. See Final Rept. Geol. and Nat. Hist. Survey Minnesota, vol. 6, 1900, opposite Pl. 37.

about 180 feet deep, has been pumped at the rate of 800 gallons a minute, and when given a head of 6 feet it will flow 200 gallons a minute. The 6-inch village well at Brownton, reported to be 304 feet deep, has been tested with an air lift at the rate of 95 gallons a minute. The 8-inch village well at Stewart, 320 feet deep, appears to have a less generous yield. According to report it will supply 60 gallons a minute when the pump is placed 107 feet below the water in the well, but fails to furnish this amount when the pump is only 87 feet below the water level.

Head of the water.—Flowing wells can be obtained in the valley of South Branch of Crow River all the way from Otter Lake to Lester Prairie (Pl. IV). The water from various sand and gravel beds will come to the surface, but the strongest artesian zone lies at a depth of about 200 feet. Several flowing wells are found east and north of Otter Lake and in the valley leading eastward from this lake. In the city of Hutchinson there are about 55 flowing wells which range in depth, according to their surface altitudes, between 180 and 210 feet. In the well at the mill, situated on the bank of the river, the water is under sufficient pressure to rise 28 feet above the surface, or to a level 1,055 feet above the sea. In wells located upon ground higher than about 1,055 feet above sea level the water does not come to the surface. A few flows have been obtained from a 45-foot seam which has about the same head as the 200-foot zone, and flows of very slight yield are obtained from a depth of about 170 feet.

Not many flowing wells have been drilled in the valley between Hutchinson and Biscay, but there are several in the vicinity of Biscay, and some at various points along the valley to Koniska and beyond. At the village of Biscay the water will rise about 20 feet above the surface, or approximately 1,040 feet above sea level. At Lester Prairie, on the north side of South Branch near the point where that stream flows out of the county, the water from a 100-foot zone and also from lower beds comes virtually to the surface, which is here 980 feet above sea level. Flows could probably be secured on the river bottom all the way from Koniska to Lester Prairie.

On the west side of Lake Marion (T. 115 N., R. 30 W.) there are several flowing wells about 100 feet deep; in the valley of Buffalo Creek the water rises virtually to the surface and in a few wells overflows with a slight head.

The head decreases toward the southeast, away from the high morainic area, which is in large measure the cause of the artesian conditions. This fact is made clear by the following table showing the head to which the water from the drift rises in the various localities in the county.

Height to which water rises from the glacial drift in McLeod County.

Locality.	Above (+) or below (−) surface.	Above sea level.
	Feet.	*Feet.*
Hutchinson	+28	1,055
Biscay	+22	1,040
Lester Prairie	0	980
Stewart	−13	1,045
Brownton	−24	995
Glencoe	−30	970

Quality of the water.—In this region there is both a vertical and a horizontal variation in the mineral character of the water from the glacial drift. In general, the hardness decreases from the west eastward, and from the upper portion of the drift downward. Thus the shallow drift water is not as hard in this county as in Renville County, but in both counties it is harder than the average water from the deep drift zones. (See the analyses in the table on pp. 257–258.)

FORMATIONS BENEATH THE GLACIAL DRIFT.

Description.—Nearly all that is known about the formations beneath the glacial drift is derived from the record of the deep well which was sunk for the city of Glencoe in 1897. The drillings of this well were preserved by Mr. T. M. Paine, of Glencoe, and were examined and described by Prof. C. W. Hall and Prof. J. A. Partridge of the University of Minnesota. The following is the section given:

Section of the deep well at Glencoe.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	3	3
Gravel and sandy clay	78	81
Blue clay	67	148
Gravelly clay	39	187
Uniform sand with streaks of clay	38	225
Gravel and sand	55	280
Blue shale	10	290
Gray sandy shale	20	310
Gray uniform sand	43	353
A drift conglomerate	1	354
Gray shale, grading into red	56	410
White sand	134	544
Pink sand, grading nearly to white and showing evidence of consolidation	34	578
White sand, grading into pink	14	592
Light-gray sand	10	602
Pink sand, toward the bottom becoming highly colored	218	820
White sandstone, varying to pink	54	874
Pink sandstone	62	936
Red shale and sandstone of uniformly persistent color	139	1,075
Red to pink shale and sandstone, with but little variation (no samples)	565	1,640

This well extends 645 feet below sea level without encountering granite, and penetrates at least 1,286 feet of stratified formations. If the section (below the drift) includes Cretaceous, Paleozoic, and Algonkian strata, it probably represents several distinct systems separated by unconformities. At Buffalo Lake, 6 miles west of McLeod County and 23 miles west of Glencoe, granitic rock is reached at about 340 feet below the surface, or 725 feet above sea level, and there are no stratified rocks present, the glacial drift resting immediately upon the granite. All the stratified formations in the Glencoe section therefore disappear before reaching Buffalo Lake.

Yield of water.—The section of the deep well at Glencoe consists largely of water-bearing sandstones. The beds lying between the depths of 310 and 354 feet yielded some water, but a larger supply came from the sandstones below 410 feet. The well is now cased to a depth of 385 feet, below which it is open. With the pump placed 100 feet below the surface, or about 10 feet below the normal level of the water, it has been tested at the rate of about 175 gallons a minute for thirty-six hours continuously. It is also reported to have been tested at 150 gallons a minute with the pump inserted only 2 feet below the water level. In the 8-inch railway well at Glencoe, which is 566 feet deep, pumping at the rate of 115 gallons a minute lowered the water about 1 foot.

Head of the water.—The deep well at Glencoe was drilled for the purpose of obtaining a flow, but this project failed. At first the water rose to a level 115 feet below the surface, or 880 feet above the sea—about the height to which it now rises in the 566-foot railway well. At a greater depth the water came within 90 feet of the surface, or 905 feet above sea level, which is the head at the present time. The view is held by some of the people that the water from the lower strata would rise higher if the well could be tightly cased, so that the deep water coming up through the well could not leak out into the upper formations. This theory is based on a sound principle too often ignored in drilling artesian wells; but the altitude at this point makes it virtually certain that the water would not rise to the surface from any horizon penetrated in the Glencoe well.

Quality of the water.—The mineral character of the water from the Paleozoic sandstones is shown by the three analyses, given in the table on page 258, of samples taken from the deep Glencoe well. This water does not differ greatly from that of the lower portions of the drift, except that it is somewhat higher in the alkalies, sulphates, and chlorine.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Hutchinson.—The public supply and nearly all of the domestic and industrial supplies at Hutchinson are obtained from the strong artesian layer that occurs at a depth of about 200 feet. This zone is so satisfactory that drilling to greater depths has never been undertaken. It gives rise to flows in all parts of the city except the southwestern, where the altitude is greatest. The well at H. H. Ames's flouring mill, which is described above (p. 252), furnishes the public supply, the city being given the use of the water free of charge. This well was drilled about twenty years ago and there appears to be no diminution in the pressure. The analysis contained in the table shows that the water is moderately hard. About 33,000 gallons is consumed daily.

Glencoe.—The public supply in Glencoe is taken from the 1,640-foot well, which has been fully described. About 1,000 people use the water, and 125,000 gallons is daily consumed. Approximately one-half the inhabitants, however, rely upon private wells, only a few of which are drilled to any considerable depth. The brewery well is 224 feet, the creamery well 230 feet, and the railway well 566 feet deep. Several analyses of water from this vicinity will be found in the table on pages 257–258.

Brownton.—The glacial drift in the locality of Brownton is known to be thick, but no definite section is available. The village well is 304 feet deep and ends with a screen in a bed of gravel. Its head and yield are given above. The water is relatively soft, as is shown by the two analyses given in the table. It is used by nearly all the people, and the daily consumption averages about 4,000 gallons.

Stewart.—At Stewart the section, to a depth of at least 320 feet, consists of bowlder clay with interbedded layers of sand and gravel. The best water zones seem to be found below 265 feet. The well which furnishes the public supply ends with a screen in one of these deeper beds. The data in regard to this well have already been given (pp. 253–254). The water, an analysis of which will be found in the table, is softer than that from the more shallow wells. About 20,000 gallons is consumed daily, but most of this is taken by the railway company, for nearly all the people, perhaps 90 per cent, use water from private wells.

Lester Prairie.—The village of Lester Prairie is located on the north side of Crow River on a level terrace underlain by alluvial sand and gravel, which extends to a depth of about 30 feet and is saturated with water nearly to the surface. Beneath the alluvium is the ordinary glacial drift, consisting of blue clay and sandy seams from which the water rises virtually to the surface, or 980 feet above sea level. North of the village, at a somewhat higher altitude, stretches the gently undulating drift plain which comprises most of the county. The public waterworks are supplied from a well 20 feet in diameter, which ends in the alluvial deposits at a depth of 22 feet. In 1907 the water stood 8 feet below the surface, and pumping at the rate of 200 gallons a minute was reported to empty the well in about one hour. The water is rather hard, as is shown by the analysis given in the table below. Only a small amount is consumed. Near all the people use water from private wells, which are driven into the alluvium and yield generously, though on an average less than 20 feet deep.

Silver Lake.—The domestic supply at Silver Lake is obtained chiefly from bored wells between 20 and 65 feet deep. The public waterworks are supplied from the lake.

Winsted.—In Winsted village, as in Silver Lake, the domestic supply is derived mainly from bored wells less than 100 feet deep, but the public waterworks are supplied from the lake.

FARM WATER SUPPLIES.

At one time virtually all the farm wells were bored or dug, and most of them are still of this type. They are shallow and yield varying quantities of hard water. Gradually they are being replaced by drilled wells, especially in the vicinities of Glencoe, Brownton, Biscay, and Hutchinson. The drilled wells are generally 2 inches in diameter and range from less than 75 to more than 300 feet in depth, most being between 100 and 200 feet.

SUMMARY AND ANALYSES.

The deposits of bowlder clay, which are everywhere several hundred feet thick, contain numerous layers of sand and gravel, the deepest of which yield large and permanent supplies. In general, the water from the lowest beds is the softest and least liable to incrust the screens placed in the wells, but there are exceptions to this rule. Flows are obtained only in certain low areas.

In the eastern portion there are thick formations of sandstone, and it is probable that these occur, at least in part, throughout most of the county, at depths of 400 to 600 feet and more. They will furnish large quantities of only moderately hard water, but will not give rise to flows at any point in this county.

Mineral analyses of water in McLeod County.

[Analyses in parts per million.]

	Surface deposits (glacial drift, etc.).										
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
Depth ... feet	21	22	22	28	39	40	112	115	120	172	180
Diameter of well ... inches	120		240	144	144	84	2			3	10
Silica (SiO_2)		28	31								22
Iron (Fe)		Tr.	.2								5
Aluminum (Al)											
Iron and aluminum oxides ($Fe_2O_3+Al_3O_3$)	3.3	8	.8	4.7	6.2	7	8.4	7.4	6.4	12	5
Calcium (Ca)	78	149	136	113	112	76	96	88	96	117	103
Magnesium (Mg)	24	50	44	46	49	24	43	38	42	42	39
Sodium and potassium (Na+K)	5	37	61	10	20	5	54	45	56	39	29
Carbonate radicle (CO_3)		.0	.0								.0
Bicarbonate radicle (HCO_3)	330	547	415	484	516	307	540	572	560	628	512
Sulphate radicle (SO_4)	27	117	110	65	61	41	79	10	71	28	67
Chlorine (Cl)	3.2	54	130	19	27	3.6	4	1.5	3	2	2
Nitrate radicle (NO_3)		12	4.2								.0
Total solids	303	740	731	496	529	308	550	467	550	549	531

Mineral analyses of water in McLeod County—Continued.

	Surface deposits (glacial drifts, etc.)—Continued.							Paleozoic sandstones.		
	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.
Depth ....feet	226	230	230	260	304	304	320	1,640	1,640	1,640
Diameter of well....inches	....	3	2	....	6	6	8	8 and 6	8 and 6	8 and 6
Silica (SiO_2)	24	....	....	....	29	....	26	....	8.8	....
Iron (Fe)	2.8	....	....	....	....	....	....	....	.5	....
Aluminum (Al)	4.9	....	....	....	....	....	....	....	4.7	....
Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	....	8	3	1.2	.8	3.1	3.2	1.7	....	1.2
Calcium (Ca)	99	117	120	40	71	75	42	78	77	75
Magnesium (Mg)	53	48	51	23	33	34	10	40	43	33
Sodium and potassium (Na+K)	28	51	51	106	74	75	113	80	85	209
Carbonate radicle (CO_3)	.0	....	....	....	.0	....	.0	....	.0	....
Bicarbonate radicle (HCO_3)	508	647	686	503	512	588	440	456	429	464
Sulphate radicle (SO_4)	98	65	54	....	20	....	24	107	116	158
Chlorine (Cl)	6	1	1	8	6	5	9	35	37	165
Nitrate radicle (NO_3)	.0	....	....	....	.0	....	1.3	....	.0	....
Total solids	568	609	622	425	491	481	449	565	600	870

1. Well at Hutchinson. November 24, 1897.
2. Well of Lee Arnold at Brownton. September 17, 1907.
3. Village well at Lester Prairie. September 19, 1907.
4. Well at Glencoe. September 3, 1888.
5. Well at Glencoe. May 3, 1888.
6. Well at Hutchinson. October 13, 1888.
7. Well at the flouring mill at Brownton. December 5, 1894.
8. Well at Brownton. December 5, 1894.
9. "Bullick's well" at Brownton. December 5, 1894.
10. Mr. Hayden's well at Glencoe. April 22, 1895.
11. Flowing well at the flouring mill at Hutchinson. This well furnishes the public supply. September 18, 1907.
12. Flowing well on the farm of William Conrad, NE. ¼ sec. 31, T. 116 N., R. 28 W. One and one-half miles east of Biscay. September 18, 1907.
13. Creamery well at Glencoe. May 9, 1895.
14. "Bretchet's well" at Glencoe. May 9, 1895.
15. Well at Stewart. March 3, 1896.
16. Village well at Brownton. September 17, 1907.
17. Village well at Brownton. October 3, 1895.
18. Village well at Stewart. September 14, 1907.
19. City well at Glencoe. July 21, 1898.
20. City well at Glencoe. September 17, 1907.
21. City well at Glencoe. July 17, 1897.

Analyses 2, 3, 11, 12, 16, 18, and 20 were made for the United States Geological Survey by H. A. Whittaker, chemist Minnesota state board of health. Analyses 1, 4, 5, 6, 7, 8, 9, 10, 13, 14, 15, 17, 19, and 21 were furnished by G. N. Prentiss, chemist Chicago, Milwaukee and St. Paul Railway Company.

MARTIN COUNTY.

By O. E. Meinzer.

SURFACE FEATURES.

The surface of Martin County constitutes a gently undulating and poorly drained upland plain with no notable irregularities except in the morainic belt southeast of Fairmont. It descends from an altitude of about 1,400 feet above sea level in the southwestern corner to about 1,100 feet in the northeastern, the slope being quite imperceptible, but nevertheless sufficient to affect in an important way the head of the underground waters. Most of the numerous lakes in this county are arranged in three nearly parallel chains, apparently occurring along the lines of a preglacial river system which drained the region toward the south.[a] At present the drainage system is entirely different. Elm Creek, Center Creek, and South Creek flow

[a] Upham, Warren, Final Rept. Geol. and Nat. Hist. Survey Minnesota, vol. 1, 1882, p. 479.

eastward and discharge into Blue Earth River a few miles beyond the county line; East Fork of De Moines River, rising along the western margin of the county, flows across the southwestern corner; and several small streams rising in the northern part flow northward into Watonwan River. These streams have shallow valleys and but few tributaries, thus leaving most of the upland prairie untouched by erosion.

SURFACE DEPOSITS.

Description.—The glacial drift, which consists of bowlder-clay and interbedded seams of sand and gravel, forms a continuous mantle over all of this county. As the underlying formations have seldom been reached in drilling, even in wells between 200 and 300 feet deep, it is certain that the drift sheet is generally thick, but there is a corresponding uncertainty as to its actual thickness. Moreover, there is evidence that the surface on which the drift rests is irregular, causing corresponding irregularities in the thickness of the drift sheet itself. Ancient valleys seem to have been cut into the underlying formations, and the drift is unusually deep where these valleys existed. In general it is most attenuated in the eastern part and increases in thickness toward the southwest. Its average thickness for the entire county is probably between 200 and 300 feet.

Yield of water.—The water-bearing portions of the drift can be divided into two rather distinct groups: (1) Gravelly deposits associated with the surficial yellow clay above the impervious blue clay, and (2) layers of sand and gravel interbedded with the blue clay or lying at its base. Few of the former deposits are more than 40 or 50 feet below the surface. Because of their imperfect porosity and the slight pressure to which their water is subjected, the yield is commonly small; and because of their surficial position the supply is readily affected by the season and may fail entirely in times of drought. The second group of deposits occur at various depths and have a wide range in thickness, porosity, and water-yielding capacity. Occasionally a well is drilled that passes through no bed sufficiently thick and coarse to furnish an adequate supply, but such wells are exceptional. In nearly every locality are found one or more sandy beds that will yield at least as much water as an ordinary windmill is capable of pumping. The village well at Sherburn, which ends with a 6-inch bore in a 10-foot stratum of sand at a depth of 248 feet, was pumped, immediately after its completion, at the rate of 160 gallons a minute for a continuous period of about six hours without noticeably lowering the water.

Head of the water.—The water in the sand and gravel beds is always under pressure, and hence rises in the wells which tap them.

The following table shows the surface altitude and the height to which the water rises above sea level in different parts of the county:

Table showing approximately the head of the water from deep-drift zones in Martin County.

Locality.	Altitude of surface.	Altitude to which water rises.
	Feet.	*Feet.*
Sherburn	1,295	1,215
Ceylon	1,260(?)	1,200(?)
Welcome	1,243	1,501
Triumph	1,230	1,130
Fairmont	1,195	1,130
Granada	1,133	1,100

In the extreme western and southwestern parts of the county, where the surface is more than 1,300 feet above sea level, the water from the deeper beds in the drift commonly fails to rise within 100 feet of the surface; throughout most of the western half of the county, where the surface is between 1,200 and 1,300 feet above sea level, the water stands somewhere between 50 and 100 feet below the surface. On the other hand, in the eastern and northeastern parts, where the surface is between 1,100 and 1,200 feet above sea level, the water usually rises within 50 feet of the surface, and in the valleys of Center, Elm, and Perch creeks, which are depressed slightly below the 1,100-foot level, flowing wells with slight pressure occur.

Flows can be obtained (1) in the valley of Center Creek from the county line upstream above Granada; (2) in the valley of Elm Creek from the county line upstream to sec. 35, T. 104 N., R. 30 W., and possibly still farther; (3) in the valleys of the two small branches which join Elm Creek in sec. 5, T. 103 N., R. 29 W.; and (4) near the headwaters of Perch Creek. Sixteen flowing wells were noted in the portion of Center Creek valley that lies in this county, and 23 in the portions of Elm Creek valley within the county. It is probable that there are a few others that were not noticed.

In an area of relatively low altitude, such as the eastern part of this county, the waters from the various zones (which occur at different depths and are apparently separated by layers of impervious clay) usually rise very nearly to the same level, the water from the deep zones is likely to be lifted slightly higher than that from the shallow ones. Thus on the farm of W. R. Benton, sec. 5, T. 103 N., R. 29 W., in a well drilled to a depth of 198 feet, beds of water-bearing sand or gravel were encountered at depths of 50, 110, 150, and 190 feet. All these produced flows, but from none did the water rise more than a very few feet above the surface. Likewise, in W. H. Thompson's flowing well at Granada water-bearing beds were encountered at depths of 50, 75, and 107 feet. From the first the water rose 2 feet above the surface; from the second, 2 feet above the surface;

and from the third, 6 feet above the surface. In a region of relatively high altitude, on the other hand, such as the western part of this county, the water generally rises higher from shallow sources than from the deeper ones; this fact could be illustrated by numerous examples.

Quality of the water.—All the waters from the drift have a high content of calcium, magnesium, and sulphates, and therefore have a great permanent hardness and form hard scale in boilers. There are however, considerable differences in the degrees of mineralization, even in the same locality, as is shown in the analyses contained in the accompanying table.

UNDERLYING FORMATIONS.

Description.—As there are no rock outcrops in this county and only a small number of wells that penetrate formations older than the drift, the geologic structure is largely a matter of conjecture. However, it seems probable that Cretaceous, Paleozoic, Algonkian, and Archean rocks are all present and are separated from each other by pronounced unconformities.

The evidence in regard to the presence of the Cretaceous can be summarized as follows: West of Martin County there are many wells that apparently end in Cretaceous rocks and a few in different parts of this county have penetrated strata of shale, sand, and sandstone which appear to belong to this series; but there is no reliable evidence of Cretaceous rocks in Faribault County to the east. Furthermore, there is considerable evidence that the Cretaceous exists south of the western and central parts of Martin County but is absent south of the eastern part. Alternating layers of shale, sand, and sandstone, which appear to belong at least in part to the Cretaceous, have been penetrated at Estherville, Iowa, and at Ringsted, Iowa, south of the western and central portions of this county, respectively; but a short distance east of Ringsted wells encounter indurated Paleozoic limestones without passing through anything that could be interpreted as Cretaceous. Likewise, north of the central and western parts a number of wells have been drilled which pass through a considerable thickness of soft shale, sand, and sandstone, apparently continuous with the great body of Cretaceous sediments to the west. It therefore appears probable that in the eastern portion of Martin County Cretaceous deposits are absent or very thin, but that in the western portion they are continuous and attain a greater thickness.

At Blue Earth, 8 miles east of the county line, at least 800 feet of Paleozoic strata lie below the glacial drift and extend downward nearly to sea level; at Mountain Lake, 7 miles northwest of Martin County, the Sioux quartzite, which is referred to the Algonkian system, lies immediately beneath the drift at an altitude of 1,237 feet above sea level. Thus, in a distance of 45 miles from Blue Earth across Martin County to Mountain Lake, all the Paleozoic formations from the Galena limestone downward terminate and the underlying surface rises from near sea level to 1,237 feet above sea level. The Paleozoic formations no doubt dip gently toward the southeast, and so if the glacial drift and Cretaceous deposits were removed they would probably be seen outcropping in parallel northeast-southwest trending belts, the oldest formations lying next to the Sioux quartzite, and successively younger formations coming to the surface toward the southeast.

Several wells have penetrated a fine-grained gray or white sandstone, and a well just south of the SW. ¼ sec. 35, T. 101 N., R. 31 W., passed entirely through this sandstone which was here found to be 100 feet thick. It is possible that the formation in question belongs to the Cretaceous sandstone that occurs at Emmetsburg, Iowa,[a] but more probably it belongs to the St. Peter sandstone, which was found to be 91 feet thick at Blue Earth. The formations older than the St. Peter are not known to have been penetrated in drilling in this county. At Blue Earth the Paleozoic rocks consist chiefly of alternate formations of sandstone and limestone, but it is probable that in Martin County, where the ancient shore is approached, the limestones give way in part to shales and sandstones. As has been explained in the report on Faribault County, there is no evidence that the Carboniferous extends into Minnesota.

Yield, head, and quality of the water.—At no great depth beneath the glacial drift occur the Cretaceous and Paleozoic sandstones which have just been discussed. Though they have not yet been explored in this county, there is no doubt that they will furnish large supplies of water, except possibly in the northwestern corner.

There is little probability that flowing wells can be obtained from the deep beds of this county, but the water may generally be expected to rise about as high as that from the lower portion of the drift. In the northern and eastern parts it will come near the surface, but in the high area comprising the southwestern part it will remain at a depth of more than 100 feet. At Blue Earth the water rises within 32 feet of the surface, or 1,050 feet above sea level; at St. James, within 32 feet of the surface, or 1,053 feet above sea level; in the sandstone wells in this county, within 50 or 100 feet of the surface; and at Estherville, Iowa, within 120 feet of the surface, or about 1,165 feet above sea level.

It is probable that the deep water is as hard or even harder than that from the glacial drift. (See the reports on Watonwan and Faribault counties.)

[a] Norton, W. H., Ann. Rept. Geol. Survey Iowa, vol. 3, 1892, pp. 186 and 187.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Fairmont.—Fairmont is situated just east of Center Chain of Lakes in a locality characterized by an irregular morainic topography. The following log of the new well at the high school presents a typical section of the upper portion of the glacial drift, the total thickness of which is here rather great.

Well section at Fairmont.

[Authority, Brown & Wilkins, drillers, Fairmont.]

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	3	3
Yellow clay	20	23
Blue clay	87	110
Gravel	3	113

The public waterworks are supplied from Lake Budd. About 1,500 people use the water, and it is also used in the locomotives of the railway companies. Altogether about 120,000 gallons is consumed daily. Nearly all the people use water from private wells for drinking and culinary purposes. Most of the private wells are 2 inches in diameter and end in beds of sand and gravel at various depths, most of them being between 60 and 100 feet deep. There are also some shallow bored and dug wells. The ground water is hard, as is shown by the analyses given in the table (p. 265).

Sherburn.—West Chain of Lakes lies just east of Sherburn village. The glacial drift is here at least 250 feet thick. The section reported for the village well is as follows:

Well section at Sherburn.

[Authority, William Tenhoff, superintendent of public waterworks, Sherburn.]

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow clay	20	20
Blue clay	110	130
Sand	4	134
Blue clay	104	238
Sand	10	248
Blue clay (entered).		

The data in regard to this well have already been given. The analysis in the table (p. 265) shows that the water is not so highly mineralized as much of the water in this region. The public supply is used by about 250 people, and approximately 13,000 gallons is consumed daily. At least 75 per cent of the inhabitants rely on private wells, which are generally shallow and provide small quantities of water. There are, however, a few drilled wells, the deepest of which yield abundant and permanent supplies. The railway company takes water from Temperance Lake; the creamery is supplied from a well 180 feet deep; and at the mill the public supply is used at present.

Welcome.—In many parts of the village of Welcome sand and gravel are found at depths of 20 to 40 feet, beneath which there is blue clay to about 150 feet. Other layers of sand occur below this depth. The public waterworks are at present supplied from a combined dug and drilled well that reaches to the 150-foot sand stratum, but because of faulty construction its yield is not great. Nearly all the people use water from private wells, most of which are bored or dug to depths of 20 to 40 feet and end in the deposit of sand and gravel mentioned above. In some parts of the village this deposit is absent, and wells are drilled to the deeper beds or get meager supplies from sandy seams at intermediate levels. In the table below analyses are given of the public supply and of water from the mill well, which is 40 feet deep.

Ceylon.—The waterworks at Ceylon are supplied from a drilled well 8 inches in diameter and 300 feet deep. Pumping from this well at the rate of 100 gallons a minute is said to produce no noticeable effect. Nearly all the people use water from private sources. The dug and bored wells end in yellow clay at depths of about 20 to 40 feet and furnish moderate supplies; the drilled wells are deeper and yield more abundantly.

Truman.—The village of Truman has a system of public waterworks supplied from an 8-inch well, which is 104 feet deep and in which the water rises virtually to the surface. The inhabitants depend almost entirely on private wells.

FARM WATER SUPPLIES.

There are two types of wells corresponding to the two groups of water-bearing beds in the drift mentioned above (p. 259)—(1) shallow bored or dug wells, which are generally less than 40 feet deep and end in yellow clay or sandy deposits above the impervious blue clay; and (2) drilled wells, with iron casings, which end in strata of sand and gravel interbedded with the blue clay. The yield from first type of wells is generally small and uncertain; it is brought to a maximum by making the wells of large diameter, with casings of wood or tile that will admit water at all depths. When the county was first settled these wells were depended on entirely, but they were found to be unreliable in dry years and to be otherwise unsatisfactory. The drilled wells range in depth from about 50 to 300 feet, but are generally between 75 and 175 feet. Their average depth is greatest in the western and southwestern parts of the county, where wells between 200 and 300 feet deep are not rare, and least in the eastern and northeastern parts, where the average depth is perhaps not more than 100 feet. The yield is generally large and is not seriously affected by drought. Most of the wells are only 2 inches in diameter and are finished with screens, which cause much trouble by becoming incrusted. Wells of such small diameter should not be drilled in this county except where flows are expected.

SUMMARY AND ANALYSES.

The deeper beds of sand and gravel in the drift furnish adequate supplies for all ordinary purposes and will probably always be the chief source of water. At greater depths lie sandstones which will yield copiously but whose water will rise no higher than that from more shallow sources, so that virtually no hope is offered that flows could be obtained in them. Moreover, much of the water from deep beds is very hard, and there is no evidence that any of it is softer than that now used from the more shallow beds.

Mineral analyses of water in Martin County.

[Analyses in parts per million.]

	Surface deposits (glacial drift, etc.)										(?)			
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.
Depth feet	25	43	42	70	100	90	103	150	185	248	265	280	296	404
Diameter of well	....	2	8	2	2	8	6	Large.	2	8	8	7	6,4	6
Silica (SiO_2)	48	....	64	24	....	....	....	23	....	10	....	....	....	....
Iron (Fe)	....	....	3	2.6	....	....	....	1	....	3	....	....	....	....
Iron and aluminum oxides (Fe_2O_3+Al_2O_3)	1	....	7	5.1	....	4.1	6	3.3	....	2.5	2.1	5	....	.9
Calcium (Ca)	67	106	181	140	210	197	195	137	212	117	121	189	186	218
Magnesium (Mg)	19	48	28	54	61	58	57	67	59	32	47	58	58	68
Sodium and potassium (Na+K)	5	17	137	22	97	119	20	113	211	22	47	42	49	86
Carbonate radicle (CO_3)	....	....	.0	.0	....	....	....	.0	....	.0	....	....	....	....
Bicarbonate radicle (HCO_3)	309	580	466	259	529	496	377	495	468	307	161	446	454	466
Sulphate radicle (SO_4)	....	19	425	389	524	556	396	367	808	233	415	398	415	598
Chlorine (Cl)	....	1.5	6	4	5	3.6	31	47	3	4	23.5	14	4	3
Nitrate radicle (NO_3)	....	....	.0	1.5	....	....	....	4	....	.0	....	....	....	....
Total solids	322	477	1,085	772	1,158	1,182	890	1,018	1,522	579	735	923	935	1,211

1. Railway well at Fox Lake on the shore of the lake. September 20, 1899.
2. Mill well at Welcome. September 20, 1901.
3. Flowing well on the farm of M. E. Davidson, NE. ¼ sec. 28, T. 103 N., R. 29 W. July 15, 1907.
4. Well of George Clynick, SW. ¼ sec. 33, T. 104 N., R. 29 W. July 15, 1907.
5. Well at the livery stable at Granada. September 20, 1901.
6. Former well of the Chicago, Milwaukee and St. Paul Railway Company at Fairmont. November 2, 1892.
7. Well at Fairmont. October 25, 1888.
8. Village well at Welcome. July 23, 1907.
9. Former village well at Welcome. September 20, 1901.
10. Village well at Sherburn. July 23, 1907.
11. Village well at Sherburn. November 15, 1895.
12. Village well at Sherburn. June 30, 1899.
13. Village well at Sherburn. July 23, 1901.
14. Former city well at Fairmont. March 21, 1894.

Analyses 3, 4, 8, and 10 were made for the United States Geological Survey by H. A. Whittaker, chemist Minnesota state board of health. Analyses 2, 5, 6, 7, 9, 11, 12, 13, and 14 were furnished by G. N. Prentiss, chemist Chicago, Milwaukee and St. Paul Railway Company. Analysis 1 was furnished by G. M. Davidson chemist Chicago and Northwestern Railway Company.

MEEKER COUNTY.

By O. E. Meinzer.

SURFACE FEATURES.

The surface of Meeker County presents the following three types of topography,[a] which correspond to different underground water conditions: (1) The irregular, morainic relief that characterizes most of the county; (2) the gently undulating surface that occurs only in the southern part; and (3) the large, sandy plain in the center of the county and similar smaller level areas. North Branch of Crow River crosses the northern and South Branch the southern part of the county, both draining toward the Mississippi. They have few tributaries and the surface is but imperfectly drained.

SURFACE DEPOSITS.

Description.—The glacial drift consists of impervious bowlder clay and beds of sand and gravel. The sand and gravel beds are intermingled with the clay in various ways, and in this county are especially prominent at the surface in the level tracts already mentioned. The drift covers the entire county, no outcrops of older rocks being known, but so few deep wells have been drilled that there is little information on which to base an estimate of its thickness. At Eden Valley underlying formations have been encountered at a depth of 200 feet, and in several other localities in the northern part at depths of 100 to 200 feet; 6 miles north of this county the rocks come to the surface. In the southern part the drift is thicker, however, so that the average for the county is perhaps not far from 250 feet.

Yield of water.—The porous beds of sand and gravel are usually saturated with water which they give up readily. Thin deposits near the surface are liable to fail in dry years, but those which lie at greater depths, as well as the thick beds at the surface, are little affected by drought.

Head of the water.—The irregular, morainic topography of a large part of this country is likely to give rise to small areas in which flowing wells with slight pressure can be obtained. Such areas are usually found on the lowest ground near streams and lakes, at the foot of high, morainic belts. There are several flowing wells on the hillside north of Eden Valley, and others could probably be obtained from the same zone in the village. A few are found along North Branch of Crow River in the vicinity of Forest City, between Eden Valley and Litchfield; one has been reported on the east side of Swan Lake, northeast of Dassel, and another west of Stella Lake, about 4

[a] Upham, Warren, Final Rept. Geol. and Nat. Hist. Survey Minnesota, vol. 2, 1885, pl. 40.

miles west of Darwin. There are also several on the low ground between Strout and Rosendale, south of Grove City. Flowing wells could no doubt be obtained in other depressed localities.

Quality of the water.—The underground waters differ chiefly in the quantity of sulphates which they contain. In this important respect they differ widely, but in a systematic manner, as is shown by the table of mineral analyses (p. 271). The water from shallow sources contains a large amount of sulphates associated with much calcium and magnesium, so that it has a permanent hardness and produces hard scale in boilers; but the water from the deeper sources contains only small quantities of sulphates, with less calcium and magnesium, and will form less hard scale. This second type is found nearer the surface in the northern than in the southern part of the county.

The shallow water is all hard, but that from the sand and gravel interbedded with the bowlder clay is somewhat harder than that from the sandy deposits at the surface.

FORMATIONS BENEATH THE GLACIAL DRIFT.

Description.—About 8 miles north of this county the granitic rocks are exposed; in the village of Eden Valley they were struck at a depth of 300 feet, and in several other wells in the northern part of the county at 200 to 300 feet; in Grove City they were probably penetrated a few hundred feet in a well which went to a depth of nearly 700 feet; and in the village of Buffalo Lake, south of this county, they were found to lie about 340 feet below the surface. From these data it seems safe to infer that throughout the northern and western parts granite exists within a few hundred feet of the surface and lies immediately beneath the drift or is separated from it by a relatively thin series of stratified rocks.

On the other hand, at Glencoe, 15 miles southeast of this county, about 1,300 feet of sandstone and other sedimentary rocks have been penetrated, and a depth of 1,640 feet below the surface, or 645 feet below sea level, has been reached without encountering granite. From Grove City and Eden Valley to Glencoe these stratified formations must therefore thicken rapidly, and the granitic surface must descend with relative abruptness. It is thus possible that the southeastern part of Meeker County is underlain by a thick sedimentary series.

The stratigraphic formations between the granite and the drift may be Cretaceous, Paleozoic, or Algonkian. From 6 to 10 miles beyond the northern boundary of the county there are outcrops of beds consisting chiefly of shale, in which Cretaceous fossils have been discovered.[a] In several wells in the northern and western portions

[a] Kloos, J. H., Am. Jour. Sci., 3d ser., vol. 3, 1872, pp. 17-26.

of this county shales, etc., probably of the same age, have been entered, but there is no evidence that Cretaceous rocks exist in the eastern or southern parts. The great thickness of sediments found at Glencoe comprises chiefly Paleozoic and Algonkian strata, and these may extend into this county. After the Paleozoic formations had been deposited and had been subjected to long erosion the Cretaceous seas probably encroached on the region from the west and spread a thin deposit over the older rocks.

At Eden Valley the following section has been reported for a deep well drilled for the railway company:

Well section at Eden Valley.

[Authority, J. F. McCarthy, driller, Minneapolis.]

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, etc	200	200
Fine sandstone	70	270
Black shale	30	300
Granitic formation	60	360

From the data at hand it is impossible to determine whether the sandstone and shale in this section should be correlated with the Cretaceous or the Paleozoic.

Yield, head, and quality of the water.—At Glencoe the sandstone provides liberal quantities of water, but it has not yet been ascertained to what extent this series is developed in Meeker County. In the railway well at Eden Valley, whose section is given above, the supply from the sandstone stratum was tested at 15 gallons a minute; in the northwestern part of the county other wells have been drilled to granite without passing through any water-bearing sandstone. In no locality can flowing wells be obtained by deep drilling. The Paleozoic rocks afford fairly good boiler water, but probably not better than that from the deeper beds of the drift. Compare the analyses in the accompanying table (p. 271) with those given in the report on McLeod County.

The granite is not water bearing, except that small supplies are rarely procured from the altered upper portion.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Litchfield.—Litchfield lies in the midst of an extensive plain underlain by a deposit of sand and gravel, which at present furnishes the entire water supply. Beneath this deposit lies the bowlder clay of the glacial drift. The public supply is derived from a system of twenty-eight 2-inch driven wells about 42 feet deep, which end in sand, the water rising to a level 20 feet below the surface. Pumping by suction from all these wells combined at the rate of 600 gallons a minute for several hours continuously produces no noticeable effect on the level. About 500 people use the water, and 60,000 gallons is reported to be consumed daily. Fully three-fourths of the inhabitants depend on private wells, nearly all of which are driven to depths of 25 to 45 feet and yield generously. The railway company is also supplied by a shallow well. The water from the sand and gravel near the surface is hard and will produce considerable scale in boilers. This is shown by an analysis of the water from J. T. McNulty's well, which is given in the table. There are some indications that better water could be obtained by drilling deeper.

Dassel.—The village of Dassel lies in the midst of a morainic area with an irregular surface and numerous small lakes. The following section is reported for the upper 65 feet:

Well section at Dassel.

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow clay	20	20
Blue clay	20	40
Sand	10	50
Blue clay	12	62
"Hardpan" (a few inches thick) Sand and gravel (water)	3	65

Beds of sand also lie at depths of 120 and 180 feet, the deeper bed furnishing much water. The public supply is taken from a well 8 inches in diameter and 180 feet deep, which is finished with a screen. The water rises to a level 55 feet below the surface, or 1,034 feet above the sea, and pumping has been continued for eighteen hours at the rate of 45 gallons a minute. The water has considerable temporary but little permanent hardness and will not produce much hard scale in boilers. An analysis will be found in the table.

Eden Valley.—The valley in which the village of Eden Valley lies is partly filled with alluvial sand and gravel, saturated with water, and most of the wells are driven to a depth of about 30 feet in these deposits. The public supply is obtained from a system of nine 2½-inch wells, one of which is 28 feet and the others 44 feet deep. The water rises to a level about 15 feet below the surface, and the combined system of wells has been tested at 75 gallons a minute. Approximately 5,000 gallons is consumed daily. The railway company has abandoned the deep well the section of which is given above, and at present uses shallow water. According to the analyses contained in the table below, the deep drift water is better for boiler purposes than that from shallow sources.

Grove City.—The village well now in use at Grove City is nearly 700 feet deep. No reliable record was kept, but the drill seems to have passed through several hundred feet of glacial drift, then through strata of shale and sandstone, and finally through a considerable thickness of partly decomposed granite. The well was at first finished in such a manner that water could enter only from the bottom, when it yielded but 16 gallons a minute. The casing was then cut at the sand and gravel zone found between the depths of 220 and 260 feet, and a 30-foot brass screen was inserted, after which the well was successfully tested at 75 gallons a minute. The water now rises to a level 57 feet below the surface, or 1,150 feet above the sea. About four-fifths of the inhabitants use water from shallow private wells. The analyses given in the table show that the water from the deep zone which supplies the waterworks is not as hard as the shallow water that is tapped by the private wells.

FARM WATER SUPPLIES.

There are three principal types of farm wells—driven, bored or dug, and drilled. The driven wells are confined to the level tracts where the sand and gravel are at the surface, and the very shallow and inexpensive wells of this type usually yield generously. Shallow-bored and dug wells still exist in large numbers and are widely distributed, though especially characteristic of the morainic areas. There are also many drilled wells, especially in the eastern and northern parts of the county, and these generally afford abundant supplies. They have a wide range in depth, about 100 feet being the most common. Nearly all are 2 inches in diameter and are finished with screens. In the southern part of the county these screens generally become incrusted in the course of several years, but in the northern part it seldom so happens. In the northern part the water from the drift has not much permanent hardness, and this is also true of the water from the lower portion of the drift in the southern part. The suggestion is therefore made that in the latter region there would be an advantage in drilling deeper than is usually done at present, both to get softer water and to diminish the difficulty with the screens. This difficulty can also be obviated in great measure by drilling wells of larger diameter.

SUMMARY AND ANALYSES.

Water-bearing sandstone may be present in the southeastern part of the county at a depth of several hundred feet, but this has not been proved by actual drilling. Where it is present it will yield a fairly good quality of boiler water, but probably not better than the deeper portions of the drift. It will nowhere give rise to flows.

The most significant fact to be noted here is that the water from the shallow sources is generally poorer for boiler purposes than that from the deposits at some depth.

Mineral analyses of water in Meeker County.

[Analyses in parts per million.]

	Surface deposits.					
	Surface sand and gravel.		Upper portion of glacial drift.	Lower portion of glacial drift.		
	1.	2.	3.	4.	5.	6.
Depth ... feet	44	40	60	130	180	250±
Diameter of well ... inches	2½	2	....	2	8	8
Silica (SiO_2)	24	25	32	27	......	28
Iron (Fe)	.5	.2	Trace.	1.2	.2	1
Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	2.4	1.2	4.8	6.4	2.4	3.2
Calcium (Ca)	93	115	154	88	84	69
Magnesium (Mg)	27	32	32	27	33	24
Sodium and potassium (Na+K)	20	21	25	8	12	21
Carbonate radicle (CO_3)	.0	.0	.0	.0	.0	.0
Bicarbonate radicle (HCO_3)	327	293	400	420	429	356
Sulphate radicle (SO_4)	94	166	183	14	15	26
Chlorine (Cl)	11	36	27	3	4	2.5
Nitrate radicle (NO_3)	2.5	.0	20	.25	.2	.0
Total solids	439	550	684	382	399	349

1. Village wells at Eden Valley. October 10, 1907.
2. Well of J. T. McNulty at Litchfield. September 21, 1907.
3. Well on West Main street at Grove City. This well belongs to the municipality, but has no connection with the waterworks. September 21, 1907.
4. Well of James McCane, near Eden Valley, on the NW. ¼ sec. 10, T. 121 N., R. 31 W. October 10, 1907.
5. Village well at Dassel. September 20, 1907.
6. Village well at Grove City. This is the well that supplies the public water works. September 21, 1907.

The above analyses were made for the United States Geological Survey by H. A. Whittaker, chemist Minnesota state board of health.

MOWER COUNTY.

By C. W. Hall and M. L. Fuller.

SURFACE FEATURES.

Mower County is among the highest and flattest of the counties in southeastern Minnesota. Its surface extends for miles with hardly an irregularity to catch the eye. The highest part is a broad, flat swell, which is crossed by the Chicago, Milwaukee and St. Paul Railway in the vicinity of Dexter, where the elevation is 1,416 feet above sea level, or 786 feet above the Mississippi at La Crosse. From this vicinity the land declines with a gentle slope to an altitude of 1,300 feet near the eastern boundary, and to about 1,200 feet along Cedar River near the western edge. The valley of the Cedar is the only one of consequence in the county, and its bottom is generally less than 100 feet below the level of the adjacent prairie tract. Other streams flow in shallow depressions or meander about over the prairie, not yet having cut valleys.

SURFACE DEPOSITS.

The surface deposits include ordinary glacial drift, outwash gravels, and recently deposited alluvium. The whole surface of Mower County, except at one or two points in the stream valleys, is covered by glacial drift, which has a thickness ranging up to 50 feet in the valley of Cedar River, from 75 to 100 feet along the eastern margin of the county, and from 150 to more than 200 feet in the central portion. The drift generally yields sufficient water for domestic and farm purposes.

Outwash gravels occur along the course of Cedar River. They are probably not more than 50 feet thick and contain moderate amounts of water. They supply domestic and farm wells at a number of points.

The alluvium deposited by the present streams is of minor importance in this county, being limited to narrow belts of no great thickness.

PALEOZOIC FORMATIONS.

The Devonian consists of a lower fine-grained dolomitic limestone and an upper shaly sandstone. The former underlies the greater part of the southern half of the county, except in the valleys of Cedar River and Rose Creek, in which the streams appear to have cut through the limestone. The sandstone, which is known as the "Austin rock," occurs immediately beneath the drift in the central and northwestern portions of the county. Its thickness has nowhere been definitely measured, but probably does not exceed 50 feet. Though not especially porous, this sandstone has yielded good supplies at several points, the volume in some places being sufficient for industrial and public supplies.

The Maquoketa, Galena, Decorah, and Platteville formations probably have a considerable combined thickness, but they have not been positively recognized in the county. They probably lie below the drift throughout a belt several miles wide in the northeastern part of the county.

Beneath the rocks already described no doubt occurs the entire Paleozoic sequence of southeastern Minnesota, older than the Platteville limestone. The separate formations are described in connection with the several counties in which they lie at the surface. A section of the formations at Austin is embodied in the following record of the deepest city well. Compare with this the record of the city well, 260 feet deep, published by the Geological Survey of Minnesota.[a]

Section of city well at Austin.[b]

	Thickness.	Depth.
Glacial drift:	*Feet.*	*Feet.*
Surface soil and loam	5	5
Sand and gravel	17	22
Clay and sand	12	34
Paleozoic formations:		
Light-colored limestone (arenaceous)	4	38
Dark-colored limestone	45	83
"Mud vein" (water-bearing)	2	85
Dark-colored limestone, etc. (Maquoketa and Galena)	340	425
Shale, etc. (Galena)	55	480
White, fine-grained sandstone (St. Peter)	105	585
Dolomite and sandstone (Shakopee, New Richmond, Oneota)	125	710

[a] N. H. Winchell, Fourteenth Ann. Rept. Geol. and Nat. Hist. Survey Minnesota, 1885, p. 16.
[b] Furnished by Prof. Andrew Nelson.

Throughout the county the St. Peter sandstone will yield large and permanent supplies, as will also the several sandstones at greater depths.

UNDERGROUND WATER CONDITIONS.

Wells.—The wells of Mower County are of four general classes: The first embraces the shallow wells ending in glacial drift; the second, the drilled wells which end in the deeper portions of the glacial drift; the third, the shallower rock wells reaching the Devonian sandstone in the southern and the St. Peter in the northern parts of the county; and the fourth, the deep rock wells. The shallowest wells are generally dug or bored, the water being obtained in sandy or gravelly layers in the drift and, in a few wells, in the Paleozoic rocks at a depth of from 10 to 40 feet. Where the drift is thick, it supplies many drilled wells. These average more than 100 feet in depth, and some of the deepest ones exceed 200 feet. Where the drift is thin, the supplies of water which it yields are not satisfactory, and rock wells are relied on, most of them obtaining their supplies from the Devonian sandstone or the sandstone lenses in the Galena and Platteville, though in some places, as at Austin, wells have been sunk to the St. Peter sandstone, from which large supplies of good water are procured.

Head of the water.—The head of the water in the shallow drift wells conforms in a general way to the topography. In the southeastern corner of the county there are several flowing wells which belong to the artesian areas of the vicinity of Chester, Iowa. In the deeper wells there is much greater variation in the head relative to the surface. At Austin the water from the St. Peter, Platteville, and Galena rises within 10 feet of the surface, or about 1,185 feet above sea level; at Rose Creek, which lies 90 feet higher than Austin, the water from the Devonian sandstone stands 130 feet below the surface, or about 1,165 feet above sea level.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Austin.—The public supply at Austin is derived from four wells, one 300 feet deep, and three ranging between 600 and 710 feet. There is also a well 175 feet deep which is no longer used. The wells are near to one another and are piped to flow into a cistern 22 feet deep, from which the water is pumped into the mains. The maximum combined daily yield is about 1,000,000 gallons. Nearly one-half of the people use the public supply, and about 500,000 gallons is consumed each day.

Adams.—The public supply at Adams is drawn from a well 291 feet deep, ending in Devonian rock, and is used by about two-thirds of the people. The rest depend chiefly upon shallow private wells, The depth to the St. Peter sandstone probably exceeds 500 feet, but ample supplies can be procured from rock formations nearer the surface.

Grand Meadow.—The public supply at Grand Meadow is obtained from a well 125 feet deep, which probably ends in Devonian sandstone. Most of the people depend on private wells.

Le Roy.—The village of Le Roy is provided with a public supply drawn from a well 422 feet deep. The log of this well to a depth of 382 feet, is as follows:

Section of village well at Le Roy.

[Authority, W. G. Banks.]

	Thickness.	Depth.
	Feet.	*Feet.*
Glacial drift	10	10
Limestone and shale	160	170
Blue clay	45	215
Sandstone	60	275
Limestone and shale	107	382

Rose Creek.—The public supply at Rose Creek is derived from a well which ends in what is supposed to be Devonian sandstone at a depth of 175 feet. This well has been tested at the rate of 100 gallons a minute. Most of the people are supplied from private wells.

Lyle.—In this village the average thickness of the surface material scarcely exceeds 35 feet. A layer of sandstone and gravel within the Devonian furnishes most of the water. The public supply is drawn from a well 240 feet deep. Most of the people depend on private wells.

SUMMARY AND ANALYSES.

In all parts of the county large and permanent supplies can be procured from the St. Peter sandstone at a depth of several hundred feet, and it is probably never necessary to drill to the sandstones that lie still deeper. For most purposes adequate supplies can be obtained from the glacial drift, Devonian sandstone, or Galena and Platteville arenaceous layers, before the St. Peter sandstone is reached. The water from all depths is moderately hard. Judging from analysis 9 in the table below, the water from the St. Peter contains but little mineral matter that will form hard scale in boilers or that can not be removed by heating.

Mineral analyses of water in Mower County.

[Analyses in parts per million.]

	Surface deposits.				Devonian, Galena, and Platteville.				St. Peter sandstone.
	1.	2.	3.	4.	5.	6.	7.	8.	9.
Depth ....feet..	....	12	30	15	226	135	263	243	600
Calcium (Ca)........................	60	97	96	56	75	62	88	67	69
Magnesium (Mg)......................	21	32	9.2	58	24	21	27	15	24
Sodium and potassium (Na+K)......	3	8.6	15	16	8.5	10	....	18	7.2
Bicarbonate radicle (HCO_3)...........	276	306	280	190	302	296	272	316	314
Sulphate radicle (SO_4)................	9	133	55	56	47	10	127	10	17
Chlorine (Cl)........................	2	2.8	16	25	4.1	5.2	11	.9	6.1
Total solids.........................	235	430	342	311	315	253	413	245	279

1. Hall's spring at Austin. May, 1901.
2. Chicago, Milwaukee and St. Paul Railway well at Ramsey October, 1892.
3. Chicago, Milwaukee and St. Paul Railway well at Le Roy. November, 1892.
4. Chicago, Milwaukee and St. Paul Railway well at Adams. December, 1892.
5. Chicago, Milwaukee and St. Paul Railway well at Dexter. October, 1892.
6. Former city well at Austin. November, 1891.
7. Old Chicago, Milwaukee and St. Paul Railway well at Austin. June, 1901.
8. New Chicago, Milwaukee and St. Paul Railway well at Austin. August, 1901.
9. City well at Austin. June, 1901.

The above analyses were reported by G. N. Prentiss, chemist Chicago, Milwaukee and St. Paul Railway Company.

MURRAY COUNTY.

By O. E. Meinzer.

SURFACE FEATURES.

The surface of Murray County consists of a gently undulating, poorly drained prairie which slopes gradually from about 1,800 feet above sea level in the western part to less than 1,300 feet in the northeastern. Two parallel moraines extend over this prairie with a northeast-northwest trend, the outer crossing the southwestern and the inner the northeastern part of the county. They have an irregular, hummocky topography and rise distinctly above the surrounding country. The streams of the county have few tributaries, and the extensive interstream areas are covered with a network of swamps, ponds, and lakes, the largest of the latter being Lake Shetek, in the north-central part. Beaver Creek rises in the outer moraine and flows eastward to the inner, where it joins the outlet of Lake Shetek to form Des Moines River, which thence flows southeastward along the outer margin of the inner moraine. The area beyond the outer moraine is drained southwestward by Chanarambie Creek, which has cut a gorgelike valley; the region inside of the inner moraine is drained in the opposite direction by Plum Creek, which likewise occupies a deep narrow valley.

SURFACE DEPOSITS.

Description.—So far as is known, the glacial drift covers the older rocks at all points in the county, and throughout most of the region it is thick. A number of wells have been reported which end in drift at depths of more than 250 feet, and several over 400 feet deep also appear, from the sections furnished by the driller, to be entirely in the drift. No record has been received of any well in the western half of the county that has reached the underlying formations, but such wells are numerous in the northeastern and southeastern corners where the drift is relatively thin. See the list of rock wells given below. The sections shown in Plate XIII are typical of the drift in this county and are especially interesting in showing the existence of the interbedded layers of yellow clay.

Yield of water.—The structure of the drift is to a great degree chaotic, and no water-bearing layer can be traced for a great distance. Thus the sections of two wells a mile apart may be quite different. Yet in nearly every locality one or more pervious beds exist which reserve ample stores of water. The 8-inch village well at Slayton, 205 feet deep, is pumped at the rate of 45 gallons a minute, and the 6-inch village well at Currie, 120 feet deep, has been tested for thirty-six hours continuously at the rate of 60 gallons a minute.

Head of the water.—Owing to differences in altitude there are important differences in the depth at which the water stands below the surface. In the two high morainic belts it remains at considerable depths, especially in the deeper wells, but on the lower prairie land which comprises most of the county it usually rises nearly to the surface from all horizons.

There are several small areas of flowing wells, which may be enumerated as follows (Pl. IV):

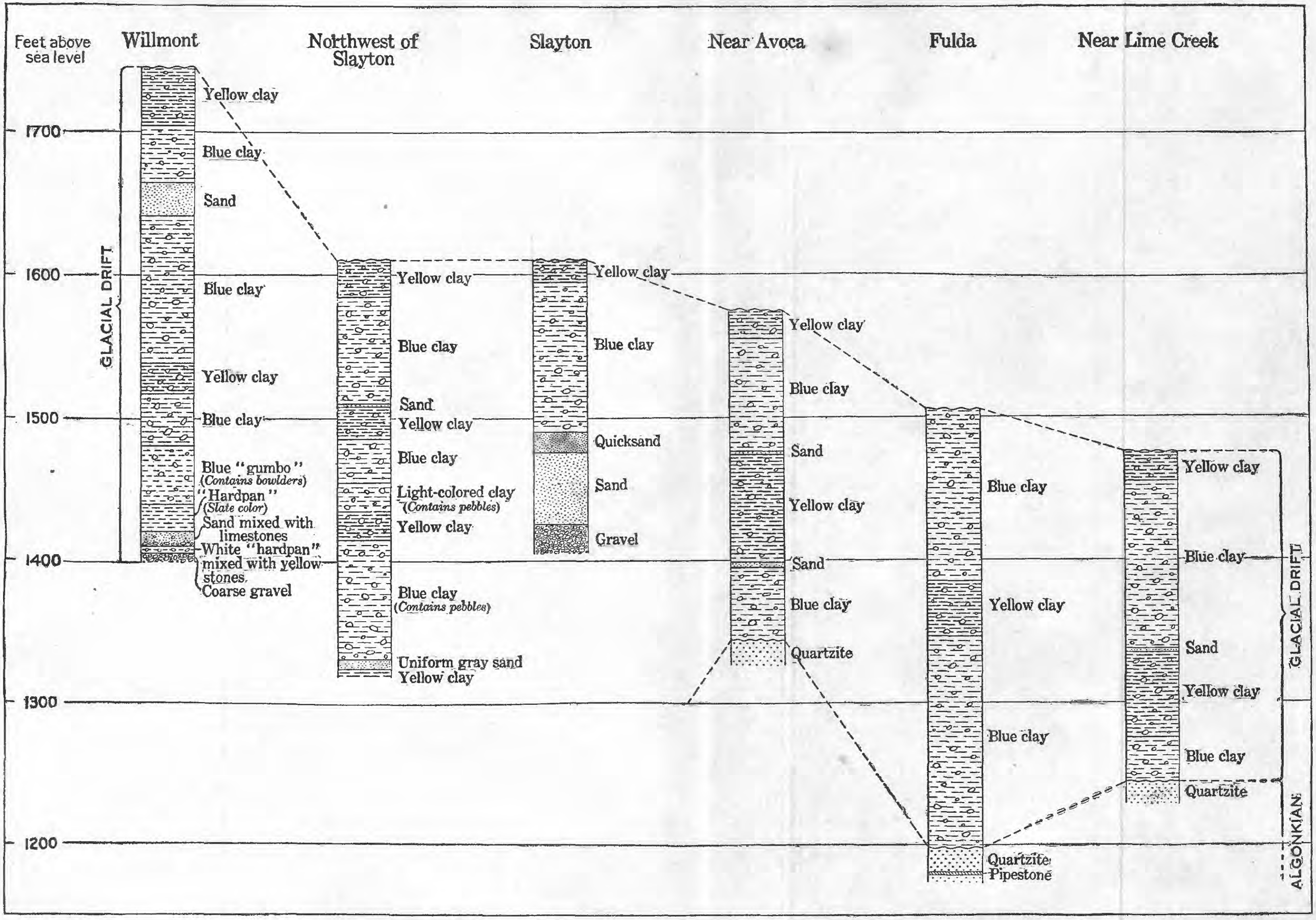
1. The Badger Lake area. This is a small district surrounding Badger Lake, 2½ miles east of Iona. About six flowing wells, ranging between 85 and 110 feet in depth, have been drilled in this basin. The lowest has a good pressure, but reduces the head of those on higher ground.

2. The Lime Creek area. There is a flowing well in the NE. ¼ sec. 34, T. 106 N., R. 41 W., and one in the SE. ¼ sec. 24, T. 106 N., R. 41 W. Others can be obtained along this stretch of Lime Creek.

3. The Lake Wilson area. Three flowing wells have been drilled in the village of Lake Wilson. These are about 85 feet deep, have a head of several feet, and flow from 5 to 10 gallons a minute each.

4. The Beaver Creek area. There is a flowing well 133 feet deep in the SE. ¼ sec. 4, T. 106 N., R. 42 W., and one 35 feet deep about 1 mile north of Lake Wilson. It seems probable that others with slight pressure could be procured along this portion of Beaver Creek. There is also a flowing well 80 feet deep 2 miles north and 2 miles east of Lake Wilson, and one of the same depth a half mile farther east.

There is little doubt that other depressed localities would afford wells in which the water would rise slightly above the surface. In a low area bordering a high morainic tract the water from the seams of sand beneath the blue bowlder clay is likely to rise approximately to the surficial ground-water level, and if a small portion of such an



GEOLOGIC SECTIONS IN SOUTHERN MURRAY AND NORTHERN NOBLES COUNTIES.

By O. E. Meinzer.

Willmont.—Village well. Authority, G. J. Savidge, driller, Wayne, Nebr.

Northwest of Slayton.—Well 4 miles north and 2 miles west of Slayton, on farm of D. F. McCarval. Authorities, Clauson & Anderson, drillers, Hadley.

Slayton.—Village well; approximate.

Near Avoca.—Well near Avoca, in NW. ¼ sec. 7, T. 105 N., R. 40 W.; approximate.

Fulda.—Village well at Fulda. Authority, William Denny, driller, Fulda.

Near Lime Creek.—Well near Lime Creek, SW. ¼ sec. 16, T. 105 N., R. 39 W.; approximate. Authority, John Durnan, driller, Currie.

The altitudes of the second, fourth, and sixth sections are only approximately known.

area is still further depressed (for example, in the valley of a stream or the basin occupied by a lake), the conditions are favorable for procuring flows. It is impossible to predict in advance the localities where flows can certainly be obtained, but it is possible to determine for any given district whether or not there is a reasonable chance. For example, in the village well at Currie the water is reported to rise within 20 feet of the top, and the surface is here fully 30 feet above the valley. If the zone from which this well is supplied extends below the valley it will there produce flows, but the structure of the drift is so irregular that such an extension is by no means certain.

Quality of the water.—All the analyses given in the accompanying table (p. 280) represent water from the glacial drift, except No. 12, which is the analysis of a sample taken from the top of the quartzite but also containing the constituents derived from the drift. Though they vary widely they are all highly mineralized and all hold great quantities of calcium and magnesium with large amounts of both bicarbonate and sulphate radicles. The water from very shallow sources is not so hard as that from greater depths, but still is by no means good for boiler purposes.

CRETACEOUS SYSTEM.

There is little doubt that most of this county is underlain by shales and sandstones of Cretaceous age, though, because of the general thickness of the drift, they have seldom been penetrated in drilling. Owing to the high altitude of most of the county the water which they contain will generally stand far below the surface. In the northeastern corner, however, the Cretaceous lies at no great depth and its water will rise very nearly to the surface. Most of the water is very hard, but the soft-water wells in Lyon, Redwood, and Cottonwood counties give reason for believing that zones of relatively soft water extend also into this county. At Walnut Grove, 2 miles north of the county line, water almost free from calcium and magnesium, but rich in alkali sulphates, occurs 300 feet below the surface, or 900 feet above the sea, and also at other levels; just east of this county the same type of water was found at a depth of 570 feet, or about 850 feet above the sea. More extended discussions of these formations will be found in the reports on Lyon, Redwood, Nobles, and Cottonwood counties.

SIOUX QUARTZITE.

In the southeastern part of the county the Sioux quartzite, or "red rock," lies relatively near the surface. The following table contains a list of several wells in the district which pass through the drift and penetrate this rock:

Table of rock wells in Murray County.

	Depth to rock.	Depth rock was pene-trated.	Total depth of well.
	Feet.	*Feet.*	*Feet.*
NW. ¼ sec. 7, T. 105 N., R. 40 W	230	14	244
Fulda village well	207	20	227
SW. ¼ sec. 17, T. 105 N., R. 40 W	238	3	241
NE. ¼ sec. 36, T. 105 N., R. 40 W	208	14	222
SW. ¼ sec. 16, T. 105 N., R. 39 W	230	15	245
Two miles east of Fulda	136	10	146
SE. ¼ sec. 28, T. 105 N., R. 39 W	100	....	....
NE. ¼ sec. 28, T. 105 N., R. 39 W	100	....	....

The head and quality of the water is similar to that of the drift in the same locality.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Slayton.—The records of deep drillings seem to show that in the locality of Slayton the glacial drift is uncommonly thick. An approximate section of the 8-inch well which furnishes the public supply is given in Plate XIII. The yield of this well has already been indicated (p. 276). It is finished with a screen, and its water rises within 50 feet of the surface. The water is hard, as is shown by the analysis given in the table, but it is otherwise good and is used by about 600 people, on an average 15,000 gallons being consumed in one day. The private wells are for the most part very shallow and provide small and uncertain supplies of rather poor water.

Fulda.—The quartzite at Fulda lies at a depth of about 200 feet, above which there is glacial drift of unusually various structure. The section of the village well is given in Plate XIII. This well is 6 and 8 inches in diameter and yields generously. The water rises to a level about 40 feet below the surface, or 1,467 feet above the sea. It is very hard, as is shown by the analysis in the table (p. 280). The private wells are of both the drilled and the bored types and range in depth from about 10 to 220 feet.

Currie.—The data at hand show that the glacial drift is deep in this locality. The following is the section of the 6-inch village well, the head and yield of which are given above.

Well section at Currie.

[Authority, John Durnan, driller, Currie.]

	Thick-ness.	Depth.
	Feet.	*Feet.*
Yellow clay	20	20
Blue clay	80	100
Sand	2	102
Blue clay	10	112
Sand and gravel	8	120
Blue clay.		

The analysis in the table shows that the water from this well is very hard. Perhaps 80 per cent of the people rely on private wells, most of which are bored or dug and are very shallow.

Iona.—The well that furnishes the public supply in Iona village is 6 inches in diameter and 204 feet deep and is provided with a brass screen where the water is admitted. The section is somewhat similar to that of the village well at Slayton. There is yellow clay at the surface, underlain by blue clay to a depth of 185 feet, below which there is much sand and gravel. The water rises to a level about 35 feet below the surface, or about 1,595 feet above the sea, and the supply is copious and permanent. About one-half of the people depend on private wells, which are generally bored to depths of 20 to 40 feet and afford rather small quantities of water. Both the mill and the creamery are supplied from wells that end in the same bed as the village well. All the water is hard, but if analyses 4 and 9 in the table can be taken as typical that from the 200-foot zone is even more highly mineralized than the shallow water.

Avoca.—In Avoca village the entire population is supplied from private wells of the usual shallow type. Formerly the public waterworks depended on a well which was about 400 feet deep and tapered from 5 inches in diameter at the top to 1½ inches at the bottom. This well has failed entirely and one 3 feet in diameter and 20 feet deep has been bored for temporary use. The railway company takes water from Lime Lake.

FARM WATER SUPPLIES.

There are two types of farm wells, bored and drilled. The former are usually shallow, have a large diameter, and are cased with wood or tile. The latter are from 2 to 6 inches in diameter and from 50 to 500 feet in depth, most being between 100 and 200 feet. When the county was first settled all the wells were either dug or bored and very shallow, but these have gradually been replaced by the deeper drilled wells, until at present the latter are found on most of the farms. As the screens in the 2-inch wells cause trouble by becoming incrusted, wells of larger diameter are recommended. This subject is fully discussed under the heading "Finishing wells in sand" (pp. 82–83).

SUMMARY AND ANALYSES.

The glacial drift is so thick and contains so much water that it will perhaps always be the most valuable source of supply, but beneath the drift (everywhere except in the southeastern part), there is probably a series of shale and sandstone which also bears water. The water from both drift and sandstone is in most places very hard, but there is a prospect of obtaining soft water from the sandstone; this matter can be investigated further by referring to the reports on

Lyon, Redwood, and Cottonwood counties. Except possibly in the extreme northeast, flowing wells are nowhere to be expected from the sandstone.

Mineral analyses of water in Murray County.

[Analyses in parts per million.]

	Surface deposits (glacial drift, etc.).											
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
Depth .... feet..	14	17	18	40	87	120	130	187	204	205	206	227
Diameter of well ...... inches..	28	120	144	36	6	6	5	6	6	8	4½	8–6
Silica (SiO_2)	22	34	....	9.4	27	28	....	19	19	25	....	24
Iron (Fe)	....	....	....	.25	....	.5	....	....	.3	.4	....	.5
Aluminum (Al)	....	....	....	5.1	2.3	6.1	....	....	10	6.5	....	....
Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	6.5	9	7	....	6.4	....	....	2	....	....	2	3.2
Calcium (Ca)	105	104	104	162	140	231	264	177	358	241	299	249
Magnesium (Mg)	35	39	32	50	40	94	120	55	86	57	101	95
Sodium and potassium (Na+K)	66	11	14	75	2	113	164	151	39	19	130	143
Carbonate radicle (CO_3)	....	....	....	.0	.0	.0	....	....	.0	.0	....	.0
Bicarbonate radicle (HCO_3)	3.71	402	339	659	427	390	440	490	605	513	432	361
Sulphate radicle (SO_4)	233	110	133	70	161	849	1,092	531	662	433	1,038	969
Chlorine (Cl)	4	2	2	102	2	4	8	34	102	5	10	7
Nitrate radicle (NO_3)	....	....	....	8	.0	.0	....	....	8	.0	....	2.5
Total solids	654	507	458	826	587	1,525	1,865	1,211	1,599	1,054	1,792	1,686

1. Railway well at Lake Wilson. October 25, 1901.
2. Railway well at Currie. October 3, 1900.
3. Railway well at Chandler. October 5, 1902.
4. Well at the Iona Hotel at Iona. July 25, 1907.
5. Village flowing well at Lake Wilson. August 7, 1907.
6. Village well at Currie. August 8, 1907.
7. "Springer & Mendrickson's well" at Fulda. October 30, 1902.
8. Railway well at Avoca. October 25, 1901.
9. Village well at Iona. July 25, 1907.
10. Village well at Slayton. August 7, 1907.
11. Village well at Fulda. February 22, 1896.
12. Village well at Fulda. July 26, 1907.

Analyses 4, 5, 6, 9, 10, and 12 were made for the United States Geological Survey by H. A. Whittaker, chemist Minnesota state board of health. Analyses 1, 2, and 8 were furnished by G. M. Davidson, chemist Chicago, St. Paul, Minneapolis and Omaha Railway Company. Analyses 3, 7, and 11 were furnished by G. N. Prentiss, chemist Chicago, Milwaukee and St. Paul Railway Company.

NICOLLET COUNTY.

By C. W. Hall and M. L. Fuller.

SURFACE FEATURES.

Nicollet County forms a part of an extensive prairie region. There is no morainic belt in the county, though there are several lakes that lie in shallow depressions. Minnesota River, which borders the county on its southwestern and southeastern sides, occupies a valley 150 to 200 feet deep, but has only a few tributaries. Several creeks, such as Little Rock Creek in the west and Nicollet Creek in the south, drain the surface sluggishly and discharge into the Minnesota.

SURFACE DEPOSITS.

Alluvium.—The thickness of the alluvium in the Minnesota Valley is not known, but the fact that rocks show at the surface at many places indicates that it is not great. The clayey portions will not supply much water, but the gravels yield generously.

Terrace gravels.—At various levels along the course of Minnesota River the stream in its earlier stages removed large quantities of rock material from the successive formations, and thus as it cut deeper it left terraces of erosion covered with thin layers of coarse alluvial material. At present these terraces are inhabited by the people whose farming or commercial interests lie in the valley. Near the exposed edges the terrace gravels do not carry much water, but elsewhere they may contain considerable amounts.

Glacial drift.—The glacial drift of Nicollet County is composed largely of clayey materials derived from the Cretaceous rocks to the northwest, but includes some bowlders from more remote sources. It covers nearly the entire county, the thickness varying from less than 100 feet at points near the edges of the bluff to 200 feet or more in the interior. At Oshawa the rock is reported at 285 feet below the surface, and there is reason to believe that it lies even deeper in the northwestern part of the county. Throughout the greater part of the area water can be obtained by shallow wells, but the depth to water increases toward the Minnesota Valley, into which the upper beds are drained. The deeper wells generally penetrate 100 feet or more of hard clay and end in beds of sand or gravel, many of which yield large quantities of water.

CRETACEOUS SYSTEM.

Along Minnesota River, between the western extremity of the county and the city of St. Peter, there are a number of outcrops of different rock types, carrying fossil leaves, carbonized wood, and lignite. These are probably a continuation of the Cretaceous rocks found on the south side of the river near the mouth of the Cottonwood, separated from them by the erosion of the Minnesota Valley.

PALEOZOIC FORMATIONS.

The lower portion of the Prairie du Chien group outcrops along the west side of Minnesota River, both above and below St. Peter, and has a thickness probably of 50 feet or more along the eastern side of the county. How far it extends westward is not definitely known.

The Jordan sandstone, which has a total thickness of about 80 feet, lies beneath the alluvium of Minnesota River for a considerable part of its course along the margin of this county. It is an important water-bearing bed and supplies many wells.

The St. Lawrence formation, which probably exceeds 100 feet in thickness, outcrops along Minnesota River below Courtland, and in this region forms a belt several miles in width. It consists of a series of pink magnesian limestones, alternating with green shales and sandy layers that carry small amounts of water.

The Dresbach sandstone probably lies immediately beneath the drift in most of the northern and western parts of the county, and constitutes the principal deep-water zone in this region. Water is found in the entire thickness of the Dresbach sandstone and the underlying shales, and, owing to the compact character of the overlying St. Lawrence, is under sufficient pressure to give rise to flows in the valley.

WELL RECORDS.

The following is the section of a well drilled in St. Peter at the State Hospital for the Insane. The top of the well is approximately 825 feet above sea level:

Section of well at St. Peter.

[Authority, J. F. McCarthy.]

	Thickness.	Depth.
	Feet.	*Feet.*
Surface soil and rock débris	8	8
Limestone (Oneota?)	20	28
Sandstone (Jordan?)	80	108
Limestone and shale (St. Lawrence?)	100	208
Sandstone (Dresbach?) and shale	290	498

The following is the section reported for the Chicago and Northwestern Railway well at Oshawa. The top of the well is 982 feet above sea level:

Section of railway well at Oshawa.

[Authority, P. P. Kennedy.]

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	3	3
Yellow clay	15	18
Blue clay with 3-inch sand layer	78	96
"Hardpan" (composed of gravel and sand)	69	165
Quicksand (water)	120	285
Limestone	76	361
White sand (water)	11	372
Hard quartz rock (not penetrated)	....	....

ALGONKIAN ROCKS.

The Sioux quartzite, which contains only small quantities of water, comes to the surface over a small area in the valley east of New Ulm. A conglomerate 50 feet or more thick, which outcrops for several miles along the river in this locality, has hitherto been regarded as constituting a part of the Sioux quartzite, but is now believed by Prof. F. W. Sardeson to belong to a younger series.[a] It is possibly to be correlated with the red clastic series found throughout the southeastern part of the State.

[a] Sardeson, F. W., Bull. Geol. Soc. America, vol. 19, 1908, p. 229.

ARCHEAN ROCKS.

The granitic rocks are found in Courtland Township, nearly opposite New Ulm, exposed in a low outcrop about 150 paces from the conglomerate and quartzite formations. These rocks are also in sight a few miles below Fort Ridgely and in a small exposure in the western extremity of the county, 2 miles west of Fort Ridgely. They probably lie at comparatively shallow depths throughout the entire western part of the county.

WATER SUPPLIES FOR CITIES AND VILLAGES.

St. Peter.—The city of St. Peter has a number of deep wells, all but one of which are located in the valley a few feet above the flood plain of Minnesota River and flow vigorously. The two at the State Hospital for the Insane yield 250,000 and 375,000 gallons daily. They were first sunk to depths of 197 and 230 feet, but later became sluggish and were drilled to 450 and 498 feet. The section that they reveal is given above.

A number of springs issue from the Oneota dolomite in this vicinity. At the Gustavus Adolphus College there is a large spring which is utilized by the college and many families in the vicinity. The public supply is obtained from an 8-inch flowing well, which is 362 feet deep and ends in the Dresbach sandstone. Most of the people use water from private wells.

Nicollet.—The village of Nicollet has a system of waterworks supplied from two wells 175 feet deep. Nearly all of the inhabitants use water from private wells.

SUMMARY.

The eastern part of the county is underlain by several porous sandstones which will yield large quantities of water. In the Minnesota Valley the deepest of these give rise to strong flows, but on the upland the water must be lifted a considerable distance. In the western part of the county the sandstones are likely not to be present and the gravel beds of the drift must chiefly be relied on for water supplies. Hundreds of springs issue from the north flank of the Minnesota Valley all the way from Fort Ridgely to Le Sueur, draining the water from the outcropping strata and lowering the head for miles back from the valley.

NOBLES COUNTY.

By O. E. Meinzer.

SURFACE FEATURES.

Through the central portion of Nobles County, with a north-south or slight northwest-southeast trend, extends a morainic belt of irregular hummocky topography that rises prominently above the prairie on either side. From this elevated tract, which in the north reaches a height of more than 1,700 feet above sea level, the surface slopes gradually downward, the lowest parts of the county being in the northeastern and southwestern corners, where the altitude is about 1,450 feet above the sea. The region east of the moraine has a youthful topography and poor drainage. The principal streams have here cut only narrow valleys into the surface clay, and they have few tributaries, so that the interstream areas abound in lakes, ponds, and swamps. West of the moraine, on the contrary, there are few lakes, and the drainage is much better. The crest of the morainal ridge forms the divide between the Des Moines and Rock river systems, and the streams in the southeastern corner of the county drain into Little Sioux River.

SURFACE DEPOSITS.

Description.—The glacial drift is well developed, but the data in regard to its thickness are meager. In much of the central and north-central parts it attains a depth of more than 300 feet, but in the northeastern and southwestern corners it is more attenuated. At Wilmont, in the village well, a depth of 345 feet was reached, at which level striated glacial pebbles were found (Pl. XIII). At Worthington and Adrian, though no reliable data are at hand, the drift appears to be about 300 feet thick, and at Sibley, Iowa, 8 miles south of this county, it was found to have a thickness of 309 feet.[a] But at Ellsworth, near the southwestern corner of the county, underlying rocks were reached at a depth of only 190 feet,[a] and at many points near the northeastern corner they have been penetrated at depths of 100 to 200 feet. No outcrops of older formations have been found in this county.

Yield of water.—In nearly every locality the drift contains one or more beds of sand and gravel that will furnish large quantities of water. The 8-inch village well at Wilmont, the section of which is given in Plate XIII, was pumped at the rate of 95 gallons a minute for several hours continuously; the two 12-inch city wells at Worthington, which are 78 feet deep, have been tested by suction pumps placed at the surface, at the rate of several hundred gallons a minute; and the village well at Adrian, which is 10 feet in diameter and 47 feet deep, has been pumped at the rate of 500 gallons a minute for one and a half hours without greatly lowering the water.

Head of the water.—In the central and especially the north-central part of this county, where the altitude is high, the head relative to the surface is not regular, but the average level is low. In general, the water rises higher in the shallow wells than in the deeper ones,

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[a] Wilder, F. A., Ann. Rept. Geol. Survey Iowa, vol. 10, 1899, pp. 108–109.

as is illustrated by the following three wells, which do not differ greatly in surface altitude:

Relation of head of water to depth of wells near Wilmont.

Location.	Depth of well.	Depth to top of water.
	Feet.	*Feet.*
SW. ¼ sec. 34, T. 104 N., R. 42 W	197	40
Village well at Wilmont	348	120
SW. ¼ sec. 1, T. 103 N., R. 41 W	[a] 572	230

[a] This well extends into formations below the drift.

On either side of the morainal ridge, where the altitude is lower, the water rises nearly to the surface, and in the northeastern part of the county, in the valley of Jack Creek, flowing wells are obtained (Pl. IV). Six flows were here reported, the one farthest upstream being on the farm of Leonard Gunderman, NE. ¼ sec. 10, T. 104 N., R. 40 W., and the one farthest downstream on the farm of J. B. Kunerth, SE. ¼ sec. 30, T. 104 N, R. 39 W. This is the kind of situation in which flowing wells can be expected from the drift, the altitude being nearly 300 feet lower than at Wilmont, 12 miles distant. But even here flows can be procured only near the streams where the surface is especially depressed, and they can not be had on the low land farther east. Flowing wells were reported at a few other points on both sides of the morainal ridge and could probably be obtained in a number of small areas in regions where the change in altitude is relatively great and abrupt. In the city wells at Worthington the water rises within 7 feet of the surface.

Quality of the water.—The water from the glacial drift is all highly mineralized. It is all rich in calcium and magnesium, which render it hard, and as sulphates are high it will produce hard scale in boilers. There is, however, a wide range in the quality of the water. In general, the hardness and total mineralization are greater (1) in the drift proper than in the deposits of sand and gravel at the surface, (2) east of the moraine than west of it, and (3) in the deep beds than in the shallow ones. The analyses given in the accompanying table (p. 290) illustrate these generalizations. No. 1 is only moderately hard; No. 6 is extremely hard and quite unfit for boiler use; Nos. 2, 3, 4, and 5 are intermediate and are more nearly typical of the ordinary water found at moderate depths in the drift.

CRETACEOUS SYSTEM.

Description.—From the scattered data collected from various sources it is safe to infer that in this county the glacial drift is generally underlain by a series of shales and sandstones, at least the upper portion of which is Cretaceous in age. It is probable that there are in fact two distinct divisions separated by a pronounced unconformity, the lower one being Paleozoic and the upper one Cretaceous. The facts bearing on the Cretaceous are summed up in the following paragraphs:

Along Big Sioux River, northward from Sioux City, Iowa, there is a succession of exposures which together give roughly the following section, the total thickness of which amounts to several hundred feet:

4. Blue shale.
3. Argillaceous limestone and chalk.
2. Blue shale.
1. Sandstone (buff to white).

These rocks are Upper Cretaceous in age, as has been proved by abundant fossil evidence. No. 1 is referred to the Dakota sandstone and Nos. 2, 3, and 4 to the Benton group.[a] The nearest outcrop is about 30 miles southwest of this county.

In the railway well at Sanborn, Iowa, 24 miles south of the Nobles County line, the following section was revealed:

Well section at Sanborn, Iowa.[a]

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow clay	75	75
Blue clay	125	200
Blue shale	160	360
Blue and green shale with streaks of lime rock	200	560
Soft white sandstone with some shale	155	715
Gray shale with streaks of rock	50	765
White sandstone	45	810
Blue and green shale mixed with sandstone	200	1,010
Green and white shale	240	1,250

[a] Norton, W. H., Ann. Rept. Geol. Survey Iowa, vol. 6, 1896, p. 198.

In the railway well at Sibley, Iowa, 8 miles south of the Nobles County line, the following succession of strata was found:

Well section at Sibley, Iowa.[a]

	Thickness.	Depth.
	Feet.	*Feet.*
Soil, yellow clay, and gravel	63	63
Blue clay with gravel	60	123
Sand and clay	6	129
Blue clay with bowlders	180	309
Soapstone (shale), no gravel	80	389
Sand (water). Penetrated 20 feet.		

[a] Wilder, F. A., Ann. Rept. Geol. Survey Iowa, vol. 10, 1899, p. 109.

In the railway well at Ellsworth, near the southwestern corner of this county, the section reported is as follows:

[a] Condra, G. E., Geology and water resources of a portion of the Missouri River Valley in northeastern Nebraska: Water-Supply Paper U. S. Geol. Survey No. 215, 1908, pp. 6 et seq.

Well section at Ellsworth.[a]

	Thickness.	Depth.
	Feet.	*Feet.*
Soil, yellow clay, sand, and gravel	95	95
Blue clay with gravel and bowlders	95	190
Blue soapstone (shale), no gravel	50	240
Clean water-bearing sand	30	270
Sand and clay	20	290
Quartzite (at depth of 281 feet).		

[a] Wilder, F. A., Ann. Rept. Geol. Survey Iowa, vol. 10, 1899, p. 109.

In the unsuccessful well drilled for E. Cooper in the village of Adrian a peculiar "green clay without grit" is reported between the depths of 260 and 380 feet, and in a well 7 miles northwest of Adrian this "green clay" was drilled into for 75 feet, the hole then being abandoned.[a]

An unsuccessful well, 530 feet deep, drilled for the city of Worthington, is reported to have passed through 5 feet of coal and to have entered a stratum of "slate."

A deep well west of Wilmont, on the farm of Francis A. Durfee, SW. ¼ sec. 1, T. 103 N., R. 41 W., appears to have penetrated a considerable thickness of soft blue shale and to have ended in a fine-grained light-colored sandstone lying between the depths of 560 and 572 feet.

A short distance east and northeast of Nobles County there are several wells that enter shale and sandstone, but to the west the Sioux quartzite comes to the surface. Immediately north of Nobles County the drift is so thick that the underlying formations are rarely reached in drilling, but in Lyon County, 25 miles north, a succession of shales and sandstones, at least in part Cretaceous, is frequently penetrated.

Yield of water.—There can be little doubt that the series above discussed contains strata of water-bearing sandstone except in the localities where these are interrupted by the Sioux quartzite. Failure in deep drilling is generally due to one of two causes: Either the drilling is stopped in the impervious shale before any water-bearing strata are reached or the water-bearing strata consist of such fine and incoherent sand that the driller does not succeed in finishing the well.

Head of the water.—In the central part of the county the water from the deep zones will remain at a depth of several hundred feet. On the lower ground along the eastern and western margins it will rise nearer the surface, but no flowing wells are to be expected.

Quality of the water.—The water from the sandstone beds beneath the drift is generally extremely rich in calcium and sulphates, and hence is very hard and unfit for boiler use. However, soft water has

[a] Authority, Scott & Day, drillers, Adrian.

been obtained from these strata in a well at Westbrook, which is 13 miles north of this county, and in many wells farther north. (See the reports on Lyon and Cottonwood counties.)

SIOUX QUARTZITE.

At Ellsworth, near the southwestern corner of the county, the Sioux quartzite or "red rock" was encountered beneath sandstone at a depth of 281 feet, and near Kinbrae and Dundee, in the northeastern corner, it lies immediately under the drift at depths of 100 feet and more, but in other parts of the county it has not been reached in drilling (Pl. III). It will yield small but permanent supplies of water, which is similar in quality and head to that from the overlying formations.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Worthington.—The unsuccessful deep well which was drilled for the city of Worthington is reported to have penetrated alternate beds of clay, sand, and gravel to a depth of 488 feet. Thence it passed successively through (1) a thin layer of "hardpan," (2) 30 feet of "black substance," (3) 5 feet of "coal," and (4) 5 feet of "slate," in which the drilling was stopped.[a]

The public supply is taken from two 12-inch wells drilled in 1906 to a depth of 77 feet and finished with brass screens. The following is the section reported:

Section of city wells at Worthington.

[Authority, George J. Savidge, driller, Wayne, Nebr.]

	Thickness.	Depth.
	Feet.	*Feet.*
Sandy loam	10	10
Blue clay	18	28
Sand and large bowlders (some water)	25	53
Blue "hardpan"	6	59
Gravel containing limestone rocks	18	77
Hard blue clay.		

The head and yield of these wells have already been given (p. 284). The water is hard and highly charged with iron, as is shown by analysis 5 in the table (p. 290). There are two shallower wells which formerly furnished the public supply but are now used only for boiler purposes and as a reserve in case of fire. One of these wells has an intake from the lake. At least 1,000 people use the water to some extent, about 65,000 gallons being consumed daily. Approximately 75 per cent of the inhabitants depend on private wells, most of which are bored or dug to depths of 15 to 40 feet and yield small amounts of water. The boiler supplies are derived either from shallow wells or from the lake.

[a] Authority, M. S. Smith, former city engineer and clerk, Worthington.

Adrian.—The waterworks in Adrian village are supplied from a well 10 feet in diameter and 47 feet deep, which ends in sand. The water is only moderately hard, as is shown by the analysis in the table. It is used by about 700 people, and 40,000 gallons is reported to be consumed daily. The mill, railway, and approximately one-half of the homes are supplied from private wells, all of which are shallow.

Ellsworth.—The public waterworks in Ellsworth village depend on a dug well 12 feet in diameter and 33 feet deep. The water is not extensively used. Most of the private wells are bored to depths of 20 or 30 feet and end in yellow clay, yielding small supplies.

Wilmont.—The glacial drift at Wilmont is more than 300 feet thick. The public waterworks, which were installed in 1907, are supplied from a 345-foot well, most of the data in regard to which have been given (pp. 284–285). The private wells are nearly all of the bored type, commonly ranging between 15 and 40 feet in depth and yielding small quantities of hard water. Analyses of water from the village well and from a typical shallow private well are given in the table (p. 290). Both samples are very hard, the former being even more highly mineralized than the latter.

FARM WATER SUPPLIES.

Over 90 per cent of the farm wells are of the bored type, from 1½ to 3 feet in diameter and cased with wood or tile. Some are very shallow and end in the surficial yellow clay or in sand and gravel near the surface, but the greater number pass through blue bowlder clay and reach stronger zones at an average depth of nearly 100 feet. The drilled wells, most of which are in the northeastern part of the county, may stop in the first gravel bed penetrated or may go deeper for larger supplies. Near Kinbrae and Dundee a few enter the quartzite, or "red rock," from which they draw their water.

Two-inch wells must be provided with screens, which become incrusted in a few years, but wells of larger diameter can nearly always be finished successfully with open ends, and are therefore more permanent and satisfactory. This subject is discussed under the heading "Problems relating to wells" (pp. 82–87).

SUMMARY AND ANALYSES.

At present the glacial drift furnishes virtually the entire supply for all purposes. If penetrated to a sufficient depth it will be found in nearly every locality to contain large and permanent stores of water. Drilling beyond a depth necessary to secure an adequate supply can not be encouraged, because no flowing wells can be obtained however deep the drilling is carried, and in a large part of the county the water will stand several hundred feet below the surface. The data at hand also indicate that the water from deep sources is generally very hard and bad for boiler use, though in Lyon, Redwood, and Cottonwood counties soft water has been found in the sandstone strata below the drift.

In the small area where quartzite or "red rock" is near the surface, the attempt should always be made to get water from seams of sand before the rock is reached. However, if it is impossible to do so, a small but permanent supply can be obtained from the quartzite.

Mineral analyses of water from wells in surface deposits (glacial drift, etc.), in Nobles County.

[Analyses in parts per million.]

	1.	2.	3.	4.	5.	6.
Depth ....feet..	47	20	60	60	78	348
Diameter of well ....inches..	120	24	144	12	12	8
Silica (SiO_2)	31	26	33	34	36	29
Iron (Fe)	1.3	.1	....	....	4.6	3
Aluminum (Al)	....	....	....	....	5.3	....
Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	5.4	.4	93	9	....	3.2
Calcium (Ca)	68	252	194	196	179	435
Magnesium (Mg)	38	58	71	75	60	159
Sodium and potassium (Na+K)	57	36	70	82	24	114
Carbonate radicle (CO_3)	.0	.0	....	....	.0	.0
Bicarbonate radicle (HCO_3)	349	395	401	567	429	38.6
Sulphate radicle (SO_4)	145	350	514	485	374	1,583
Chlorine (Cl)	5	150	45	1.5	3	6
Nitrate radicle (NO_3)	.5	45	....	....	.0	Trace.
Total solids	529	1,112	1,217	1,164	907	2,540

1. Village well at Adrian. July 30, 1907.
2. Well at the residence of Doctor Williams, at Wilmont. August 1, 1907.
3. Railway well at Bigelow. November 28, 1900.
4. City wells at Worthington. November 27, 1900.
5. Two city wells at Worthington. July 31, 1907.
6. Village well at Wilmont. August 1, 1907.

Analyses 1, 2, 5, and 6 were made for the United States Geological Survey by H. A. Whittaker, chemist Minnesota state board of health. Analyses 3 and 4 were furnished by G. M. Davidson, chemist Chicago, St. Paul, Minneapolis and Omaha Railway Company.

OLMSTED COUNTY.

By C. W. Hall and M. L. Fuller.

SURFACE FEATURES.

The greater part of the surface of Olmsted County belongs to the plateau which extends over the entire region. In the southern half it stands at an elevation of about 1,300 feet above sea level, but to the north, where softer rocks are exposed, it subsides to an altitude of 1,000 to 1,200 feet. In this region the upland surface is not continuous, the rather even crests of the ridges between the streams being its only representative in places. In certain localities the general plateau level is broken by mounds and hills of the Galena, Decorah, and Platteville formations or by the sinks of the limestone surface. The principal valleys are those of the Zumbro, in the western part of the county, and of the tributaries of the Root and other streams in the southeast and east. The valleys are only 200 to 300 feet deep, and, though marked by steep walls or bluffs in places, do not commonly have the canyon-like character exhibited by the streams nearer the Mississippi. In the limestone areas the streams sometimes flow in underground channels for considerable distances. About three-fourths of the area of Olmsted County is drained due north by the South Fork of the Zumbro. The erosion which has been effected by the Zumbro has caused a rapid encroachment of its tributaries from the south upon the basins of streams draining the region covered by Olmsted and Dodge counties, thus affording a clear example of stream piracy.

SURFACE DEPOSITS.

The surface deposits include alluvium, loess, and glacial drift.

The alluvium consists of irregularly stratified gravels and sands deposited along the valleys of the present streams, especially Zumbro and Root rivers. Its thickness varies, but probably rarely exceeds 50 feet, though locally it may be considerably greater. It contains moderate amounts of water and affords supplies to shallow wells sufficient for domestic and farm purposes. The narrow shelves or terraces which occur in some localities along the borders of the valleys contain little water at depths above the level of the adjacent streams.

The loess deposits are too thin to be important as sources of supply, but they serve to collect the rain falling on the upland surfaces and to feed it to the underlying rock formations.

The glacial drift in Olmsted County is a heterogeneous mass of clay, pebbles, and bowlders. There seem to be two sheets, separated locally by beds of peat. Near the southwestern corner of the county the drift is 75 to 100 feet thick, but it becomes thinner eastward until in the eastern part of the county it is present only in scattered patches. In the southwestern area the drift includes a number of sandy or gravelly layers capable of holding considerable amounts of water, which is yielded to farm and domestic wells throughout the uplands. Where the drift is in patches it is rarely of importance as a source of water.

PALEOZOIC FORMATIONS.

The Maquoketa shale, as represented in this county, consists of about 15 feet of argillaceous shale, sandy shale, and impure limestone. It is present only in a small area in the southwestern part of the county, where it yields small supplies to domestic and farm wells of moderate depth.

The Galena limestone, Decorah shale, and Platteville limestone have an aggregate thickness of about 200 feet. They are found beneath the higher uplands, where the limestones locally yield water supplies of moderate volume. The Decorah shale is not water bearing but serves to collect the water from the overlying limestones, bringing it to the surface as springs, which are locally important for farm purposes.

The St. Peter sandstone is about 110 feet thick and outcrops along the Root River valley in the southeastern part of the county and along the Zumbro River valley and its tributaries in the northern and northwestern parts of the county. Generally it has a flat grass or timber-covered surface, which is locally broken by mounds of sandstone preserved by a hard cap of the overlying Platteville limestone. It dips southwestward and underlies the greater portion of the county. It usually affords abundant water for domestic and farm purposes and even for small industrial and public supplies.

The Shakopee dolomite, which is about 35 feet thick, outcrops in the cliffs along the principal rivers and underlies extensive areas of uplands near the northern border of the county. It affords a very compact widespread base for the overlying St. Peter, but yields water enough only for the most restricted requirements. Many springs emerge from the top of this formation where it outcrops.

The New Richmond sandstone is exposed in the upper portion of the Zumbro and Root River valleys. It underlies a large part of the Shakopee area in the northern part of the county and will furnish supplementary supplies of importance to wells of moderate depth.

The Oneota dolomite occurs beneath the alluvium in the bottom of the Zumbro Valley and its tributaries in the northern part of the county and in the Root River valley near the county line on the south. It also underlies the uplands throughout the county and is about 200 feet or less in thickness. It contains very little water but gives rise to springs along the valleys mentioned.

The Jordan sandstone is about 120 feet thick. The formation underlies the entire county and is generally saturated with water, yielding good supplies to deep wells, though on the uplands the water must be lifted several hundred feet by pumps.

The St. Lawrence formation consists of 200 feet or more of calcareous shales and sandstones. It carries some water, but the amount is less than in the overlying Jordan or in the underlying Dresbach.

The Dresbach sandstone, which is here about 50 feet thick, underlies the St. Lawrence and is a strong water-bearing bed, but not stronger than the Jordan, 250 feet above it. Where large volumes are needed, however, for industrial or public purposes, the Dresbach sandstone will furnish supplementary supplies that will doubtless prove important.

Below the Dresbach sandstone are about 150 feet of grayish or greenish shales, and below these is more than 200 feet of porous sandstone containing abundant water. As is true of the Dresbach, however, owing to the abundance of water in the overlying Jordan, there is no advantage in sinking wells to this lower sandstone except for supplementary supplies.

The red clastic series, consisting of red shale, sandstone, and quartzite, underlies the sandstone just described and is in turn underlain by the granite. Neither of these, however, affords water supplies and neither has been reached by borings in this county.

UNDERGROUND WATER CONDITIONS.

Wells.—Formerly wells 10 to 35 feet deep were common throughout the county, but the supplies were found deficient in dry seasons and the water more or less liable to pollution. For these reasons drilled wells entering the rock have been largely substituted, though many shallow wells are still in use. Most of the drilled wells penetrate the rock only a short distance, but at Rochester a well has been sunk to the Dresbach sandstone, this being the only well of notable depth in the county.

Head of the water.—The head of water, relative to the surface, varies considerably, owing to the topographic irregularities. In the northern portion of the county there are a few flowing wells.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Rochester.—The public supply of Rochester is obtained from a series of wells sunk into the alluvium near the mouth of Bear Creek. These wells derive their head from the alluvium of the creek valley south of the city. The water is used by about one-half of the people.

Several years ago a deep well was drilled at the State Hospital for the Insane near Rochester. As the hospital grounds are considerably above the city, the drilling was begun in Galena or Platteville limestone. The section is interesting because it represents nearly the entire Paleozoic development of southeastern Minnesota:

Well section at Rochester.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil, loess, drift, and broken limestone	75	75
St. Peter sandstone	100	175
Shakopee dolomite, New Richmond sandstone, and Oneota dolomite	150	325
Jordan sandstone	175	500
Limestone and sandstone (St. Lawrence and Dresbach?)	300	800
Shale	80	880
Sandstone	80	960

Stewartville.—A well 63 feet deep has furnished the public supply at Stewartville up to the present, but a new well was being drilled in 1908. About 8,000 gallons of water is consumed daily.

Eyota.—A compressed air system of waterworks has recently been installed by the village of Eyota. The supply comes from a well 10 inches in diameter and 203 feet deep.

SUMMARY AND ANALYSES.

The sandstones that underlie this county yield ample and permanent supplies. Usually an adequate amount of water can be obtained from the St. Peter at a moderate depth, but where it can not there need be no hesitation in drilling to the Jordan, which lies about 200 feet deeper and has proved an excellent water-bearing formation wherever it has been encountered. No flows can be obtained on the uplands, to whatever depth drilling may be carried.

Mineral analyses of water in Olmsted County.

[Analyses in parts per million.]

	Alluvium and glacial drift.		St. Peter sandstone.	Jordan sandstone.	Dresbach sandstone.
	1.	2.	3.	4.	5.
Depth ... feet..	32	32	140	150	965
Silica (SiO_2)	13	14	12	9.8	13
Calcium (Ca)	80	77	65	73	79
Magnesium (Mg)	22	15	17	31	18
Sodium and potassium (Na+K)	11	7.6	2.6	15	5.9
Bicarbonate radicle (HCO_3)	352	360	279	368	288
Sulphate radicle (SO_4)	11	15	2.7	22	6
Chlorine (Cl)	9.6	4.7	4	11	5
Total solids	320	290	241	343	290

1. City wells at Rochester. July, 1890.
2. City wells at Rochester. October, 1906.
3. Chicago and Northwestern Railway well at Eyota. May, 1889.
4. Chicago and Northwestern Railway well at Rochester. May, 1889.
5. Rochester well at the Hospital for the Insane at Rochester. October, 1906.

Analyses 1, 2, 3, and 4 were furnished by G. M. Davidson, chemist, Chicago and Northwestern Railway Company. Analysis 5 was made for the United States Geological Survey by H. S. Spaulding.

PIPESTONE COUNTY.

By O. E. Meinzer.

SURFACE FEATURES.

Most of Pipestone County consists of a gently undulating prairie, but near the northeastern corner it is crossed by an irregular morainal ridge that rises above the surrounding plain and reaches an altitude of more than 1,900 feet above sea level. This ridge forms the boundary between the swampy, lake-covered region to the northeast and the better-drained area virtually free of lakes or swamps to the southwest. It also forms the divide between the Mississippi and Missouri basins, giving rise to Redwood and Des Moines rivers on its northeastern flank and to Flandreau Creek and Rock River on its southwestern. Rock River flows southward through a rather wide valley near the eastern margin of the county, and just before it leaves this county it is joined by Chanarambie Creek coming from the east. Flandreau, Pipestone, and Split Rock creeks drain the western half of the county, all flowing southwestward.

SURFACE DEPOSITS.

Description.—The upland surface is in general covered with the bowlder clay and sandy deposits of the glacial drift, but in the valley of Rock River and in some of the smaller valleys are found extensive alluvial deposits, for the most part also of glacial origin. The drift varies greatly in thickness. On the morainal ridge in the northeastern corner it is several hundred feet deep and the underlying formations have seldom if ever been reached in drilling, but in many localities in the central, southern, and western parts it is absent or very thin. A line drawn diagonally from the northwestern to the southeastern corner will roughly form the boundary between the deep and the shallow drift. Plate II shows the thickness of the drift in as much detail as possible.

Yield of water.—In the northeastern part of the county and in other localities in which the drift is deep, it will usually supply plenty of water for all purposes, but where its depth is not great the yield is frequently inadequate. In the areas where it is thinnest the drift furnishes only a small percentage of the water consumed, but the proportion increases with the thickness and is virtually 100 per cent where the drift is as much as 300 feet thick. The drift is so chaotic in its structure that chance must determine whether, in a given locality, with a given thickness of drift, a satisfactory supply can be procured without drilling into rock, but the chances increase with the thickness in a geometric progression.

Head of the water.—The only flowing wells reported in this county are one 19 feet deep, just north of Edgerton, and one 45 feet deep, situated southwest of Pipestone on the farm of Anna M. Kothe, NW. ¼ sec. 22, T. 106 N., R. 46 W. The level to which the water rises varies considerably and is farthest below the surface in the deepest wells on the morainal ridge. Where the quartzite projects above the general level of a region the head of water in the surrounding drift is higher than elsewhere, and many springs occur.

Quality of the water.—All the water from the surface deposits is more or less highly mineralized, the drift water generally being harder and richer in dissolved minerals than the water from the alluvium.

CRETACEOUS SYSTEM.

Throughout most of southwestern Minnesota a series of shales and sandstones of Cretaceous age lies below the drift, and it is not improbable that this series extends into the northern and eastern parts of Pipestone County, but it has probably never been reached in drilling.

SIOUX QUARTZITE.

Description.—Beneath the less indurated deposits lies the Sioux quartzite, or "red rock," which is referred to the Algonkian system.

Although on the whole this rock is remarkably uniform in color, hardness, and composition, consisting essentially of a thoroughly indurated red quartzite of great thickness, yet it is not entirely uniform. Its color ranges through various shades of red, from light pink to dark purple. The hardness also varies greatly, and in a few places strata of incoherent sand are encountered. Neither is the composition altogether uniform, for interbedded with the quartzite there are occasional thin layers of pipestone, of which one outcrops in the famous Indian quarry near the city of Pipestone and others are reported by drillers. The rock is plainly stratified and commonly cross-bedded and ripple marked, has a gentle but varying dip, and is broken up by a system of joints.

The quartzite surface consists for the most part of relatively level plateaus cut by canyons and abruptly terminated by escarpments. The following is a representative list of wells which enter the quartzite, together with the depth to the rock and the distance it was penetrated:

Table of typical wells in the Sioux quartzite of Pipestone County.

[Given on the authority of drillers and other persons.]

Owner and location.	Depth to rock.	Distance drilled in rock.	Total depth of well.
	Feet.	*Feet.*	*Feet.*
C. M. Flagg, NW. ¼ sec. 36, T. 107 N., R. 46 W	30	270	300
W. L. Tallman, SE. ¼ sec. 25, T. 107 N., R. 46 W	60	110	170
M. Ackerman, NE. ¼ sec. 18, T. 107 N., R. 45 W	140	80	220
J. R. Atwood, NW. ¼ sec. 17, T. 107 N., R. 45 W	100	70	170
J. Huemoeller, NW. ¼ sec. 32, T. 107 N., R. 45 W	80	90	170
A. Johnson, SW. ¼ sec. 31, T. 107 N., R. 45 W	30	130	160
W. F. Boock, SW. ¼ sec. 27, T. 106 N., R. 46 W	50	72	122
J. R. Hubbard, S. ½ sec. 8, T. 106 N., R. 46 W	300	0	300
J. Johannsen, SE. ¼ sec. 32, T. 106 N., R. 46 W	42	258	300
W. S. McDonald, NE. ¼ sec. 22, T. 106 N., R. 46 W	102	27	129
I. B. Smith, SE. ¼ sec. 29, T. 106 N., R. 46 W	22	96	118
F. V. Whitehead, SE. ¼ sec. 18, T. 106 N., R. 46 W	80	6	86
Pipestone city well, No. 1	27	173	200
Pipestone city well, No. 2	27	323	350
R. O. Curl, NW. ¼ sec. 19, T. 106 N., R. 45 W	80	80	160
A. McQuaid, NE. ¼ sec. 6, T. 106 N., R. 45 W	30	140	170
F. Buck, NE. ¼ sec. 7, T. 105 N., R. 46 W	70	50	120
L. Erickson, SE. ¼ sec. 22, T. 105 N., R. 46 W	10	200	210
S. Grummer, SW. ¼ sec. 19, T. 105 N., R. 46 W	81	44	125
H. F. Hanson, NW. ¼ sec. 30, T. 105 N., R. 46 W	35	0	35
H. O. Hogsted, SE. ¼ sec. 34, T. 105 N., R. 46 W	17	85	102
A. Mitchell, SW. ¼ sec. 27, T. 105 N., R. 46 W	4	146	150
G. Nelson, NW. ¼ sec. 34, T. 105 N., R. 46 W	20	210	230
Taylor & Burg, SW. ¼ sec. 18, T. 105 N., R. 46 W	97	38	135
J. W. Wehrman, N. ½ sec. 29, T. 105 N., R. 46 W	70	31	101
L. W. Alexander, NW. ¼ sec. 5, T. 105 N., R. 45 W	100(?)	100(?)	200
J. O. Alexander, SW. ¼ sec. 5, T. 105 N., R. 45 W	80(?)	70(?)	150
Myers & Miller, E. ½ sec. 4, T. 105 N., R. 45 W	37	500	537
J. D. Quinn, NW. ¼ sec. 6, T. 105 N., R. 45 W	60	100	160

Yield of water.—Formerly the quartzite was not considered a water-bearing formation, but the great dearth of water in some localities forced the experiment of deep drilling into it. Almost everywhere it was found to yield some water, and it is now depended on as a reliable source of supply. The body of the quartzite is massive and firmly cemented; but the water percolates through the joints or "crevices" by which the rock is broken and also through certain portions in which the pore space is not entirely filled by cementation. Below the ground-water level all open spaces are saturated and will contribute some water to a well brought into communication with them. Although the amount furnished by any single "crevice" or pervious layer is usually small the effect is cumulative, and as drilling is continued the well becomes connected with more and more of these water-bearing elements. The depth to which it is necessary to sink in order to get an adequate supply is to a large extent determined by chance, depending on the course of the well in passing through compact and unbroken rock or in encountering many "crevices" or pervious beds.

Nevertheless, the yield of rock wells is usually very small as compared with that of wells in more porous formations. It is customary for drillers to guarantee only 100 gallons an hour in farm wells, though the actual yield is often much greater. In nearly all wells the supply is found to be permanent and sure. The two city wells at Pipestone, which are 6 and 8 inches in diameter and 200 and 350 feet deep, together deliver 140 gallons a minute for an indefinite period when an air-tight lift is employed. It seems that tolerably large yields can nearly always be procured if the wells are sunk to a sufficient depth.

Head of the water.—The level at which the water stands in the wells depends largely on the topography. It is generally less than 100 feet but commonly more than 50 feet below the surface.

Quality of the water.—The quartzite itself contributes very little mineral matter to the water, and hence where the rain enters it directly the water remains soft. But in most localities the rock is covered by a layer of drift through which the water must first percolate, thereby being rendered more or less highly mineralized. The analyses given in the accompanying table (p. 300) are representative of the quartzite waters of this county.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Pipestone.—The Sioux quartzite is at or near the surface in the eastern part of the city of Pipestone and at no great depth in the western part. To the north it forms a low west-facing ledge, over which Pipestone Creek leaps in a small cataract.

The public supply is derived from two wells in the center of the city, about 20 feet apart. One of these is 200 and the other 350 feet deep. The upper 27 feet consist of clay, below which there is quartzite, the casing extending only to the rock. The water rises to a level 96 feet below the surface or 1,630 feet above the sea. By means of an air lift the wells have been made to yield 127 gallons a minute for ten hours continuously, and this is reported to have lowered the water level about 10 feet. More recently they have been tested at 140 gallons. The water is remarkably clear and, as the analyses show, is only moderately hard. It is used by about 2,300 people, or perhaps 90 per cent of the total population, the average daily consumption amounting to approximately 60,000 gallons. In most of the city the quartzite is so near the surface that no water can be obtained except by expensive drilling, but in the western part, where the distance to rock is greater, there are some shallow bored wells.

Jasper.—The Sioux quartzite, which outcrops in the eastern part of the village of Jasper as a west-facing ledge, gives rise to springs, one of which near the center of the settlement furnishes the public supply. This spring yields somewhat more than 50 gallons a minute and is reported not to be greatly affected by drought. Its water is relatively soft, as is shown by the analysis given in the table (p. 300), and is used by about 200 people, an average of 10,000 gallons being consumed daily. Perhaps two-thirds of the inhabitants depend on private wells. In the western part of the village most of these end in deposits of sand and clay at very shallow depths, the ground-water table being at or near the surface; but in the eastern part there are several rock wells.

Edgerton.—The village of Edgerton is located between Rock River and Chanarambie Creek, on a wide low terrace built of alluvial sand, gravel, and clay, with which the valley is partly filled. The public supply is taken from a well 16 feet in diameter, sunk to a depth of 24 feet in the alluvial deposits. The level at which the water stands in this well varies somewhat with the season. In August, 1907, it stood about 13 feet below the surface; at that time pumping at the rate of 265 gallons a minute for two hours continuously would lower the water to 21 feet below the surface, and the same rate of pumping continued for four hours would empty the well. In dry years the ground-water table is lower and the yield is probably much less. The water is only moderately hard, as is shown by the analysis given in the table (p. 300). The private wells, which supply water for approximately 75 per cent of the people, are dug or bored to a depth of about 15 or 20 feet and end in alluvium. In a part of the village sand and gravel beds are absent and consequently there are no wells. No deep drilling has been done, but there are several abandoned holes between 100 and 200 feet in depth.

Ruthton.—The village of Ruthton is situated near the headwaters of Redwood River, where the altitude is relatively high and the glacial drift is deep. The following is the approximate section of the 6-inch well that supplies the public waterworks:

Well section at Ruthton.

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow clay	25	25
Blue clay	70	95
Sand and gravel	10	105
Blue clay	139	244
Sand	16	260

In this well the water rises to a level about 60 feet below the surface or 1,680 feet above the sea. After it was drilled (in 1905) it was finished with a 16-foot screen and was then pumped at the rate of 35 gallons a minute for ten hours continuously without noticeable effect. The water, which is hard, is utilized very little at present except for fire protection. All the people use water from private wells, most of which are sunk to depths of only 20 or 30 feet and afford small supplies. The creamery and mill are provided with drilled wells about 105 feet deep and there are several other wells of this type.

FARM WATER SUPPLIES.

The farm supplies are drawn from two distinct sources, the deposits of drift and alluvium and the quartzite or "red rock." The wells which terminate in the drift and alluvium are drilled, bored, dug, or driven; those which penetrate the quartzite are of course all of the drilled type and are generally 6 inches in diameter. In the region including Pipestone, Jasper, and Trosky, which was described above as the area of shallow drift, a large proportion of the farms are supplied from rock wells ranging from about 60 to 300 feet in depth. Formerly almost the only source of water consisted of the shallow wells that ended in the drift above the quartzite, but these proved so unreliable that they have to a great extent been abandoned for rock wells. Drilling in quartzite at first presented serious difficulties, but those who have made a specialty of this kind of work have overcome these difficulties to such a degree that failures are now very rare. No one need hesitate to have a well sunk into the rock if he can afford the cost, but it is important to employ an experienced rock driller, as otherwise there is liable to be trouble. Problems involved in drilling in quartzite are discussed under the heading "Problems relating to wells" (pp. 87–88).

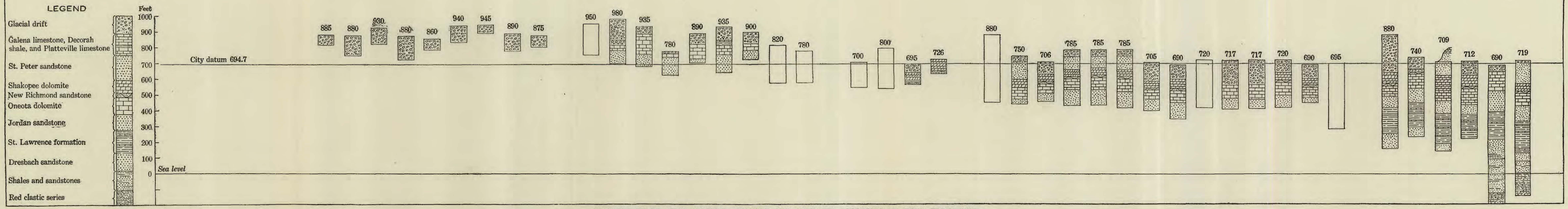
SUMMARY AND ANALYSES.

Pipestone County is divisible into two distinct ground-water provinces—(1) the area of thin drift in which the rock is near the surface and (2) the area of thick drift where the rock is deeply buried. The portions of the county included in each are shown on

PARTS PER MILLION	PUBLIC SUPPLY						GLACIAL DRIFT									
	1	2	3	4	5	AV.	6	7	8	9	10	11	12	13	14	AV.
Silica (SiO_2)	9.	18.	1.5	8.	8.6	9.	20.	17.	2.6	21.	28.	15.	3.	26.	7.	16.
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	1.8	2.1	Tr.	.7	.5	1.	.7	.9	.5	.1	1.	1.4	5.4		3.3	1.7
Calcium (Ca)	48.	56.	36.	37.	40.	44.	55.	59.	47.	61.	9.	66.	81.	57.	63.	55.
Magnesium (Mg)	19.	22.	11.	17.	14.	17.	25.	23.	14.	18.	21.	24.	25.	28.	26.	22.
Sodium and potassium (Na+K)	12.	3.7	5.2	5.5	.6	5.4	6.6	8.	14.	2.2	13.	11.	4.3	16.	7.7	9.2
Bicarbonate radicle (HCO_3)	305.	292.	159.	193.	179.	226.	307.	294.	207.	258.	135.	316.	357.	339.	309.	269.
Sulphate radicle (SO_4)	Tr.	Tr.	Tr.	12.	11.	4.6			6.	14.	8.5	19.	11.	Tr.	20.	11.2
Chlorine (Cl)	Tr.	Tr.	Tr.	3.4	.9	.8	1.3	1.6	3.2	3.4	13.	6.7	6.7	3.5	6.7	5.1
Total solids	224.	244.	140.	180.	164.	191.	260.	254.	234.	248.	329.	300.	308.	306.	288.	280.

PARTS PER MILLION	ST. PETER										NEW RICHMOND				
	15	16	17	18	19	20	21	22	23	AV.	24	25	26	27	AV.
Silica (SiO_2)		14.	22.	6.2	24.	12.	7.4	1.5	7.	12.	10.	11.	17.	2.1	9.7
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	1.5	Tr.	3.	3.4	2.8		5.6	2.4	.2	2.4	.1		6.2		
Calcium (Ca)	57.	44.	53.	66.	60.	61.	46.	59.	63.	56.	61.	37.	72.	69.	58.
Magnesium (Mg)	16.	24.	8.1	30.	31.	26.	27.	24.	12.	22.	22.	16.	31.	28.	23.
Sodium and potassium (Na+K)	3.3	18.	21.	2.5	4.8	2.	5.	1.5	19.	8.6	.6	17.	5.9	9.4	7.9
Bicarbonate radicle (HCO_3)	255.	291.	200.	362.	345.	315.	282.	300.	289.	293.	298.	310.	350.	355.	328.
Sulphate radicle (SO_4)	Tr.	Tr.	3.6	Tr.	Tr.	2.	4.	6.	Tr.	1.8		10.	26.	14.	
Chlorine (Cl)	4.1	7.3	32.	Tr.	3.5	3.	Tr.	Tr.	7.3	6.4	1.1	9.1	1.8		
Total solids	232.	250.	242.	346.	242.	258.	237.	244.	252.	254.	242.	204.	332.	297.	261.

PARTS PER MILLION	JORDAN															DRESBACH, ETC.						
	28	29	30	31	32	33	34	35	36	37	38	39	40	41	AV.	42	43	44	45	46	47	AV.
Silica (SiO_2)	21.	8.4	9.	2.6	1.5	5.6	3.6		1.4	4.	8.	9.5			6.3	15.	1.5	16.		6.	2.	8.1
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	2.9	17.						2.4	2.3				3.7			1.7	2.1	2.3		3.		2.2
Calcium (Ca)	57.	60.	54.	57.	50.	54.	56.	72.	64.	47.	51.	53.	79.	52.	58.	58.	56.	49.	55.	40.	52.	52.
Magnesium (Mg)	24.	37.	20.	22.	21.	23.	21.	18.	15.	20.	18.	22.	25.	20.	22.	22.	22.	13.	22.	25.	17.	20.
Sodium and potassium (Na+K)	6.7		6.8	2.2	8.6	21.	9.1		.8	16.	9.6	5.5		8.2	6.8	8.	7.	12.	7.4	14.	12.	10.
Bicarbonate radicle (HCO_3)	308.	372.	273.	277.	260.	217.	291.	312.	270.	263.	256.	275.	367.	272.	278.	306.	302.	235.	276.	130.	262.	252.
Sulphate radicle (SO_4)				7.	7.8	11.			2.4	.4	8.5	6.		5.1	6.		Tr.	2.1		7.2	7.	4.1
Chlorine (Cl)	1.3		6.	3.4	6.7	14.	6.7		.5	12.	Tr.	3.4		1.	5.	1.3	3.5	3.5	11.	11.	1.3	5.3
Total solids	264.	301.	230.	242.	240.	277.	240.	247.	228.	236.	226.	240.	247.	222.	246.	257.	240.	228.	231.	238.	220.	236.



ANALYSES OF ST. PAUL WATERS ARRANGED AND AVERAGED ACCORDING TO ROCK FORMATIONS.

By C. W. Hall.

1. Public supply taken at state capitol. 1889. Dearborn laboratory.
2. Public supply taken at office of St. Paul Dispatch. October, 1898. Dearborn laboratory.
3. Public supply taken at Oakland Cemetery. December, 1899. Dearborn laboratory.
4. Public supply taken at City and County Hospital. June, 1900. Dearborn laboratory.
5. Public supply analyzed April, 1901, by G. M. Davidson, chemist, Chicago, St. Paul, Minneapolis and Omaha Railway Company.
6. Artesian well at Centerville. September, 1899.
7. Artesian well at Vadnais. September, 1899.
8. White Bear Elevator Company well at White Bear. March, 1896. Dearborn laboratory.
9. Lutheran Seminary well. December, 1895. Dearborn laboratory.
10. Minnesota Harvester Company well.
11. Ramsey County almshouse well. January, 1898. Dearborn laboratory.
12. McAllister College well. December, 1895. Dearborn laboratory.
13. St. Anthony Furniture Company well. September, 1896. Dearborn laboratory.
14. St. Paul Foundry Company well. June, 1898. Dearborn laboratory.
15. Waterworks well at North St. Paul. October, 1893.
16. Experimental station well.
17. Reform School well. July, 1885. Hewitt, analyst.
18. Union Manufacturing Company well. June, 1903. Dearborn laboratory.
19. St. Anthony Furniture Company well. August, 1903. Dearborn laboratory.
20. Northern Pacific Railway well. January, 1905. Professor Sidener, chemist.
21. Minnesota Transfer, Archer & Co. well. September, 1898. Dearborn laboratory.
22. St. Paul Furniture Company well. April, 1900. Dearborn laboratory.
23. Portland Apartments well. June, 1896. Dearborn laboratory.
24. Villaume Brothers well. December, 1895. Dearborn laboratory.
25. Buckingham Apartments well. February, 1896. Dearborn laboratory.
26. McMillan Packing Company well. May, 1906. Dearborn laboratory.
27. Chicago, Rock Island and Pacific Railway well.
28. Centerville well.
29. Golden Rule well.
30. Horn & Danz well. February, 1897. Dearborn laboratory.
31. Ernst Building well. January, 1904. W. A. Converse, chemist.
32. Barney Block well. April, 1899. Dearborn laboratory.
33. Germania Bank Building well. January, 1896. Dearborn laboratory.
34. White Lead Oil Company well.
35. Towle Syrup Company well at West St. Paul. February, 1905. N. Lehner, analyst.
36. Foley Brothers & Kelly well. January, 1905. Minnesota State Board of Health.
37, 38. Lindeke Roller Mills well.
39. American Hoist Derrick Company well. June, 1900. Dearborn laboratory.
40. Well near Towle syrup factory at West St. Paul. February, 1905. Minnesota State Board of Health.
41. Chicago, Milwaukee and St. Paul Railway well. November, 1891.
42. Vadnais well.
43. Pioneer Press Building well. October, 1899. Dearborn laboratory.
44. Gas Light Company well.
45. Chicago Great Western Railway well.
46. Swift & Co. well at South St. Paul.
47. Mendota well.

Plates II and III. Jasper, Trosky, Ihlen, Pipestone, and Altona lie in the first area; Ruthton, Holland, Woodstock, and Edgerton are in the second. In the former it is often necessary to drill into rock, which, if penetrated to a depth of several hundred feet, will usually afford enough water not only for farm purposes, but also for ordinary industrial and public supplies. In the second area large and permanent stores of water are usually contained in the sand and gravel seams of the drift and in the alluvial deposits of the Rock River valley. The composition varies, but the water from the quartzite, as well as that from the alluvium, is on an average softer than the glacial drift water. In neither area are flowing wells to be expected.

Mineral analyses of water in Pipestone County.

[Analyses in parts per million.]

	Surface deposits (glacial drift, etc.).		Sioux quartzite.				
	1.	2.	3.	4.	5.	6.	7.
Depth .... feet..	24	42	......	210	230 (?)	{200 350}	367
Diameter of well .... inches..	192	......	......	6	......	6 and 8	6
Silica (SiO_2)	25	......	16	19	......	17	10
Iron (Fe)	.2	......	.0	2.5	......	.12	......
Aluminum (Al)	......	......	......	10	......	3.2	......
Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	4	5	4.2	......	3	......	1.2
Calcium (Ca)	124	97	48	160	85	72	104
Magnesium (Mg)	21	30	19	68	41	28	49
Sodium and potassium (Na+K)	15	11	16	33	20	38	110
Carbonate radicle (CO_3)	.0	......	.0	.0	......	.0	......
Bicarbonate radicle (HCO_3)	346	444	261	620	351	317	372
Sulphate radicle (SO_4)	67	23	16	41	89	59	368
Chlorine (Cl)	35	.6	11	98	31	36	8
Nitrate radicle (NO_3)	35	......	3.6	80	......	4	......
Total solids	504	385	269	845	442	425	833

1. Village well at Edgerton. August 1, 1907.
2. Railway well at Hatfield. October 15, 1888.
3. Spring which furnishes the public supply at Jasper. August 6, 1907.
4. Well near Jasper, on the farm of L. Erickson, SE. ¼ sec. 22, T. 105 N., R. 46 W. August 6, 1907.
5. "City well" at Pipestone. June 24, 1889.
6. Mixture of water from the two city wells at Pipestone. August 2, 1907.
7. Well at Pipestone. October 25, 1901.

Analyses 1, 3, 4, and 6 were made for the United States Geological Survey by H. A. Whittaker, chemist, Minnesota state board of health. Analyses 2 and 5 were furnished by G. N. Prentiss, chemist, Chicago, Milwaukee and St. Paul Railway Company. Analysis 7 was furnished by G. M. Davidson, chemist, Chicago, St. Paul, Minneapolis and Omaha Railway Company.

RAMSEY COUNTY.

By C. W. Hall.

SURFACE FEATURES.

The southern two-thirds of the surface of Ramsey County is covered with rough moraines, among which lie many lakes. In the northern third the surface is flat or undulating, but poorly drained, broad swampy tracts and numerous lakes occupying the shallow depressions. There is little variation in the altitude of the upland surface. The highest points are in the morainal hills along the eastern border and at points in the southwestern part of the county, the altitudes here being somewhat more than 1,000 feet above sea level. The Mississippi flows in a deep channel, the width varying from a few hundred yards above Fort Snelling to a mile or more below that point and to several miles below St. Paul. The river is bordered by a terrace cut into the rock at a height of 100 feet or more above the water. This terrace is nearly continuous across the south edge of the county, but varies in width from a mile or more near the mouth of the Minnesota and near St. Paul to about one-eighth of a mile at the southeastern corner of the county. The tributary streams are numerous, but generally meander over the undulating surface in indefinite valleys, except near the Mississippi, where they have cut somewhat deeper channels.

SURFACE DEPOSITS.

Alluvium occurs chiefly along the Mississippi Valley below St. Paul, but some of it borders the river as far as the mouth of the Minnesota, and small amounts occur along the smaller streams. Its greatest thickness is not known, but is probably 50 to 100 feet or more. It is saturated with water and will afford moderate supplies, but not enough for industrial purposes.

Terrace gravels occur along the Mississippi at various levels, but are most prominent on the 100-foot terrace described above. Near the river the water has generally been drained from them, but back from the stream considerable supplies may be obtained.

The glacial drift varies from indistinctly laminated clay to a heterogeneous mixture of clay, sand, and gravel. Beneath the clay, incorporated between successive beds of it, or spread over the surface, are many thick layers of sand and gravel. The clay generally has a reddish tinge, due to material brought in by the Lake Superior lobe of the last glacial invasion. The total thickness of the drift is considerable, in many localities being more than 100 feet. The sandy parts and interbedded gravel beds are saturated with water, which is given up freely to wells penetrating them.

One of the features of special geologic interest, as well as of importance with regard to underground water, is the buried preglacial stream valley entering St. Paul from the northeast and joining the Mississippi. To the north it has been penetrated at Lake Vadnais, where a well was sunk 230 feet before striking rock, though the rock on either side occurs at only about half this depth. Similar relations exist in St. Paul, well records on either side showing the surface rock to be Galena limestone, whereas within the channel the first rock penetrated is the Shakopee dolomite or the Oneota dolomite, which is stratigraphically about 200 feet lower. The well of the St. Paul Harvester Works, near Phalen Creek, a short distance south of the outlet of Lake Phalen, found 235 feet of drift in the channel, this depth of drift being about 150 feet greater than the average at either side. The channel bottom is at least 100 feet below the present level of the Mississippi and represents the bed of an old stream entering the Mississippi when the latter flowed at a much lower level than at present.

PALEOZOIC FORMATIONS.

The Galena, Decorah, and Platteville formations are here represented by a blue limy shale, with alternating thin limestone layers, having a maximum thickness, according to the record of the well at the reform school, of at least 132 feet. The beds are seen in the south bluffs of the Mississippi, between Mendota and St. Paul, and they underlie the high residence district known as St. Anthony Hill. The lower beds are calcareous and partly crystalline and are economically important as a source of building stone. The jointed condition gives rise, along the transition bed, to springs which otherwise would issue much higher. The beds, as a whole, however, are not to be regarded as a source of water supply.

The St. Peter sandstone is about 150 feet thick, and about 40 feet above the bottom has a shale parting. It outcrops along the bluffs of the Mississippi and underlies the formations previously described throughout the county. Near the northeastern and northwestern corners it probably lies immediately below the glacial drift. It contains abundant supplies of water. Even near the river water is obtained, often under considerable pressure, from the bed beneath the shale parting, this portion not being drained, because it lies below the river level, except in the southern part of the county. In the city of St. Paul, however, where the wells are close together, they interfere, to a certain extent, with one another, and the supplies are correspondingly reduced.

The Shakopee dolomite lies deep below the general surface of the county and forms the rock walls at the bottom of the Mississippi gorge from the neighborhood of the St. Paul levee to the south limit of the county. It carries relatively little water and is not to be regarded as a source of supply.

The New Richmond sandstone is only a few feet thick and is not continuous. Where present it contains a moderate supply of water, though much less than the thicker sandstones.

The Oneota dolomite has a considerable thickness, but, like the Shakopee, it carries relatively small amounts of water.

The Jordan sandstone is between 70 and 125 feet in thickness. Although merging into shale at the base, it is an excellent water-bearing formation and yields large supplies to a considerable number of wells in St. Paul and the vicinity. Where wells are crowded together, however, as they are in this county, the supply is considerably depleted and the head of the water noticeably lowered.

The St. Lawrence formation consists of blue limestone, alternating with blue or green shales and a few sandstone layers, and has a total thickness of 150 to 200 feet. Some water is present, especially in its sandy layers, but the amounts are small in comparison with those yielded by sandstones above and below.

The Dresbach sandstone and underlying shales aggregate several hundred feet in thickness. The sandstone carries rather large amounts of water and is the source of supply in a number of deep wells. In general, the amounts to be obtained are no larger than in the Jordan, but where the Jordan has been depleted by the multiplication of wells the Dresbach constitutes an important supplementary source.

The red clastic series of shale and sandstone comprises the lowest rocks entered in Ramsey County. It has considerable thickness, but the amount of water which it yields is too small to be of economic value.

UNDERGROUND WATER CONDITIONS.

Head of the water.—The northern part of Ramsey County abounds in lakes, which lie between 880 and 930 feet above sea level and mark the surficial ground-water table of the drift deposits. The deeper wells show a lower head than those ending in the glacial drift. Nevertheless, in the lower part of the city of St. Paul and along the entire stretch of the valley of the Mississippi bordering this county, the surface is so much below the upland level that flowing wells are obtained. Within the city of St. Paul the boundary of the flowing area extends into the business district as far as Seventh street, between Minnesota street and the border of Daytons Bluff, and corresponds roughly to the 740-foot contour. The head was at one time higher than this and is probably steadily falling, so that the statement of altitude is merely an approximation. In the northern part of the county the water from deep sources will rise somewhat higher above sea level than in the valley of the Mississippi, and though it will not come to the surface the pressure is everywhere adequate to bring it to a height sufficient for economic uses.

Quality of the water.—In Plate XIV will be found a large number of analyses of waters from all the principal zones. It will be noted that the waters from the glacial drift and from the St. Peter, Jordan, and Dresbach sandstones do not differ greatly from one another. Each group is moderately mineralized, the principal dissolved constituents being the calcium, magnesium, and bicarbonates, which produce a rather soft scale in boilers, but render the water hard. These constituents can be removed in large part by heating, so that the water is left softer and better for boiler use. An important fact developed by the assembling of the analyses is that the water beneath St. Paul is somewhat softer than that from the same formations beneath Minneapolis. (Compare Pls. X and XIV.)

ST. PAUL PUBLIC SUPPLY.

The public supply for the city of St. Paul is obtained from several sources. Most of it is derived from glacial lakes north of the city, but a part comes from wells at Lake Vadnais and Centerville Lake.

At Lake Vadnais there are 12 wells. The following is the log of one of the deepest, which is 10 inches in diameter and was sunk in 1904:

Section of deep well at Lake Vadnais.

[Authority, Twenty-third Rept. Board of Water Commissioners, St. Paul, 1905.]

	Thickness.	Depth.
	Feet.	*Feet.*
Clay and sand	20	20
Sand	210	230
Limestone	67	297
Hard sandstone	27	324
Hard limestone	27	351
Fine white sandstone	83	434
Very fine white sandstone	186	620
Coarse white sandstone	39	659

When this station was first installed it had a capacity of 5,000,000 gallons, the wells all being connected and working together, but a test made in 1904 showed the total capacity at that time to be only 3,516,000 gallons, a decrease of about 63 per cent for the deep wells and of about 37 per cent for the shallow wells.

The Centerville group consists of 10 deep wells 12 inches in diameter and 302 to 523 feet in depth, all of which enter the Jordan sandstone, and 18 shallow wells 8 inches in diameter and 51 to 76 feet, averaging 62½ feet deep. In the report on Anoka County the section of one of the deep wells is given (p. 130.)

In 1907 the average daily consumption of public water was 10,781,044 gallons.

SUMMARY.

The four principal water zones are (1) the glacial drift, (2) the St. Peter sandstone, (3) the Jordan sandstone, and (4) the Dresbach and basal Cambrian sandstones. Their stratigraphic position and depth beneath the surface, as well as the mineral character of the water from each, are shown in Plate XIV. The water from the deeper sandstones is under sufficient pressure to rise considerably above the level of Mississippi River.

REDWOOD COUNTY.

By O. E. Meinzer.

SURFACE FEATURES.

Most of Redwood County consists of a flat plain that rises imperceptibly southwestward. This plain is intermediate in altitude between the valley of Minnesota River on the northeast and the Coteau des Prairies on the southwest. With reference to the valley, which is 150 to 200 feet deep, it constitutes a plateau, but in relation to the coteau, which lies 500 feet higher, it is a lowland tract. The ascent to the coteau begins in the southwestern extremity of the county, where the upward grade is greatly augmented.

Redwood and Cottonwood rivers flow eastward across the county, occupying rather shallow valleys until as they approach the Minnesota, into which they discharge, they descend into deep and picturesque gorges. This is especially true of Redwood River, which cascades over a granite ledge at Redwood Falls. Until the principal streams have cut their valleys down to accord with the Minnesota most of the county will have insufficient relief for an adequate drainage. Near the southwestern corner, however, where the descent from the coteau is relatively steep, many ravines have been cut, some of which extend down to the ground-water level and have permanent streams fed by springs. This is why nearly all the affluents of Cottonwood River come from the south.

SURFACE DEPOSITS.

Description.—The surface deposits consist of glacial drift and recent alluvium. The drift occurs everywhere except in small areas in the Minnesota Valley, in the valley of Redwood River below the falls, and in some of the western townships where older formations are exposed. Over most of the eastern, central, and southwestern parts of the county it is between 100 and 200 feet thick and locally it reaches a still greater thickness. In the northwestern part it is generally thinner, being less than 50 feet thick throughout a large portion of the following six townships: Vail (T. 111 N., R. 37 W.), Granite Rock (T. 111 N., R. 38 W.), Westline (T. 111 N., R. 39 W.), Sheridan (T. 112 N., R. 37 W.), Vesta (T. 112 N., R. 38 W.), and Underwood (T. 112 N., R. 39 W.).

Yield of water.—Where the drift has considerable thickness it generally includes deposits of sand and gravel that will produce water supplies adequate for all ordinary purposes, but where it is less than 100 feet thick it may not contain a reliable water-bearing bed. In the northwestern part of the county, especially in the townships mentioned above, the drift is not an entirely satisfactory source of supply, although in a large portion of these townships it is the only available source.

Head of the water.—The water from the glacial drift is generally under considerable pressure but is not known to rise above the surface. The flowing wells in the southwest are supposed to be supplied from the Cretaceous rocks, but no record could be obtained of most of them, and it is possible that some end in the drift. Many springs issue from the sides of the Minnesota Valley, and these have lowered the head of the water beneath the adjacent uplands.

Quality of the water.—The analyses given in the accompanying table (p. 313) reveal a wide range in the mineral composition of the water. The Walnut Grove analysis (No. 5) represents a very poor variety of water that is not uncommon in the drift of the region; the Redwood Falls analyses (Nos. 1 and 2) are perhaps more typical of the average water from this source.

CRETACEOUS SYSTEM.

Description.—Throughout most of this county Cretaceous strata lie beneath the drift. In the southwest they have a thickness of several hundred feet, but they thin out toward the east and north. They occur everywhere in the southern tier of townships and almost everywhere in the tier next north. They are also found adjacent to Lyon County nearly or quite to the north boundary but are absent in the vicinity of Vesta and Seaforth and in much of the northwestern part of the county. Small and irregularly distributed areas containing thin deposits of this age are concealed below the drift in the northeastern part, but the accurate mapping of these patches can not be accomplished until many more well sections are available than at present.

The following specific data bear on the occurrence of the Cretaceous in this county: (1) At Tracy, 1 mile west of the county line, a series of Cretaceous shales and sandstones about 450 feet thick has been penetrated. (2) At Walnut Grove there is a considerable thickness of the same series but no definite section is available. (3) Near Pell Creek, along the road from Revere to Lamberton, Cretaceous clay and sandstone come to the surface, and in the SE. ¼ sec. 11, T. 109 N., R. 38 W., shale was struck at a depth of 110 feet. (4) At Lamberton an 80-foot stratum of shale was reached at a little more than 200 feet below the surface. (5) In Sanborn a sandstone and shale series was entered at a depth of 217 feet and was penetrated for 53 feet. (6) A few miles east of Sanborn, along Cottonwood River, Cretaceous outcrops are found. (It seems probable that the deposits of Cretaceous clay, sandstone, etc., exposed in the outcrops lie above the thicker shale beds encountered in drilling and are not generally differentiated from the drift in well sections.) (7) Near Cottonwood River, south of Milroy, a number of deep wells have been sunk and shale and sandstone about 400 feet in thickness have been penetrated by the drill. (8) In the village of Milroy shale is encountered at a depth of only 35 feet, and it seems to have been penetrated for about 230 feet. (9) In the southwestern corner of Underwood Township (T. 112 N., R. 39 W.), a 75-foot stratum of blue shale, underlain by white sand, was reached 45 feet below the surface. (10) One mile west of Lucan, on the farm of Patrick Curtin, NE. ¼ sec. 20, T. 111 N., R. 38 W., shale was found at a depth of 70 feet. (11) At Clements the same material was struck at 115 feet and was penetrated only a short distance. (12) In the valley of Redwood River below the falls and in the Minnesota Valley between Redwood Falls and Morton outcrops of thin Cretaceous strata are found.[a] (13) In the northern part of the county shale has been encountered in drilling.

There are two phases of the Cretaceous in this region. One phase, which consists of rapidly alternating and imperfectly assorted strata of clay, sand, sandstone, etc., indicates by the rude stratification the cross-bedding of the sandstone, the red oxidized character of much of the clay, the lignite beds, the fossil leaves, and other features that the conditions of deposition were nonmarine or littoral. The other phase consists for the most part of a thoroughly assorted series of soft shale and sandstone, the shale greatly predominating and having a characteristic gray-blue color. It attains a maximum thickness in this State of at least 500 feet, and was evidently laid down in a large and quiet body of water, where thorough assortment and stratification were possible. It is to be correlated with the Cretaceous in South Dakota and other Western States. These two phases are described in the reports on Brown and Lyon counties where they are respectively best developed. Their exact relation to each other has not been determined. The series in the western and southern parts of Redwood County belongs to the Lyon County phase, and the rocks in the northeastern part belong with those in Brown County.

Yield of water.—Where the Cretaceous is several hundred feet thick it will yield moderately large quantities of water, as is illustrated by the 6-inch city well at Tracy, which is pumped at the rate of 50 gallons a minute, and by the 6-inch village well at Walnut Grove, which is pumped at the rate of 35 gallons a minute. In general it may be said that in the vicinity of Milroy and thence southward and southeastward to Walnut Grove and Revere the Cretaceous can be depended on for adequate supplies, but that northeast of Lamberton and Lucan it is generally absent or devoid of any good water-bearing stratum, though in a few localities it will furnish some water.

Head of the water.—The Cretaceous area of flowing wells, the extent of which is shown in Plate IV, projects from Lyon County into the southwestern part of this county. The southwestern margin of the area enters the county about 4 miles north of the southern boundary and thence passes to Walnut Grove and approximately to the Cottonwood county line. It enters the county between the 1,200-foot and 1,300-foot contours and gradually descends until it

[a] Upham, Warren, Final Rept. Geol. and Nat. Hist. Survey Minnesota, vol. 1, 1882, pp. 570, 572, and 578.

nearly coincides with the latter. The northeastern margin enters the county about 3 miles north of Cottonwood River and for some distance runs roughly parallel to that stream but eventually crosses it and passes southward to Revere, where there are several flowing wells. The northeastern margin is determined to a great degree by the thinning out of the Cretaceous and the consequent failure of the deep artesian beds; this condition is more fully discussed in the report on Lyon County. However, throughout the flowing area the head is not great and the natural flow never exceeds a few gallons a minute. Moreover, immediately outside of this area there are wells in which the water rises nearly to the surface. Thus in the Cretaceous wells at Walnut Grove it fails only by a few feet to reach the top, and in the similar wells at Milroy it comes within 15 to 20 feet of the top.

Quality of the water.—The Cretaceous contains both hard and soft water zones. At Milroy soft water is reported at a depth of about 100 feet and hard water at about 260 feet. South of that village a number of wells 300 to 500 feet deep yield hard water, and in the vicinity of Walnut Grove and Revere the principal zones to a depth of at least 300 feet supply soft water. (See the analyses given in the accompanying table.) The Sanborn analyses may represent a mixture of drift and Cretaceous waters.

SIOUX QUARTZITE.

The Sioux quartzite, which attains a relatively great thickness farther south, projects into the southern part of Redwood County in the form of a wedge between the Cretaceous and the granite. At Lamberton it is reported to have a thickness of several hundred feet. It is probably of no economic value in this county as a source of water.

ARCHEAN ROCKS.

ARCHEAN PROPER.

The Archean consists of granite and gneiss, which constitute the basal rocks. Throughout the northern and eastern parts of the County it is everywhere relatively near the surface. In the vicinity of Seaforth three outcrops are known, and there are several others in Yellow Medicine County, within a mile or two of the boundary line; it is frequently encountered in drilling in this region. Moreover, in the Minnesota Valley and in the Redwood Valley both above and below the falls it is exposed. In the southern part of the county, however, the granitic surface descends and within a short distance is many hundreds of feet below the surface. Thus at Tracy, Lyon County, it occurs at a depth of a little more than 600 feet, or not quite 800 feet above sea level, and at Lamberton it was reported about 600 feet below the surface, or only 550 feet above the sea.

Farther south it lies at so great a depth that it is very seldom reached by the drill. At Blue Earth, Faribault County, and at Sioux City, Iowa, it was struck at a level 135 feet below the sea,[a] and at Lemars, Iowa, at 215 feet above the sea.[a]

The upper part is generally much altered and passes gradually into the unchanged granite. This decomposed mantle is best exposed in the gorge of Redwood River below the falls, where it has been described by Prof. N. H. Winchell,[b] but the same kind of material is encountered in many of the wells of the region. Drillers do not always differentiate clearly between the Cretaceous beds and the rotted granite, though it is of great practical importance that the distinction be made. Brilliant colors (red, yellow, green, white, etc.), flakes of mica or steatite, which give the drillings a silvery appearance not possessed by the Cretaceous shale ("soapstone"), transparent and angular grains of quartz, which give a gritty character never found in the shale, and hard quartzose ("glassy") layers alternating with soft material, all indicate that the granitic residuum has been reached.

WHITE CLAY.

Material from an outcrop near Morton, in Renville County, is described as follows by N. H. Winchell:[c]

A substance was met here for the first time which was afterward seen at a number of places. Its origin seems to be dependent upon the granite. Its association is so close that it seems to be the result of a change in the granite itself. It lies first under the drift, or under the Cretaceous rocks, where they overlie the granite, and passes by slow changes into the granite. It has some of the characters of steatite and some of those of kaolin. In some places it seems to be a true kaolin. It is known by the people as "Castile soap." It cuts like soap, has a blue color when fresh or kept wet, but a faded and yellowish ash color when weathered, and when long and perfectly weathered is white and glistening. The boys cut it into the shapes of pipes and various toys. It appears like the pipestone, though less heavy and less hard, and has a very different color. It is said to harden by heating. This substance, which may, at least provisionally, be denominated a kaolin, seems to be the result of the action of water on the underlying granite. Since it prevails in the Cretaceous areas, and is always present, so far as known, whenever the Cretaceous deposits have preserved it from disruption by the glacier period, it may be attributed to the action of the Cretaceous ocean. In some places it is gritty, and in others it may be completely pulverized in the fingers. A great abundance of this material exists in the banks of the Birch Coolie, within a short distance of its mouth.

Since the above statements were made, this clay, which is commonly whiter and less ferruginous than the sample described, has been found in scores of deep wells, and thus much additional evidence has been obtained as to its distribution and character. All this new evidence, however, corroborates Winchell's statements that it overlies the granite, into which it passes by slow changes, and that it prevails

[a] Norton, W. H., Geol. Survey Iowa, vol. 6, 1896, pp. 227–229, 232, 233, and 235.
[b] Final Rept. Geol. and Nat. Hist. Survey Minnesota, vol. 1, 1882, p. 571.
[c] Second Ann. Rept. Geol. and Nat. Hist. Survey Minnesota, 1873, p. 163.

in the Cretaceous areas and is generally present wherever the Cretaceous deposits have preserved it. A conception of its wide distribution can be gained by referring to the reports of the counties in which the Archean lies beneath the Cretaceous. In this county it is exposed in the valleys of Minnesota and Redwood rivers and has frequently been reached in drilling, especially in the vicinity of Vesta and Seaforth, where it is near the surface.

In the gorge of Redwood River decomposed granite occurs which has a matrix of white clay very similar to the white clay under discussion, except that it is less compact. In this matrix are imbedded the angular, transparent grains of quartz which existed in the mother rock. It is the thoroughly weathered and leached granitic residuum left in its original position. On the south side of the wagon road from Redwood Falls to Morton, where the descent is made from the upland into the valley, there is a typical exposure of the white clay. It is here evidently of sedimentary origin, as it is free from quartz grains and lies above a stratified layer of grit. The outcrop appears nearly white. Two samples, one from each of the above-described exposures, were analyzed for the United States Geological Survey by Prof. F. F. Grout, of the University of Minnesota, with the results shown below. In preparing sample 1 the white matrix was washed out from the quartz grains, so that the latter do not enter into the analysis. No. 3, which gives the composition of kaolin, is inserted for comparison.

Composition of granitic residuum, white clay, and kaolin.

	1. Granitic residuum.	2. White clay.	3. Kaolin.
Silica (SiO_2)	45.92	43.86	46.5
Alumina (Al_2O_3) [a]	39.84	41.82	39.5
H_2O on ignition	14.12	14.65	14.0
	99.88	100.33	100.0

[a] With the alumina of No. 1 is associated a trace of iron, and with that of No. 2 a little iron and about 0.3 per cent of titanium oxide (TiO_2).

The analyses show that the composition of the white clay is similar to that of the granitic residuum, and that both are similar to kaolin. It will be seen, however, that the white clay and, to a less extent, the residuum are a little higher in alumina and a little lower in silica than kaolin, as a result, according to Professor Grout, of the presence of small amounts of beauxite. The white color is due to the fact that the iron has nearly all been leached out.

Well sections and outcrops show that in some places the white clay contains imbedded grains of quartz and is clearly residual, as in the exposure in the Redwood gorge; that in others it is entirely free from grit but includes interbedded strata of sand, as in the Tracy well, the exposure near Morton, etc.; and that in still others quartz grains are present in the lower part and absent in the upper, as in many wells in Renville County. In brief, the white clay consists in part of granitic residuum, and in part of sedimentary deposits derived therefrom.[a] Essentially this conclusion has been reached by Warren Upham and others.[b]

It is important that drillers should distinguish this clay both from the ordinary Cretaceous shale and from the ordinary decomposed granite, because its significance as to water supplies is somewhat different from that of either. It does not usually yield water, but the interbedded layers of grit, where they occur, may furnish adequate supplies. A number of good wells draw from this source, but there are also many instances on record where drilling into the clay has resulted in failure. The white clay is always a warning that the drill is approaching granite.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Redwood Falls.—The city of Redwood Falls is located at the point where Redwood River cascades over the granite ledges into a steep and rugged gorge. The granite is everywhere relatively near the surface. The public supply is derived from two springs about 1 mile south of the city, on the east bank of the river. They issue from a bed of gravel immediately above the granite, and in dry years their yield is not great. The water is hard and will form scale in boilers, as the analysis in the table shows (p. 313). Approximately 1,000 people are supplied, and the average daily consumption amounts to about 30,000 gallons. The railway company takes water from a shallow well and also uses the public supply, and at the mill water from the river is used. The private wells are shallow and unsatisfactory.

Lamberton.—The following is the approximate section for the locality of Lamberton as revealed in the deep drilling done for the village.

Well section at Lamberton.[a]

	Thickness.	Depth.
	Feet	*Feet.*
Yellow clay Sand (thin)	35	35
Blue clay	135	170
Quicksand	3	173
Blue clay	50±	223±
White material (Cretaceous)	2	225±
Blue shale (Cretaceous)	80	305±
Red quartzite (Algonkian)	300±	605±
Granite (Archean).		

[a] The information was derived from several sources, and there is some question as to the correctness of the lower portion of the section.

The public supply is derived from an 8-inch well, which draws its water through an open end from a gravel bed 19 inches thick 64 feet below the surface. The water rises to a level 30 feet below the

[a] The decomposition of an igneous rock which contains no quartz might produce a white clay free from grit, but this can not be the entire explanation in southwestern Minnesota.

[b] Upham, Warren, The glacial Lake Agassiz: Mon. U. S. Geol. Survey, vol. 25, 1895, pp. 88-90. Also Hall, C. M., and Willard, D. E., Casselton-Fargo folio (No. 117), Geol. Atlas U. S., U. S. Geol. Survey, 1905, p. 2.

surface. When the well was completed (1901) it was tested for thirty-six hours continuously at the rate of 60 gallons a minute, and at present it is pumped at about 35 gallons a minute. The water is hard. Approximately 10,000 gallons is consumed daily. Private wells, which furnish the supply for most of the inhabitants, have an average depth of about 40 feet and their yield is closely dependent on the amount of precipitation.

Walnut Grove.—The public supply for the village of Walnut Grove is obtained from a 6-inch well 312 feet deep, in which the water rises within 12 feet of the surface, or 1,216 feet above sea level. The well was tested at the rate of 37 gallons a minute for eight hours continuously. The water is soft but rich in sodium and potassium. Approximately 3,000 gallons is consumed daily, and about 300 people, nearly three-fourths of the total population, are supplied. The railway company uses a soft-water well which is a few feet deeper than the village well. Three analyses of deep water will be found in the table.

Sanborn.—The following section is reported from Sanborn village:

Well section at Sanborn.

[Authority, C. S. Hall, resident engineer Chicago and Northwestern Railway Company, Sanborn.]

	Thickness.	Depth.
	Feet.	*Feet.*
Blue clay, etc	217	217
Sandstone (Cretaceous)	13	230
Hard shale (Cretaceous)	20	250
Sandstone (Cretaceous)	20	270

FARM WATER SUPPLIES.

Drilled wells are most numerous in the flowing area and adjacent parts, that is, in the southwestern portion of the county, where the Cretaceous is a sure source of supply. They have an advantage over the shallower-bored wells in that they can be sunk to beds which in most of this area will yield flows of soft water. Flowing wells, those that end in sandstone and those that are 4 inches or more in diameter, are generally finished with open ends, but others must be provided with screens to keep out the sand. Where the water is truly soft the screens will give no trouble, but where it is hard they become incrusted in a few years by the precipitation of calcium carbonate and other mineral matter.

In the area northeast of a line drawn through Lamberton and Lucan (including by far the greater part of Redwood County) bored and dug wells greatly predominate. As the depth to the impervious formations in this area averages probably not more than 200 feet and is locally much less, it is necessary to procure water relatively near the surface; and as larger supplies can be developed from weak zones by means of bored or dug wells than by means of the ordinary drilled wells there is reason for preferring the former type.

SUMMARY AND ANALYSES.

In the area which lies southwest of a line drawn through Revere and Milroy wells yielding moderate supplies can be obtained at depths ranging from 100 to 500 feet. In a large part of this region the water will flow and much of it is soft (Pl. IV).

In the remaining portion of the county supplies can for the most part be procured only in the upper 200 or 300 feet, no flows are to be expected, and the water is usually hard. Every effort should here be made to finish wells in the deposits of sand and gravel interbedded with the yellow and blue bowlder clays near the surface. Any one of the following kinds of material may be found immediately below the bowlder clay: (1) Blue shale or "soapstone," (2) white clay, (3) decomposed granite, or (4) unaltered granite. If blue shale is encountered, drilling should be continued, as a water-bearing stratum may yet be found; if the white clay is reached the chances of obtaining water are poorer but there is still some reason for hope; if decomposed granite is entered, the chances are still poorer; and when the granite becomes hard drilling should invariably be stopped. It is important to understand the difference between the blue shale, the white clay, and the decomposed granite. There is no good reason for abandoning a drill hole when blue shale is struck, but this is frequently done.

Mineral analyses of water in Redwood County.

[Analyses in parts per million.]

	Surface deposits (glacial drift, etc.).						(?)			Cretaceous		
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
Depth ... feet	.....	.....	17	34	40	47	254	275	111	312	322	325
Diameter of well ... inches	.....	.....	2	3	96	18	2	8	2	6	2 and 1¼	4½
Silica (SiO_2)	35	30	26	29	25	26	14	11	8	12	8	7
Iron (Fe)	4	.....	.....	.....	.....	.....	.....	.....	.....	3.8	.....	.....
Iron and aluminum oxides (Fe_2O_3 + Al_2O_3)	.....	1.4	3	2	.....	4	.....	.....	.....	.....	2.6	1
Calcium (Ca)	199	158	55	84	511	125	222	196	72	17	57	32
Magnesium (Mg)	66	50	8	28	207	47	100	49	20	12	12	7
Sodium and potassium (Na+K)	26	26	4	11	355	33	51	156	2	423	508	457
Carbonate radicle (CO_3)	.0	.....	.....	.....	.....	.....	.....	.....	.....	.0	.....	.....
Bicarbonate radicle (HCO_3)	542	543	195	370	1,371	470	526	383	202	268	371	701
Sulphate radicle (SO_4)	361	187	15	39	1,683	180	594	672	660	709	912	450
Chlorine (Cl)	7	12	1	2.5	13	1.3	19	8.4	25	23	29	40
Nitrate radicle (NO_3)	.9	.....	.....	.....	.....	.....	.....	.....	.....	.0	.....	.....
Total solids	972	732	206	377	3,468	647	1,296	1,280	1,173	1,345	1,816	1,339

1. Springs which furnish the principal part of the public supply at Redwood Falls. They are located about 1 mile south of the city and a short distance south of the pumping station, in a ravine on the east side of Redwood River. August 30, 1907.
2. Mixture from all the springs which contribute to the public supply at Redwood Falls. November 2, 1893.
3. Well at Vesta. November 27, 1899.
4. Well at Vesta. September 30, 1899.
5. Former railway well at Walnut Grove. February, 1890.
6. Railway well at Wabasso. January 24, 1902.
7. Well at Sanborn. September 15, 1899.
8. Railway well at Sanborn. December 2, 1899.
9. Flowing well at Revere. January 26, 1899.
10. Village well at Walnut Grove. August 14, 1907.
11. Well at Walnut Grove, owned by the municipality. July 31, 1895.
12. Railway well at Walnut Grove. April 13, 1891.

Analyses 1 and 10 were made for the United States Geological Survey by H. A. Whittaker, chemist Minnesota state board of health; the others were furnished by G. M. Davidson, chemist Chicago and Northwestern Railway Company.

RENVILLE COUNTY.

By O. E. Meinzer.

SURFACE FEATURES.

The surface of Renville County constitutes for the most part a very gently undulating drift plain covered with a plexus of lakes, ponds, and swamps. The monotony of this plain is interrupted only along the southwestern margin, where Minnesota River flows through a valley 1 to 3 miles wide and 175 to 200 feet deep, and where many short, rugged tributary gorges dissect the level uplands. Much the greater part of the county still retains the gentle prairie topography inherited from the Pleistocene epoch, and is quite unmodified by postglacial erosion.

SURFACE DEPOSITS.

Description.—The glacial drift is found everywhere except in parts of the Minnesota Valley and its tributaries, where underlying formations are exposed. Owing to irregularities in the surface on which it rests its thickness varies somewhat, but in general increases from the Minnesota Valley eastward and northward, attaining a maximum of more than 400 feet, and having an average for the county of perhaps 250 feet. The following table shows the thickness of the drift and the altitude of the surface upon which it rests in the different localities of the county:

Thickness and altitude of drift in Renville County.

Locality.	Thickness of drift.	Altitude of surface on which drift rests.
	Feet.	*Feet.*
Renville	264	790
Olivia	297	770
Bird Island	280	800
Hector	438	635
Buffalo Lake	340	725
Morton	0	850
Franklin	122	900
Fairfax	202	840

Yield of water.—The beds of sand and gravel, which occur at different depths, constitute the water-bearing members of the drift. The supplies from the shallow beds are generally meager and are readily affected by drought, but the yield of the deeper zones is generous and permanent. In many places at or near the base of the drift there is a thick stratum of sand and gravel (Pl. XV) that will furnish large quantities of water. The 6-inch village well at Renville, which is 236 feet deep, has been tested at the rate of 50 gallons a minute for eight hours continuously; the 6-inch village well at Olivia, which is 320 feet deep, has been tested at 60 gallons a minute for twenty-four hours continuously; the 8-inch village well at Bird Island, which is supplied from about 200 feet below the surface, has been tested at 100 gallons a minute for several hours continuously; the 10-inch railway well at the same place, which also derives its water from a depth of about 200 feet, has been tested at 105 gallons a minute for forty-eight hours continuously; and the new 8-inch village well at Hector, which is 400 feet deep, has been tested at 60 gallons a minute for twelve hours continuously. In the southern part of the county, where the drift is not as thick as elsewhere, the underlying formations are sometimes penetrated before a satisfactory supply is obtained.

Head of the water.—Throughout most of the county the water rises nearly to the surface, but no flowing wells have been reported. In the vicinity of the Minnesota Valley the head is lower than elsewhere, because of the water lost through the numerous large springs in the valley. The following table shows the height to which the water rises in the various village wells:

Head of the water in Renville County.

Locality.	Depth to top of water.	Head above sea level.
	Feet.	*Feet.*
Renville	50	1,005
Olivia	14	1,065
Bird Island	30	1,050
Hector	12	1,060
Buffalo Lake	10	1,055
Franklin	50	970
Fairfax	80	960

Quality of the water.—Throughout the northeastern part of the county the water from the deep beds of the drift is lower in total mineralization, total hardness, and permanent hardness than that from the shallow sources. This is shown by the accompanying table of analyses. In the southern and western parts of the county, where the drift has only a moderate thickness, the difference between the shallow and deep waters is less marked.

The deep-drift water differs both from the shallow-drift water and from the Cretaceous water which exists west of this county. In its content of calcium and magnesium it is intermediate between the two—the shallow-drift water containing large amounts, the Cretaceous water small amounts, and the deep-drift water moderate amounts of these elements. In its content of sodium and potassium the deep-drift water approximates rather closely to the shallow-drift water, both containing moderate quantities of these elements, whereas the Cretaceous water contains large quantities. In its content of sulphates it differs sharply from the other two in that it is low in this constituent, whereas they are very high. These differences seem to indicate that the deep water in this county is not derived entirely from the overlying drift nor from the Cretaceous to the west, nor yet from a mingling of the waters from these two sources.

An interesting phenomenon noticed in the northern part of the county is the presence of inflammable gas which is brought up in small quantities with the water from a number of the deeper wells.

CRETACEOUS AND ARCHEAN ROCKS.

DESCRIPTION.

At various points along the valley of the Minnesota are found outcrops of stratified rocks consisting of blue, black, green, and white shales, and of marl, limestone, coal, sand, sandstone, etc. The section exposed is everywhere thin and changes within short distances from one kind of material to another. In some places Cretaceous fossils have been found in these deposits and there is little doubt that they are all Cretaceous in age. The outcrops that have been described in this county can be summed up as follows:

1. In sec. 10, T. 112 N., R. 34 W., on the north side of Minnesota River, up the valley of a small creek, are outcrops, described by N. H. Winchell,[a] of concretionary marl or limy earth of a white color, which he refers to the Cretaceous.

2. Warren Upham[b] described exposures of Cretaceous clay or shale along Fort Creek, in sec. 31, T. 112 N., R. 32 W. At one place these contain a thin layer of limestone and at another a seam of clayey lignite. He also described an exposure near the foot of the bluff of the Minnesota Valley, in the NE. ¼ sec. 34, T. 112 N., R. 33 W., which consists of gray Cretaceous shale visible to a thickness of 7 feet.

3. C. W. Hall[c] described an exposure of white sandstone along the wagon road in the same section, and also in the gorge of Birch Coulée at the border of secs. 32 and 33, T. 113 N., R. 34 W., and in sec. 28, T. 113 N., R. 34 W. This sandstone is exposed for 12 or 15 feet.

Beneath the Cretaceous rocks is a white or nearly white noncalcareous clay which consists largely of kaolin. In some places it is entirely free from grit, in others it contains embedded grains of quartz, and in still others it is free from grit at the top but contains embedded quartz grains at the bottom. This clay was described by N. H. Winchell,[d] and a quotation from his description appears in

[a] Second Ann. Rept. Geol. and Nat. Hist. Survey Minnesota, 1873, p. 187.
[b] Final Rept. Geol. and Nat. Hist. Survey Minnesota, vol. 2, 1885, p. 197.
[c] Bull. U. S. Geol. Survey No. 157, 1899, pp. 42 and 43.
[d] Second Ann. Rept. Geol. and Nat. Hist. Survey Minnesota, 1873, p. 163.

the report on Redwood County (p. 309). It has been encountered in many wells in Renville County and in other parts of southwestern Minnesota where granite is reached in drilling, and without doubt owes its origin to the decomposition of the granitic rocks on which it rests. Where it is thin and contains embedded grains of quartz it is probably the undisturbed granitic residuum, but where it has a considerable thickness, is free from quartz grains, and contains interbedded layers of grit it has evidently been handled by water and is a sedimentary rather than a residual deposit. If this sedimentation took place at the time when the Cretaceous seas invaded the region, as would seem probable, it is a sort of basal formation belonging to the Cretaceous. Evidently it is not always possible, especially in well sections, to locate the precise boundary between the granitic residuum and the Cretaceous. In the maps and sections the white clay is included with the granitic residuum except where it is evidently Cretaceous. Though this method is somewhat arbitrary it represents the facts as accurately as is feasible.

Beneath the white clay there is generally decomposed granite, which plainly shows its origin and which gradually gives place downward to the firm, unaltered rock.

The Cretaceous rocks are nowhere thick and are absent in some parts of the county; the white clay is found chiefly in the southern part. In some places the Cretaceous rocks, the white clay, and the decomposed granite have all been swept away by the invading ice sheets, and the glacial drift rests immediately upon hard granitic rock.

Plate XV gives a detailed section across the northern part of Renville County along the line of the Chicago, Milwaukee and St. Paul Railway. In the east (Hector and Buffalo Lake) the glacial drift seems to rest directly upon the granite, but in the west (Renville, Olivia, and Bird Island) a certain amount of shale and decomposed granite forms the transition between the drift and the unaltered granite. It is not everywhere certain at what point the boundary should be drawn between the Cretaceous and the granitic residuum.

The following sections of wells are given to illustrate the character of the formations in the southern part of the county:[a]

Section at Fairfax (mill well).

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow bowlder clay	20	20
Blue bowlder clay	165	185
Sand	1	186
Blue bowlder clay	16	202
White, putty-like material free of grit White, putty-like material containing grit (water) Decomposed granite (water)	36	238
Granitic rock.		

[a] Principal authorities, John Ford, driller, Franklin, and B. Henderson, Fairfax.

Well section at Franklin.

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow bowlder clay Blue bowlder clay	110	110
Sand and gravel	12	122
White clay.		
Granite.		

Well section at Morton (Catholic church).

	Thickness.	Depth.
	Feet.	*Feet.*
Coarse gravel	40	40
White clay	75	115
Sand (water)	3	118
White clay Sandstone	27	145

Section of well 1 mile north of Morton, on the farm of John Eder.

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow bowlder clay Blue bowlder clay	120	120
White clay	17	137
Sand and gravel (hard water)	3	140

Section of well 2½ miles north of Morton, on the farm of Peter Kavney.

	Thickness.	Depth.
	Feet.	*Feet.*
Bowlder clay 'Hardpan"	120	120
Soft, sticky, blue-gray clay without grit	2	122
"Coal"	3	125
Sand (water).		
White clay.		

Section of well 4 miles north of Morton, on the farm of John Jones.

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow bowlder clay Blue bowlder clay	124	124
White clay	6	130
Sand (water).		

Section of well 4 miles north of Franklin, on the farm of John Drury.

	Thickness.	Depth.
	Feet.	*Feet.*
Bowlder clay, etc	130	130
White clay	168	298
Decomposed granite (water).		

The following table shows the approximate depth to the granitic surface and its altitude above sea level in the various localities of the county:

Depth and altitude of granitic surface in Renville County.

	Depth to granitic rock.	Altitude of granitic surface.
	Feet.	*Feet.*
Granite Falls (Yellow Medicine County)	(*a*)	900
Renville	325	730
Olivia	345	730
Bird Island	345	730
Hector	438	635
Buffalo Lake	340	725
Morton	(*a*)	850
Franklin (bottom of white clay)	150(?)	860
Fairfax (bottom of white clay)	230	810

a At surface.

YIELD OF WATER.

In the northern part of the county attempts to obtain water in the formations beneath the drift have generally failed, but in the southern part a number of wells have been reported which derive their supplies from layers of sand or sandstone encountered after the Cretaceous deposits or the white clay have been entered. This is true of nearly all the wells whose sections are given above. The mill well at Fairfax, which derives its water from grit and decomposed granite below a layer of the white material, received a rather severe test. The following statement was made by one of the drillers in this county:

Beneath the clay (glacial drift) there is a white formation, in general from 30 to 50 feet thick, beneath which there is rotten granite and then hard red granite. The white material is at first soft and putty-like but changes into a harder formation containing grit. This gritty white material and the decomposed granite usually contain a good supply of water.

QUALITY OF THE WATER.

The water from beneath the white clay is of various mineral character, much of it being very hard but some being similar to the deeper drift water. No. 15 in the table (p. 324), the only analysis that was made of water from this source, represents an extremely hard water.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Renville.—The granitic surface seems to be somewhat irregular in the vicinity of Renville. The assertion is made that it was encountered at a depth of 250 feet in drilling done for the village, but in the railway well a considerably greater depth was reached before granite was struck (Pl. XV). Meager supplies of hard water are obtained near the surface, and more abundant supplies of softer water from the deposits of sand and gravel at the base of the drift (between about 190 and 265 feet below the surface), but no deeper water zones exist.

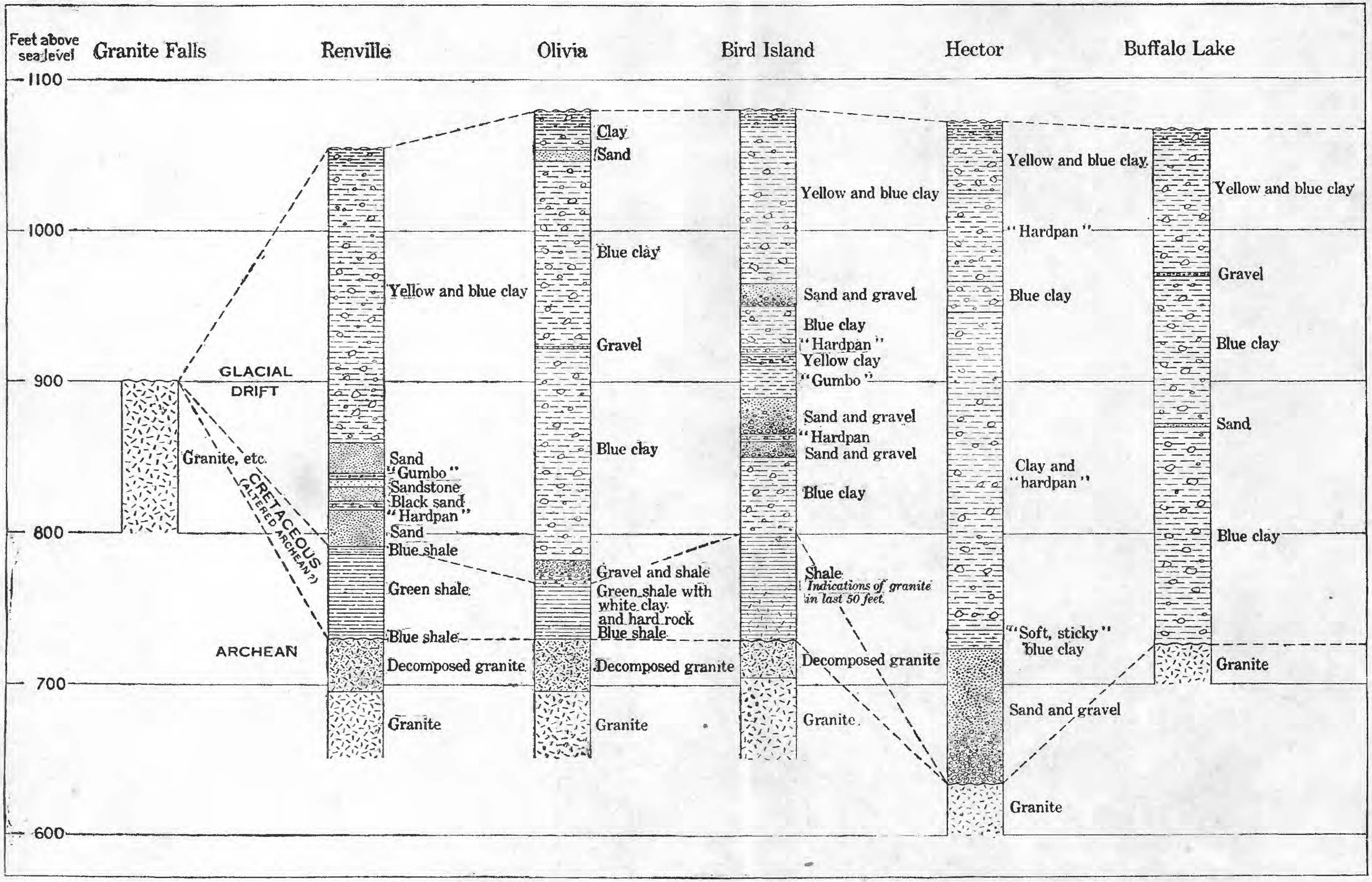
The public supply is derived from a well 236 feet deep, which has already been referred to (pp. 314–315). About 300 people use the water, and 10,000 gallons is consumed daily. An analysis is given in the table. Perhaps three-fourths of the inhabitants use water from private wells, which have an average depth of about 25 feet and are generally cased with wood or brick. The railway company uses a well that admits water from the sand stratum between 240 to 264 feet below the surface.

Olivia.—When the deep drilling for the village of Olivia was done the stratigraphic record was carefully kept, and this record forms the basis of the section given in Plate XV to a depth of 349 feet. There is some uncertainty as to the exact depth at which the decomposed granite was entered. The upper portions of the glacial drift yield small amounts of hard water, but the sand and gravel at a depth of about 300 feet, at the base of the drift, furnish adequate quantities of softer water.

The public supply is obtained from a well 320 feet deep, the data in regard to which have already been given. The water, an analysis of which will be found in the table (p. 324), has little permanent hardness and will not form much hard scale in boilers. About 250 people use the water, and it is also used at the canning factory, mill, and laundry, approximately 17,000 gallons being consumed daily. The creamery is supplied from a shallow well which yields harder water, and about three-fourths of the people use water from private wells, most of which are dug or bored and end in yellow clay or sandy deposits at depths of 20 to 30 feet. One private drilled well similar to the village well was reported.

Bird Island.—There are several water-bearing beds in the glacial drift at Bird Island, the upper ones yielding harder water than those that lie deeper. Apparently there is no water-bearing formation at a greater depth than 230 feet (Pl. XV).

The public supply is obtained from an 8-inch well which was drilled to a depth of 298 feet but which receives its water from about 200 feet below the surface. As the analysis in the table shows, the water has little permanent hardness and will not form much hard scale in boilers. Approximately 16,000 gallons is reported to be consumed daily, but only a small proportion of the inhabitants use the public water. The majority of the private wells are dug or bored to depths



GEOLOGIC SECTIONS IN RENVILLE COUNTY.

By O. E. Meinzer.

Renville.—Railway well. Authority, Mr. Hayden, water-supply superintendent, Hastings and Dakota division, Chicago, Milwaukee and St. Paul Railway, Glencoe.

Olivia.—The upper 349 feet represents deep drilling done for the village and reported by the village authorities.

Bird Island.—Railway well; reported by Mr. Hayden.

Hector.—Railway well; reported by Mr. Hayden.

Buffalo Lake.—Village wells; from an examination of drillings and from various reports.

of about 20 to 40 feet, but there are also a few drilled wells which obtain more satisfactory supplies from about 200 feet below the surface. The railway company is supplied from a well that was drilled to a depth of 375 feet but derives its water from between the depths of 190 and 230 feet.

Fairfax.—Water is obtained at Fairfax from the various beds in the glacial drift and from a sandy zone between the white clay and the decomposed granite. (See the section given above.) The public waterworks are supplied from a 6-inch well which is finished with an open end in a layer of sand at a depth of 185 feet, gravel having been put into the well to act as a screen. It is pumped at 10 or 20 gallons a minute and should not be pumped at a more rapid rate as long as it has an open end. The water, which is used only to a small extent, is hard and is objected to because of the iron which it contains. Most of the private wells are bored or dug into the yellow clay or sand near the surface and are readily affected by drought, but there are a few deeper drilled wells. The well at the flouring mill, which is 234 feet deep and derives its supply from immediately above the granite, yields water that is reported to be harder than that from the glacial drift. This water probably belongs to the same type as that from John Eder's well, north of Morton, an analysis of which is given in the table.

Hector.—At Hector the best water-bearing bed, both as to quality and quantity, is the deposit of sand and gravel immediately above the granite (Pl. XV).

The public supply is obtained from two wells. The old well has a depth of 380 feet, of which the upper 35 feet is 12 feet in diameter and cased with brick and the remaining portion is 9 inches in diameter and has an iron casing with a screen at the bottom. The new well is 400 feet deep and 8 inches in diameter and is also finished with a screen. The water is relatively soft and will form almost no hard scale in boilers. An analysis is given in the table. At the time the waterworks were visited (1907), the combined yield of the two wells was small and inadequate, but it seemed probable that this was due to some mechanical difficulty rather than to the limitations of the water-bearing bed itself. When the new well was completed (1902), it is reported to have been pumped at the rate of 60 gallons a minute for twelve hours continuously. By far the greater number of the people use water from private wells, most of which are shallow. The railway company has an 8-inch well that was drilled to a depth of 728 feet but derives its supply from the sand and gravel above the granite. An analysis of this water, which resembles that from the village well, will be found in the accompanying table (p. 324). The mill also is supplied from a deep well.

Morton.—The village of Morton is situated on the north bank of Minnesota River and lies in the valley and on the valley side. The granite is at or near the surface and there is no deep water-bearing bed. There are numerous springs on the flanks of the valley, one of which, situated east of the village and at a higher altitude, furnishes the public supply. The water from this spring flows directly into the mains and gives a pressure sufficient for ordinary purposes, and water pumped from the spring into a reservoir on the uplands furnishes the greater pressure necessary in case of fire. The yield of this spring is not great. At the time it was visited (1907) it did not supply the pump operated at the rate of about 30 gallons a minute, and in dry years the yield is reported to be inadequate. The water is hard, as is shown by the analysis given in the table. Perhaps one-fourth of the people use water from private wells, most of which are shallow and furnish only meager supplies.

Sacred Heart.—Deep drilling has never been undertaken in Sacred Heart, but it is probable that the granitic rocks occur at no great depth. The public supply is obtained from a well 14 feet in diameter and 40 feet deep, which is cased with brick and mortar. It passes through yellow and blue bowlder clay and ends in a layer of coarse sand. In 1907 the water normally rose within 18 feet of the surface, and pumping at the rate of 50 gallons a minute for four hours continuously lowered this level 4 or 5 feet. The water is used by about 125 people, perhaps 80 per cent of the inhabitants being supplied from private wells, which are generally dug to a depth of about 30 feet and end in sand or gravel.

Franklin.—Franklin village is located on the level upland near the cliffs of the Minnesota Valley. The glacial drift is about 120 feet deep, the basal 10 feet of it consisting of water-bearing sand and gravel. Below the drift are the white clay and the granitic rocks. (See the section given above.)

The public supply is obtained from a well 6 feet in diameter and 108 feet deep, which is cased with boiler iron. This well reaches to the sand and gravel layer mentioned above. The upper portion of the layer consists of very fine sand, which was prevented from rising in the well by covering the bottom with 5 wagonloads of gravel. In 1905, when the well was completed, it was pumped at the rate of 50 gallons a minute for forty-eight hours continuously, whereby the water was lowered 14 inches. About 500 people are supplied, and approximately 10,000 gallons is consumed daily. There are only a few private wells, and these are shallow and readily affected by drought.

Buffalo Lake.—At the village of Buffalo Lake there is a thin layer of water-bearing sand or gravel at a depth of about 100 feet and another at about 200 feet, both of which belong to the glacial drift.

Granite occurs at about 320 feet or somewhat lower, and immediately above the granite there is a little water, but not enough to furnish a satisfactory supply. The public supply is derived from two wells, both of which were drilled to depths between 300 and 400 feet (Pl. XV). The present supply of the old well comes from the 100-foot gravel bed; the new well seems to obtain its water above the granite. The yield of each is small. Most of the people use water from shallow private wells, but there are a few private drilled wells which end in the 100-foot zone, and the well at the mill is reported to be about 400 feet deep.

FARM WATER SUPPLIES.

In the northern part of the county most of the farms are supplied from shallow bored wells which end in the upper portion of the drift and yield meager and uncertain quantities of hard water, but there are a few deeper drilled wells similar to the village and railway wells along the Chicago, Milwaukee and St. Paul Railway. The deep wells are superior to the shallow ones in the following respects: (1) The water is softer, (2) the yield is larger and more permanent, and (3) there is less danger of pollution.

In the southern part of the county there are more drilled wells. These range from 2 to 6 inches in diameter, and from less than 100 to more than 300 feet in depth, but are generally between 100 and 150 feet. They generally end in the glacial drift, but a few penetrate the underlying formations, as has already been explained. The shallow wells have hard water but some of the deeper ones yield water which is softer. Six-inch drilled wells are recommended for farm purposes in all parts of the county.

SUMMARY AND ANALYSES.

The principal sources of water are the deposits of sand and gravel which occur at various depths interbedded with the bowlder clay or lying immediately below it. The shallow deposits furnish only small supplies but the deeper ones generally yield abundantly. Moreover, the shallow water is hard and the deeper water is commonly much softer, especially in the northeastern part of the county.

Below the glacial drift the drill generally penetrates thin layers of blue or green shale "soapstone", a white clay, or ordinary decomposed granite. In the southern part of the county water is obtained in some places from sandy layers in these beds, but at best they constitute only an uncertain source.

Granite has frequently been encountered at depths ranging up to 450 feet. It will not yield water and no water-bearing formation occurs beneath it.

Mineral analyses of water in Renville County.

[Analyses in parts per million.]

	Surface deposits (glacial drift, etc.).														White clay.
	Upper portion.				Lower portion.										
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.
Depth .... feet	26	45	74	Spring.	160	190	211	236	396	320	298	390	400	408	140
Diameter of well .... inches		24			6			6		6	8		8		
Silica (SiO_2)		40		48	59			19		20	20		11		27
Iron (Fe)		3		.05	3.8						.08		8.1		15
Aluminum (Al)				4							4.5		4.6		
Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	11	4	8		2.8	4.5	4.5	3.2	1.4	2.8		9.3			2.4
Calcium (Ca)	59	267	283	113	56	63	149	67	42	45	55	58	63	66	339
Magnesium (Mg)	49	123	108	34	31	29	79	25	23	28	27	40	41	46	159
Sodium and potassium (Na+K)	43	25	65	12	84	103	100	120	122	111	67	133	115	115	35
Carbonate radicle (CO_3)		.0		.0	.0			.0		.0	.0		.0		.0
Bicarbonate radicle (HCO_3)	342	360	555	449	463	452	528	473	457	522	452	660	624	650	508
Sulphate radicle (SO_4)	147	452	795	69	13	104	417	123	1	17	6	0	15	43	1,120
Chlorine (Cl)	6	280	6	3	40	13	13	14	11	13	7	40	41	16	3
Nitrate radicle (NO_3)		80		.7											
Total solids	483	1,456	1,538	519	534	539	1,041	610	476	483	382	607	618	596	1,945

1. Former village well at Renville. April 24, 1893.
2. Well at the Commercial Hotel at Buffalo Lake. September 13, 1907.
3. Former railway well at Bird Island. May 6, 1894.
4. Springs which furnish the public supply at Morton. August 31, 1907.
5. Well on the farm of John Ford, sec. 1, T. 113 N., R. 34 W. August 31, 1907.
6. Former railway well at Renville. October 13, 1888.
7. Railway well at Renville. April 24, 1893.
8. Village well at Renville. September 7, 1907.
9. Former village well at Olivia. January 23, 1901.
10. Village well at Olivia. September 12, 1907.
11. Village well at Bird Island. September 12, 1907. The water comes from a depth of about 190 feet.
12. Well of Berry Brothers at Hector. August 4, 1899.
13. New village well at Hector. September 13, 1907.
14. Railway well at Hector. December 4, 1900.
15. Well on the farm of John Eder, 1 mile north of Morton. August 31, 1907.

Analyses 2, 4, 5, 8, 10, 11, 13, and 15 were made for the United States Geological Survey by H. A. Whittaker, chemist Minnesota state board of health. Analyses 1, 3, 6, 7, 9, 12, and 14 were furnished by G. N. Prentiss, chemist Chicago, Milwaukee and St. Paul Railway Company.

RICE COUNTY.

By C. W. Hall and M. L. Fuller.

SURFACE FEATURES.

The upland surface of Rice County ranges from 1,000 feet above sea level near the northwestern corner to 1,200 feet near the southeastern corner. The greater portion, though rolling, is nearly uniform in elevation, but the general level is broken by the valleys of the Cannon and its tributaries and by morainal ridges which rise 50 to 100 feet above the surrounding region. The more easterly of these ridges is an interrupted belt of irregular hills crossing the country from north to south a little east of Faribault. South of this city, where the ridge is about 6 miles wide, it is cut near the middle by the valley of Straight River. The other moraine is much broader, covering the western third of the county and having a maximum width of 12 miles, a part of which, however, lies within Lesueur County. Between the two moraine belts there are numerous undrained depressions containing lakes and marshes, but in the western moraine lakes are even more abundant. East of the eastern moraine the surface is much broken by the valley of Cannon River and by the valleys tributary to Cannon and Zumbro rivers, but remnants of the plateau still remain. The principal stream, Cannon River, crosses the county from the southwestern to a point near the northeastern corner, occupying a valley 100 to 200 feet deep, the bottom of which is in rock north of Faribault. The smaller streams have valleys reaching 100 feet in depth and likewise in many places flow over rock, especially in the northeastern part of the county. Terraces one-half to 2 miles or more in width occur along Cannon River.

SURFACE DEPOSITS.

The glacial drift is a heterogeneous pebbly clay with some bowlders and interbedded bodies of sand and gravel. Several stages of deposition are represented, the older drift forming a belt several miles wide along the eastern border and extending westward beneath the younger, which covers the central and western parts of the county. Both contain sandy or gravelly layers, but these are distinctly more numerous in the younger drift than in the older. The total thickness varies from less than 50 feet along the river valleys to more than 200 feet in the western part of the county. Water occurs in considerable quantities in the sandy and gravelly layers and is most abundant, because these porous layers are more numerous in the younger drift of the western part of the county. The supplies are nearly everywhere sufficient for domestic and farm purposes and are generally ample for the needs of small industries.

The terrace gravels include the deposits made by glacial streams flowing, from the ice sheet lying to the west, through the Cannon River valley to the Mississippi. In the upper courses of the river they occupy the full width of the valley, but in the central and northern part of the county the stream has at present cut far below their level and has left them standing as terraces, in some places, as at Faribault, from 1 to 2 miles or more in width. There are two distinct series of terraces, a lower series, upon which Faribault is situated, about 45 feet above the river, and an upper series at a considerably higher level. Their height above the river, however, varies from place to place, becoming greater downstream toward the north. The gravel of which the terrace deposits are composed readily absorbs the water falling on its surface, but it permits an equally ready escape to the valleys, for this reason the supplies are usually small near the drainage lines.

During the northward retreat of the ice a small lake was formed in front of its margin in the valley of northward-flowing Straight River. In this lake were laid considerable amounts of sand and gravel of essentially the same character as the terrace deposits. Elsewhere in the county there are many areas of stratified gravel and sand, interminably intermingled with the terraces on the one hand and with the unmodified drift on the other.

The alluvial deposits include the gravel and sand laid down by the existing streams. They are not extensively developed and are of little importance with regard to water supplies. Wherever drawn upon they yield enough for domestic use.

PALEOZOIC FORMATIONS.

The Galena limestone, Decorah shale, and Platteville limestone are all present in this county, with an aggregate thickness of about 130 feet. Outcrops of the Platteville limestone are found along Cannon River, and the Galena limestone lies immediately beneath the drift on the uplands near the southeastern corner of the county. From well records the Platteville limestone also appears to lie beneath the drift of the uplands throughout extensive areas in the northwestern part of the county. The Galena and Platteville limestones furnish only small supplies of water.

The St. Peter sandstone, which varies in thickness from 160 feet to an eroded remnant of only a few feet, is exposed along Cannon River from a point above Faribault and lies beneath the uplands both east and west of this stream. To the east, and especially to the southeast, it generally underlies the Platteville limestone and affords good supplies of water under some pressure.

Northwest of the Cannon the Galena, Decorah, and Platteville formations are generally missing and the St. Peter lies immediately below the drift. In such localities the water is not under much pressure and does not enter the wells as freely as when the formation is under cover, though nearly everywhere supplies sufficient for domestic and farm purposes can be obtained.

Thirty-five feet of Shakopee dolomite, a buff to pinkish magnesian limestone, is exposed in the Cannon River valley at the north line of the county. The formation probably occurs immediately beneath the drift near the northwest corner and it underlies the St. Peter throughout the remainder of the county.

The New Richmond sandstone, which probably attains a thickness locally of 25 feet, dips southeastward below the Shakopee and contains water under pressure at practically all points within the county. It affords a valuable supplementary supply where the St. Peter sandstone is not under cover or where its supplies have been lessened by heavy pumping.

The Oneota dolomite, a bed of pinkish magnesian limestone attaining 150 feet in thickness, lies beneath the New Richmond and affords a cap to confine the waters of the underlying Jordan sandstone.

The Jordan sandstone, which should be reached at 200 or 225 feet below the bottom of the St. Peter, is a porous sandstone about 90 feet thick, saturated with water under sufficient pressure to cause it to enter wells freely. It constitutes a stronger water zone than any above it and is valuable where large supplies are required.

Below the Jordan are the shales and limestones of the St. Lawrence formation, about 140 feet thick; the Dresbach sandstone, about 90 feet thick; and the underlying basal Cambrian shales and sandstones, probably reaching 350 feet in thickness. The sandstones are saturated with water under considerable pressure and afford valuable supplementary supplies to the St. Peter and Jordan wherever they are reached by wells.

UNDERGROUND WATER CONDITIONS.

Wells.—As is usual where the surface materials are mainly drift, water is easily obtained in the sandy and gravelly layers at a short distance below the surface by open or bored wells. However, drilled wells are also common because the water in the deeper beds of the drift give a more permanent and reliable supply than do the shallow beds. In the eastern part of the county many of the upland wells pass through the drift, which in many localities does not much exceed 100 feet in thickness, and enter the underlying rocks. In the valleys driven wells sunk into the alluvium or terrace gravels are the most common source of water, but for large supplies, such as the public supplies of Faribault and Northfield, deep wells drilled to the Jordan or some lower sandstones are necessary.

Head of the water.—In the middle and lower portions of the drift the water always stands under considerable head, but no flowing wells from the drift have been reported in this county. In the Paleozoic sandstones the head of water is a more nearly constant factor. Thus at Faribault and Northfield, situated in the Cannon River valley, strong flows are obtained, the water rising 10 or 20 feet above the surface, but on the uplands the Paleozoic sandstones will not give rise to flows.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Faribault.—The city of Faribault has a system of water supply derived from two deep wells, which tap the Jordan and Dresbach sandstones. The section of the deeper of the two is approximately as follows:

Section of public well at Faribault.

	Thickness.	Depth.
	Feet.	*Feet.*
St. Peter sandstone, in part	75	75
Shakopee dolomite, New Richmond sandstone, and Oneota dolomite (estimated)	265	340
Jordan sandstone (estimated)	80	420
St. Lawrence formation (shales) (estimated)	225	645
Dresbach sandstone and underlying shale (entered)	355	1,000

Several other wells in the city have been sunk to the deep-water zones; for instance, the one at the Consolidated Gas and Electric Light Company's plant and the one at the school for the deaf and dumb. In the bottom of the valley the water rises approximately to the surface. A number of analyses of water from various depths are given in the accompanying table (p. 329).

Northfield.—The city of Northfield has a public supply drawn from an artesian well sunk in 1894. This well was originally 647 feet deep, but in order to obtain water of less hardness it was plugged at a depth of 300 feet, and the supply now comes from the Jordan sandstone. The water will rise 20 feet above the surface and the flow from an 8-inch casing is reported to be 1,000 gallons a minute. The section of the well is as follows:

Section of public well at Northfield.

	Thickness.	Depth.
	Feet.	*Feet.*
Shakopee, New Richmond, and Oneota	265	265
Jordan (white sandstone)	50	315
St. Lawrence (blue shale)	225	540
Sandstone (Dresbach ?)	20	560
Shale	3	563
Sandstone	15	578
Shale	9	587
Sandstone	35	622
Limestone	25	647

The water from several water-bearing beds penetrated in this well was examined by the Minnesota state board of health, with the following results:

Analyses of water from the Northfield city well.

[Parts per million. Authority, C. F. Loweth, civil engineer.]

Depth.	Residue.			Chlorine.	Hardness.		
	Volatile.	Fixed.	Total.		Temporary.	Permanent.	Total.
Feet.							
82	51	320	371	4.69	72	148	220
500	85	295	380	2.85	82	158	240
647	15	435	450	3.75	294	146	440

Lonsdale.—The village of Lonsdale has a public water supply, which, however, is not extensively used by the people, nearly all of whom have private wells.

SUMMARY AND ANALYSES.

When large supplies are required drilling should be continued to one of the Paleozoic sandstones that underlie the county and contain large stores of water, which they yield generously. For farm and domestic purposes it is generally possible to obtain, from shallower sources and at less expense, supplies which are adequate and, moreover, occcur under better head than those from the deep zones. On the uplands deep drilling should not be undertaken for the purpose of obtaining flowing wells.

Mineral analyses of water in Rice County.

[Analyses in parts per million.]

	Glacial drift.							
	1.	2.	3.	4.	5.	6.	7.	8.
Depth feet	12 and 30	30	70	25	21	180	180	190
Silica (SiO_2)								
Iron (Fe)	9.2	1.0	1.3					
Calcium (Ca)	73	81	86	205	130	98	99	147
Magnesium (Mg)	21	26		94	45	43	42	
Sodium and potassium (Na+K)	13	10	8.9	52		41	23	44
Bicarbonate radicle (HCO_3)	329	350	226	502	388	594	573	482
Sulphate radicle (SO_4)	25	38	37	169	40			
Chlorine (Cl)	5.2	3.8	7.9	164	61			
Total solids	309	334	352	1,174	569	506	508	578

	New Richmond sandstone.			Jordan sandstone.	Dresbach sandstone.					
	9.	10.	11.	12.	13.	14.	15.	16.	17	18.
Depth feet	322	76	227	647	647	500	600	600	825	1,000
Silica (SiO_2)	20		18	3.9		2.6	21	12.7		
Iron (Fe)	6.5	2.7	1.9	.2	3					1.7
Calcium (Ca)	103	91	87	97	96	92	97	96	91	99
Magnesium (Mg)	41	31	30	34	32	30	32	29	29	30
Sodium and potassium (Na+K)	42	13	1.9	5.1	12	21	34	11	21	9.4
Bicarbonate radicle (HCO_3)	543	449	410	378	437	407	417	410	407	431
Sulphate radicle (SO_4)	24	14	16	69	32	46	82	38	46	38
Chlorine (Cl)	2.2	1.2	3	7.9	1.2	10	18	3	11	1.2
Total solids	509	376	350	352	391	402	490	392	400	391

1. Former city well at Faribault. June, 1892.
2. Well at Faribault. September, 1892.
3. City well at Faribault. April, 1899.
4. Well of Joseph Marek at Lonsdale. December, 1901.
5. Well of F. Shiask at Lonsdale. May, 1902.
6. Well of T. Wilbey at Lonsdale. December, 1901.
7. Well of T. Wilbey at Lonsdale. May, 1902.
8. Well of J. Malscha at Lonsdale. May, 1902.
9. Village well at Lonsdale. November, 1906.
10. Chicago, Milwaukee and St. Paul Railway well at Northfield. August, 1890.
11. Northfield Hemp Company's well at Northfield. November, 1906.
12. City well at Northfield. January, 1896.
13. City well at Northfield. July, 1895.
14. Well at the school for the deaf and dumb at Faribault. April, 1896.
15. Consolidated Gas and Electric Light Company's well at Faribault. October, 1893.
16. Well supplying the waterworks at Faribault. September, 1896.
17. Well at the school for the deaf and dumb at Faribault. 1896.
18. City well at Faribault. July, 1895.

Analyses 1 to 8, 10, 13, and 18 were furnished by G. N. Prentiss, chemist Chicago, Milwaukee and St. Paul Railway Company. Analyses 9 and 11 were made by H. S. Spaulding. Analyses 12 and 14 to 17 were furnished by the Dearborn Drug and Chemical Company, Chicago.

ROCK COUNTY.

By O. E. Meinzer.

SURFACE FEATURES.

The surface of Rock County is a gently undulating prairie which differs from that of the counties farther east in being much better drained and in being essentially free from lakes and swamps. The north-central section is occupied by a low rock plateau, which is terminated abruptly on the southeast by a bold quartzite cliff. This part of the plateau stands about 175 feet above Rock River and is known as "the Mound." The south-facing cliff becomes lower toward the west and terminates within a short distance, but that facing the east is more persistent and appears in low rocky outcrops approximately to the north boundary.

Rock River, which is the largest stream, flows southward through the eastern portion of the county, occupying a wide open valley and receiving numerous tributaries, which reach it through more narrow and gorgelike valleys. The western half is drained by several smaller streams that flow toward Big Sioux River in South Dakota.

SURFACE DEPOSITS.

Description.—The surface deposits of Rock County consist chiefly of glacial drift. The valleys contain extensive alluvial deposits, which are in large part of glacial origin.

In the northwestern and north-central portions of the county the drift is thin or entirely absent and the quartzite lies near the surface. This area of attenuated drift comprises Rose Dell Township (T. 104 N., R. 46 W., and T. 104 N., R. 47 W.), all but the eastern margin of Denver Township (T. 104 N., R. 45 W.), and all but the southern margins of Mound Township (T. 103 N., R. 45 W.) and Spring Water Township (T. 103 N., R. 46 W., and T. 103 N., R. 47 W.). (See Pls. II and III and also the list of rock wells given below.) Eastward and southward from this area the drift thickens rapidly, and within a few miles is so deep that the rock is rarely reached in drilling. The only rock well reported east of Rock River is on the farm of H. Engebretson (NE. ¼ sec. 4, T. 103 N., R. 44 W.), where quartzite was struck at a depth of 157 feet. Only a few rods south of the Mound (NE. ¼ sec. 34, T. 103 N., R. 45 W.) the drift was found to be 200 feet thick, and at Luverne deep drilling has been done without encountering rock.

Yield of water.—At many points where the drift is thin the quantity of water that it will furnish is quite inadequate, but where it has a considerable thickness copious supplies are drawn from the deeper portions. The deposits of sand and gravel in the valleys of Rock River and other streams will surrender their water very freely and are not easily affected by drought. The public supplies of Edgerton and Luverne and of several villages in Iowa located in the Rock River valley are obtained from this source.

Head of the water.—The water from the drift generally rises near the surface, and on the relatively low ground surrounding a quartzite ridge or plateau conditions are peculiarly favorable for producing flows. The rock here affords the intake area through which the water is transmitted to the water-bearing beds of the drift, and the impervious bowlder clay, which laps up over the rock plateau and extends as a continuous sheet to an altitude considerably higher than the surrounding surface, acts as a confining bed that allows the water to accumulate sufficient head to rise nearly or quite to the level of the lowland surface (fig. 4). An area in which flows are produced in the manner just outlined extends from the low ground east of Hardwick southeastward to Rock River (Pl. IV). Wells near the rock plateau have a head that is uncommon for the drift, but the pressure diminishes rapidly with increase in distance from the plateau, and no flows have been obtained east of the river. The following wells are located in this area:

Flowing wells near Hardwick.

Owner and location.	Depth.	Diameter.	Head relative to surface.	Natural flow (gallons per minute).
	Feet.	*Inches.*	*Feet.*	
E. T. Thorsen, SE. ¼ sec. 25, Denver Township (T. 104 N., R. 45 W).	140	6	Several above.	Several.
O. Halverson, NE. ¼ sec. 36, Denver Township (T. 104 N., R. 45 W).	125	6	More than 20 above.	Many.
H. R. Halverson, SW. ¼ sec. 31, Battle Plain Township (T. 104 N., R. 44 W). [a]	114	6	More than 20 above.	Many.
I. Smotel, SE. ¼ sec. 6, Vienna Township (T. 103 N., R. 44 W.).	110	....	Several above.	Few.
F. C. Mahony, SE. ¼ sec. 5, Vienna Township (T. 103 N., R. 44 W.).	147	....	([b])	([b])
— Halverson, SE. ¼ sec. 12, Mound Township (T. 103 N., R. 45 W.).	110	....	6 below.......	None.
H. Engebretson, NE. ¼ sec. 4, Vienna Township (T. 103 N., R. 44 W.). [c]	180	6	6 below.......	None.

[a] The water forced its way up on the outside of the casing and made a large hole. A new well was drilled to the same zone.
[b] A feeble flow was obtained at this depth, but drilling was continued 4 feet deeper through clay into a second seam of sand and gravel, the first seam being cased out. The water then remained 4 feet below the surface, and when the casing was drawn back to the first seam it would not rise again to the surface.
[c] This well is in rock below the depth of 157 feet.

No other flowing wells from the drift were reported, but it is not improbable that others could be procured near the margins of the rock plateau, for they exist outside of this county in similar locations. A well several hundred feet deep was once drilled at Luverne for the purpose of getting a flow, but the project ended unsuccessfully.

Quality of the water.—The water from the surface deposits is all hard, but the ordinary glacial drift water is generally more highly mineralized than that from the alluvial and outwash deposits. (See the analyses given in the accompanying table, p. 336.)

CRETACEOUS SYSTEM.

Cretaceous rocks are frequently encountered in southwestern Minnesota and northwestern Iowa. At Ellsworth, which is less than

2 miles east of this county, shale and unconsolidated sandstone belonging to this system were found between the depths of 190 and 280 feet, and it is altogether probable that these deposits extend into the eastern and southern portion of this county. The sandstone will usually afford liberal quantities of hard water. (See the report on Nobles County.)

SIOUX QUARTZITE.

Description.—The Sioux quartzite, or "red rock," is for the most part a hard, red, siliceous formation of nearly uniform character and great thickness. But though it is generally very firmly cemented there are marked differences in the degree of hardness, some layers of incoherent sand being encountered. There is also considerable variety in the color, which ranges from light pink to dark purple. The formation is distinctly stratified, in many places cross-bedded and ripple-marked, in general has a gentle dip, and is much broken by joints. It has been penetrated only a few hundred feet in this county and the bottom has never been reached.

Throughout the northwestern and north-central parts of the county this rock lies near the surface and is exposed in a number of localities. Toward the east and south it slopes rapidly downward and within a short distance is deeply buried, but it again appears near the surface along the southern margin of the county (Pl. III).

The following is a representative list of wells which enter the quartzite, together with the depth to rock and the distance it has been penetrated, as given by drillers and other persons:

Table of typical wells in Sioux quartzite of Rock County.

Owner and location.	Depth to Sioux quartzite.	Distance drilled in Sioux quartzite.	Total depth of well.
	Feet.	*Feet.*	*Feet.*
L. H. Gilbertson, E. ½ sec. 26, T. 104 N., R. 47 W	105	55	160
J. Kohler, SE. ¼ sec. 2, T. 104 N., R. 47 W	106	45	151
Aug. Beyer, S. ½ sec. 21, T. 104 N., R. 46 W	2	158	160
E. Heckman, NE. ¼ sec. 21, T. 104 N., R. 46 W	12	148	160
C. and O. Houg, N. ½ sec. 22, T. 104 N., R. 46 W	7	86	93
C. and O. Houg, N. ½ sec. 22, T. 104 N., R. 46 W	6	237	243
J. J. Houg, NE. ¼ sec. 15, T. 104 N., R. 46 W	20	214	234
G. C. Huntington, NW. ¼ sec. 2, T. 104 N., R. 46 W	85	215	300
F. A. Hyke, SE. ¼ sec. 22, T. 104 N., R. 46 W	6	194	200
H. Larson, SE. ¼ sec. 3, T. 104 N., R. 46 W	6	174	180
F. Seeman, SE. ¼ sec. 11, T. 104 N., R. 46 W	60	100	160
K. K. Steen, NW. ¼ sec. 14, T. 104 N., R. 46 W	....	....	337
W. E. Stork, NE. ¼ sec. 4, T. 104 N., R. 46 W	18	119	137
G. W. Vickerman, SE. ¼ sec. 20, T. 104 N., R. 46 W	8	100	108
H. Wiese, NE. ¼ sec. 28, T. 104 N., R. 46 W	1	334	335
P. E. Brown, SW. ¼ sec. 15, T. 104 N., R. 45 W	52	171	223
L. M. Grandy, SE. ¼ sec. 14, T. 104 N., R. 45 W	67	101	168
Hardwick city well	80	340	420
Henry Lamp, N. ½ sec. 1, T. 104 N., R. 45 W	227	57	284
A. J. Nickey, NE. ¼ sec. 9, T. 104 N., R. 45 W	83	134	217
J. Sand, E. ½ sec. 21, T. 104 N., R. 45 W	75	145	220
H. J. Stammon, NE. ¼ sec. 17, T. 104 N., R. 45 W	70	152	222
A. Barck, E. ½ sec. 22, T. 103 N., R. 45 W	18	162	180
W. and A. Dysart, E. ½ sec. 15, T. 103 N., R. 45 W	7	351	358
F. A. Hyke, SE. ¼ sec. 23, T. 103 N., R. 45 W	0	45	45
J. E. Mitchell, NE. ¼ sec. 34, T. 103 N., R. 45 W	200	0	200
W. A. Moore, NW. ¼ sec. 11, T. 103 N., R. 45 W	60	281	341
J. Welzenbach, SW. ¼ sec. 14, T. 103 N., R. 45 W	18	182	200
H. Engebretson, NE. ¼ sec. 4, T. 103 N., R. 44 W	157	23	180

In the area in which the Sioux quartzite is near the surface it lies immediately below the glacial drift, but in much of the eastern and southern parts where it has not been reached in drilling the Cretaceous shales and sandstones probably intervene between it and the drift.

Yield of water.—In general the quartzite is so firmly cemented that there are virtually no pore spaces through which water can be transmitted. Nevertheless, the great dearth of water in some localities forced the experiment of drilling into this rock, and in almost all the wells it yielded some water; it is now depended on as a reliable source of supply. The water percolates through the formation in two ways—(1) through the "crevices," that is, the system of joints into which the rock is broken, and (2) through the less firmly cemented portions. Occasionally a well will find a large "crevice" or very porous layer that will deliver generous quantities of water, but more commonly the "crevices" are small and the beds are but slightly pervious, so that only minute amounts of water are given up, and it is only by continued drilling, bringing the well in contact with many of these water-bearing elements, that an adequate supply is obtained. However, the yield generally increases with the depth in more than a direct ratio, and therefore doubling the depth does not merely double the supply but may augment it many fold. There seem to be two reasons for this—(1) the pressure with which the water enters the well increases with the depth, and (2) the water-bearing layers apparently are more abundant and more porous at lower levels. On the other hand, the fissures are perhaps less abundant and open at rather great depths than near the surface, but the rock has such great strength that this counteracting factor is not important for zones thus far reached in drilling.

In putting down farm wells it is customary to guarantee only 100 gallons an hour, though many wells will furnish much more. The village well at Hardwick, which is 420 feet deep and penetrates the rock for a distance of 340 feet, has been pumped for ten hours continuously at the rate of 25 gallons a minute. The average depth of the farm wells is considerably less, as is shown by the list given above, and their average yield is accordingly less.

Head of the water.—There is a flowing well on the low ground near the junction of Pipestone and Split Rock creeks (E. ½ sec. 26, T. 104 N., R. 47 W.). It has a depth of 160 feet, of which 55 feet is in rock, and its action is perhaps similar in principle to that of the flowing wells from the glacial drift described above. In general, flows can not be obtained from the quartzite. The height at which the water stands varies, depending on the topography and other factors.

Quality of the water.—The quartzite itself contributes very little mineral matter, and where it is at or near the surface the rain may enter it without becoming mineralized and may remain soft and almost free from dissolved solids. But in most localities the quartzite is covered with a mantle of drift, and as the drift contains much soluble matter the water is liable to be highly charged by the time it reaches the rock. Hence the quartzite water varies widely in its mineral content; but on an average it is softer and otherwise less mineralized than that from the drift, though the substances which it contains are the same and generally occur in approximately the same relative proportions. It is, however, characteristic of much of the quartzite water to have a small content of iron, perhaps chiefly because much of the water reaches the rock directly from the oxidized zone of the drift and so contains free oxygen, which keeps the iron out of solution but does not interfere with the other dissolved constituents. (See the analysis in the accompanying table, p. 336.) No. 3 is remarkably free from dissolved matter of any kind.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Luverne.—The city of Luverne lies west of Rock River on a terrace about 25 feet above the level of the flood plain. Both terrace and flood plain are composed of alluvial sand and gravel saturated with water. The public supply is taken from two wells, each 19 feet deep, one 20 and the other 13 feet in diameter. They are located on the flood plain about 200 feet from the river. In July, 1907, the ground-water level was 10 feet below the surface, and pumping at the rate of 750 gallons a minute from the two wells lowered this level only about 3 feet. In dry years the supply is less copious. The water is only moderately hard, as is shown by the analysis given in the table (p. 336). It is used by most of the people, and approximately 100,000 gallons is consumed daily. Most of the private wells, though usually bored or dug only a short distance into the alluvium, furnish water freely.

Hardwick.—In some parts of Hardwick village the quartzite outcrops and in others the drift is 100 feet thick, the rock surface being very irregular. The public waterworks is supplied by a 6-inch well 420 feet deep, all but 80 feet of this depth being in rock. The water rises within 36 feet of the surface. The test of this well has been mentioned above (p. 333). The analysis in the table (p. 336) shows that the water is only moderately hard. There is no system of mains and little use is made of the supply except in dry years, when many of the shallow private drift wells fail.

FARM WATER SUPPLIES.

In the area of attenuated drift the inexpensive but unreliable shallow wells have gradually been replaced by the much more costly but also more satisfactory rock wells, until now there are scores of the latter and more are being sunk each year. At first drilling in the quartzite presented serious difficulties, but by patience and skill these have now been almost entirely overcome, so that though the drilling of a rock well is still a slow and expensive process it is no longer an uncertain project. The special difficulties are discussed under the heading "Problems relating to wells" (pp. 87–88). The original cost of a rock well is relatively great, but such a well when once drilled will last an indefinite time without further expense, as there is no screen to become corroded. As the supply is generally nearly constant, the farmers content themselves with a small yield rather than go to the additional expense of drilling deeper. One hundred gallons an hour, which is the yield guaranteed by some drillers, appears very small, but it is enough to keep a windmill working slowly and to supply amply the consumption on an ordinary farm.

In the larger area where the quartzite is deeply buried the farm supply is derived from the glacial drift, or, locally, from the alluvial and outwash deposits. The wells in the drift are mostly of the shallow bored type, but there are also a few drilled wells. In the alluvial and outwash deposits satisfactory supplies are obtained from driven wells.

SUMMARY AND ANALYSES.

The following formations will yield water: (1) Alluvial and outwash deposits, (2) glacial drift (proper), (3) Cretaceous sandstone, and (4) Sioux quartzite ("red rock").

The first are available chiefly in the wide valley of Rock River, where they furnish large quantities of water at shallow depths. The second constitutes the most valuable source throughout the eastern and southern parts of the county, where it has considerable thickness and affords large supplies. The third is believed to lie at a depth of several hundred feet in some localities in the eastern and southern parts of the county and, though it has not yet been utilized, would here probably yield liberally. The fourth contains a relatively small store of water, but if penetrated several hundred feet will generally furnish enough not only for farm purposes but also for ordinary industrial and public supplies. Where other formations are wanting it is invaluable.

The water from the alluvial and outwash deposits is only moderately hard, and that from the quartzite varies, though it is commonly rather soft; but the water from the drift is invariably hard, and the Cretaceous water is liable to be still less satisfactory.

There is no water-bearing formation below the quartzite, and there is no prospect of obtaining either flowing wells or soft water by deep drilling. It is, of course, advisable to sink to a depth of several hundred feet either in the drift or in the quartzite if this is necessary to acquire an adequate supply.

Mineral analyses of water in Rock County.

[Analyses in parts per million.]

	Surface deposits.		Sioux quartzite.	
	Alluvium.	Glacial drift.		
	1.	2.	3.	4.
Depth .... feet..	19	60	....	420
Diameter of well .... inches..	Large.	3	....	6
Silica (SiO_2)	16	10	18	12
Iron (Fe)	....	6	.2	.3
Iron and aluminum oxides (Fe_2O_3+Al_2O_3)	26	4.2	2	2.2
Calcium (Ca)	96	152	15	81
Magnesium (Mg)	17	42	9	36
Sodium and potassium (Na+K)	16	76	2	7
Carbonate radicle (CO_3)	....	.0	.0	.0
Bicarbonate radicle (HCO_3)	350	681	58	310
Sulphate radicle (SO_4)	50	126	24	45
Chlorine (Cl)	5	11	5	45
Nitrate radicle (NO_3)	....	.0	.2	5
Total solids	399	768	106	393

1. City wells at Luverne.
2. Well at the rear of E. Olson's blacksmith shop at Hardwick. July 30, 1907.
3. Spring on the farm of L. McDermott, SW. ¼ sec. 25, T. 103 N., R. 45 W. July 29, 1907.
4. Village well at Hardwick. August 1, 1907.

Analyses 2, 3, and 4 were made for the United States Geological Survey by H. A. Whittaker, chemist Minnesota state board of health. Analysis 1 was furnished by Mr. C. N. Philbrick, chief engineer city light and waterworks, Luverne. The analyst and date are not given.

SCOTT COUNTY.

By C. W. Hall and M. L. Fuller.

SURFACE FEATURES.

Scott County is topographically the lowest county south of Minnesota River. It has a maximum altitude of a little over 1,100 feet on Mount Herber and at one or two other points in the southern part, and a minimum of 690 feet on the flood plain of the Minnesota, its average altitude being about 925 feet. The morainal accumulations in the eastern half of the county, though of no great height, are marked by hills of very irregular outline, interspersed with which are numerous depressions occupied by marshes and lakes. In the western half of the county the surface is gently rolling, or even flat, and is characteristic of the type of plateau which southeastern Minnesota represents. Its surface is broken in places by streams flowing in valleys, some of which are 150 feet or more in depth. On the northwest is the valley of the Minnesota, which lies 200 to 225 feet below the neighboring uplands and has broad, swampy, alluvial bottoms 1 to 3 miles in width. Bordering the alluvium, and lying 25 to 50 feet above it, are a number of low rock terraces, the principal examples of which are found near Shakopee, Merriam Junction, and Jordan. Still higher, at an elevation of 100 to 150 feet above the river, are a number of broad terraces known locally as "prairies"—the Shakopee, Belle Plaine, and Sand prairies near Jordan being the most important. A number of ancient stream channels lead eastward into Cannon River.

SURFACE DEPOSITS.

The glacial drift has a thickness of over 200 feet along the river, but is thinner inland, where the rock rises in places nearly to the surface, as along the eastern edge of the county. The gravelly portions commonly carry an abundant store of water, which is available to wells of moderate depth. Usually the supplies are sufficient for small industries, as well as for farm and domestic uses, but are not commonly adequate where much water is required.

Alluvium is found principally along Minnesota River, but minor amounts are found along other streams. The boring at Belle Plaine revealed 200 feet of sands and gravels, but it is doubtful whether these consist entirely of alluvium. Rock shows through the deposits at a number of places, and it is probable that the average thickness of the alluvium is not more than 50 feet. It contains considerable amounts of water, but owing to the presence of silt its supplies are given up rather slowly.

The terrace sands and gravels occur at a number of points along the Minnesota, especially south of Shakopee and southeast of Belle Plaine. They represent the deposits of glacial streams, their occurrence at the present time as terraces being due to more recent erosion. The materials generally consist of clean sands and gravels, having a thickness of 30 to 40 feet and resting on benches cut in the underlying drift or in the more ancient Paleozoic rocks. They readily absorb the rain, but the water is quickly lost by drainage into the adjoining valleys, at least near the edges of the terraces. Farther back, and where there are depressions in the underlying drift surfaces, considerable water remains.

PALEOZOIC FORMATIONS.

The Platteville limestone occurs beneath the drift in the highest lands in the eastern and southeastern parts of the county, but its total thickness is probably not more than 20 feet. It is a protecting cap to the underlying St. Peter sandstone.

The St. Peter sandstone, which probably exceeds 110 feet in thickness, is exposed at the surface nowhere within the county. It covers a broad area, however, beneath the drift and underlies the Platteville along the eastern border, stretching thence westward into the central part of the county. Where it lies immediately under the drift it is commonly reported as a loose sand rather than as a sandstone; indeed many drillers fail to distinguish it from the glacial drift. It appears to hold much more water than the drift and affords ample supplies for most purposes. However, as the water is not under much pressure it does not enter the wells freely enough to furnish large supplies.

The Prairie du Chien group is here represented by 150 feet of buff magnesian limestone, occasionally mottled with red and yellow, separated in the upper part by about 5 feet of sandstone, which is believed to represent the New Richmond sandstone. It outcrops along Minnesota River near the village of Shakopee, from which the upper dolomite derives its name. The rocks as a whole are characterized by numerous joints, bedding planes, and solution passages which may contain water. Good supplies are generally obtained whenever it is possible to sink wells to the level of the adjoining river, which controls the water level in the limestone along its borders. Much of the water of the deep upland wells probably comes from the sandy bed, which is regarded as the equivalent of the New Richmond sandstone of other counties.

The Jordan sandstone is about 125 feet thick. It is exposed at Jordan and along Minnesota River to the north. Southward it bends away from the river, leaving the limestone of the St. Lawrence formation outcropping in the valley, but it returns again to the valley near the southwestern corner of the county. The formation is a magnificent water-bearing bed, furnishing, even along its outcrop, abundant supplies for ordinary domestic, farm, and industrial purposes, though the water rises but little. Under the uplands it constitutes an important source of supply to the deeper wells.

The St. Lawrence formation here consists of a red or yellow shaly dolomite, having a total thickness of about 150 feet and outcropping along the eastern bank of Minnesota River. It carries very little water, but gives rise to a few springs of small size. Its principal value results from the fact that it serves as a cap to the underlying Dresbach sandstone, confining the water of the latter under considerable artesian pressure.

Beneath the St. Lawrence formation, at a depth of about 200 feet below the river in the southwestern part of the county, occurs the Dresbach sandstone, a water-bearing bed of the best character. Owing to the greater pressure upon its water, incident to its protected situation, it affords larger supplies and better head along the Minnesota than does the Jordan. In the valley of the Minnesota it gives rise to flows. Farther back, beneath the uplands, the advantage of the Dresbach over the Jordan is not great. Below the Dresbach occurs a considerable thickness of Cambrian shales, underlain by sandstones whose characters and water supplies are very similar to those of the Dresbach sandstone. Their yield, however, is not materially greater than that of the Dresbach sandstone, and there is therefore generally no object in sinking wells to them.

Many years ago the discovery of a slightly saline spring led to the drilling of a deep well at Belle Plaine for the purpose of prospecting for brine. The record of this well, together with the hypothetical correlation of the strata, is given below.

Record of the Belle Plaine salt well.[a]

	Thickness.	Depth.
	Feet.	*Feet.*
Alluvium and drift (?)	216	216
Sandstone [basal Cambrian]	16	232
Red ocherous sand and shale	10	242
Purple shale mottled with white	40	282
Red to greenish shale as above	108	390
Red shale or marl	6	396
Purple and mottled shale	24	420
Red quartzite and shale	20	440
Ocherous shale	10	450
Dark-brown micaceous quartzite	10	460
Dark greenish brown micaceous quartzite	10	470
[Red clastic series:]		
Dark reddish brown quartzite and greenish shale	50	520
Iron-stained light green	10	530
Red sandy shale	20	550
Red, brown, and green shale	40	590
Brown, red, and green shale	24	614
[Sioux quartzite]:		
Shale and quartzite (entered)	96	710

[a] Upham, Warren, Final Rept. Geol. and Nat. Hist. Survey Minnesota, vol. 2, 1885, pp. 117-119.

The red clastic series, which is present everywhere in southeastern Minnesota, appears here to be 240 feet thick. The above section is significant in apparently showing the absence of the water-bearing Dresbach sandstone, which furnishes such desirable supplies at Chaska, Merriam Junction, and Henderson. The "Sandstone [basal Cambrian]" is apparently a remnant of this formation. Compare the Jordan well only 7 or 8 miles away. (See p. 340.)

UNDERGROUND WATER CONDITIONS.

Wells.—Open wells obtaining supplies from sandy or gravelly layers only 15 or 20 feet below the surface were formerly the principal source of supply. They were found, however, to fail in times of drought, and drilled wells going to depths of 50 to 150 feet have been generally substituted, the supplies being obtained from sand or gravel beds in the drift. The deeper water is not only more ample, but, being beyond the reach of pollution, is much safer than that from the old shallow wells. Wells drilled to the rock are not common on the uplands, but nearly every township has one or more. In the valleys driven or drilled wells sunk in the alluvium or underlyimg drift are common where these deposits have considerable thickness, but where the rocks are near the surface, as at Shakopee, Jordan, etc., the wells nearly all enter the rock, obtaining water from the immediately underlying formation at depths of 30 to 50 feet or deeper. The supplies from the alluvium and surface rocks are rather meager. Hence where large supplies are required it is necessary to sink to the Dresbach or lower sandstones.

Head of the water.—Owing to the relief and the varied sources of supply, the range in the head of water relative to the surface is considerable. In the shallow wells ending in the upper part of the drift the water usually stands near the surface, but where the deeper drift is drawn upon the head is generally lower. Along the edge of the bluff bordering the Minnesota Valley it is not uncommon to have to lift the water from depths of 50 to 100 feet, but on the flood plain of the Minnesota the wells penetrating the Dresbach and lower sandstones overflow at the surface and may have a head of 25 to 50 feet above the river level.

Springs.—Springs are common at the base of bluffs along the valleys of the Minnesota and its tributaries, and afford domestic and stock supplies for many farms. Most of them are small, but where the limestone is present to collect the water flows of considerable volume sometimes occur. The so-called Jordan mineral springs, owned by O. Rosendahl, have in recent years attracted considerable attention. They issue from the lower part of the bluff on the south side of the Minnesota Valley. The water is charged with sulphureted hydrogen and is reputed to have medicinal value.

WATER SUPPLIES FOR CITIES AND VILLAGES.

New Prague.—The city of New Prague has a public supply which is used by about three-fourths of the inhabitants. The water is obtained from an 8-inch well that is 289 feet deep.

Belle Plaine.—A system of public waterworks has recently been installed in this city. The supply is taken from a well 8 inches in diameter and 213 feet deep. The underground conditions in this vicinity have already been discussed.

Shakopee.—The city of Shakopee has no public supply, but is provided with an engine and hose, the water being pumped from the river in case of fire.

Jordan.—As the city of Jordan has no system of waterworks, all the people depend on private supplies, derived chiefly from water-bearing sand near the surface. The Minneapolis and St. Louis Railroad well is supplied from the Dresbach sandstone, which was penetrated at a depth of 210 feet. The water in this well rises within 4 feet of the surface, and the well has been tested at 125 gallons a minute. The section is given below:

Well section at Jordan.

[Authority, H. G. Kelley, chief engineer.]

	Thickness.	Depth.
	Feet.	*Feet.*
Alluvium	112	112
Shale and dolomite (St. Lawrence)	98	210
Sandstone (Dresbach)	75	285
Shale	2	287

Merriam Junction.—The following is the section of the Chicago, St. Paul, Minneapolis and Omaha Railway well at Merriam Junction. An analysis of the water is given in the table below.

Well section at Merriam Junction.

[Authority, J. F. McCarthy, driller.]

	Thickness.	Depth.
	Feet.	*Feet.*
Alluvium	130	130
Hard, crystalline dolomite (St. Lawrence)	85	215
Soft, shaly dolomite (St. Lawrence)	95	310
Sandstone (Dresbach and possibly in part the red clastic series) (entered)	351	661

SUMMARY AND ANALYSES.

The beds of sand and gravel that are generally encountered on the uplands within 200 feet of the surface almost invariably yield supplies adequate for ordinary purposes, but still larger supplies can be obtained from the several sandstone formations at greater depths. The water will rise nearer to the upland surface from the shallow zones than from the deeper one, but in the valley generous flows can usually be obtained from the deep sandstones, though the section of the so-called salt well at Belle Plaine gives a warning that these sandstones may locally vary in their water-carrying capacity. After the red clastic series is encountered the prospects of obtaining a satisfactory supply are poor.

Mineral analyses of water in Scott County.

[Analyses in parts per million.]

	1.	2.	3.	4.	5.	6.	7.	8.
Depth feet		80	{66 and 106}	45	18	85	68	661
Silica (SiO_2)	18	20	4.4	23	20	16	20	12
Iron (Fe)	18	Trace.	24	2.9	4.9		2.1	11
Calcium (Ca)	79	72	139	74	72	193	92	97
Magnesium (Mg)	22	25	57	25	29	102	31	38
Sodium and potassium (Na+K)	1.3	3.9	230	1.3	1.8	39	14	58
Bicarbonate radicle (HCO_3)	320	344	390	333	370	962	384	413
Sulphate radicle (SO_4)	20	6	95	14		168	65	92
Chlorine (Cl)	2.2	3.6	471	2.2	2.8	16	3.6	64
Total solids	338	291+	1,212	307	314	1,025	420	576

1. Spring at Savage.
2. Well of Christopher Schmidt at Belle Plaine. April, 1897.
3. Chicago, St. Paul, Minneapolis and Omaha Railway well at Belle Plaine. June, 1900.
4. Gran Milling Company well at Belle Plaine. March, 1906.
5. Chicago, St. Paul, Minneapolis and Omaha Railway well at Savage. June, 1901.
6. Well at Jacob Ries's Bottling Works at Shakopee. June, 1897.
7. Well of George A. Cole at Jordan. June, 1897.
8. Chicago, St. Paul, Minneapolis and Omaha Railway well at Merriam Junction.

Analyses 3, 4, 5, and 8 were furnished by G. M. Davidson, chemist Chicago and Northwestern Railway Company. Analyses 2 and 7 were furnished by Edgar & Mariner. Analysis 6 was furnished by Jacob Ries.

SIBLEY COUNTY.

By C. W. Hall and M. L. Fuller.

SURFACE FEATURES.

Sibley County has an average elevation of about 1,000 feet above sea level, or fully 200 feet above the broad valley of Minnesota River, which borders it on the east. Though its surface is generally only gently undulating, locally it is rolling, and the depressions are occupied by lakes. However, no prominent moraines are found in the county. Its southern and eastern portions are drained by Rush River and other tributaries of the Minnesota, whose valleys near their mouths attain a depth of 150 to 200 feet.

SURFACE DEPOSITS.

Crystalline rocks are found at a few points in the valley of the Minnesota, but the rest of the county is covered by a thick mantle of surface deposits through which very few wells penetrate.

Alluvium is found in the valleys of Minnesota River and its largest tributaries. Its thickness varies, probably averaging less than 50 feet. The depth to which wells are sunk at points along the valley before reaching rock indicate the presence of a deep preglacial channel, which is seemingly west of the present stream where it borders Carver County and mainly east of it along Sibley County.

The alluvium contains moderate quantities of water, but owing to the presence of considerable amounts of silt it is not given up as in coarser deposits. Supplies sufficient for ordinary purposes may be secured, but volumes adequate for large industries or public supplies are not to be expected.

Along the Minnesota at heights of 75 to 150 feet above the stream there is a series of terraces, cut principally into the bowlder clay of the glacial drift. The lower terraces are covered by only a thin layer of ancient alluvium, but on the higher ones this sand and gravel deposit is at many points 20 to 30 feet thick. The terrace deposits are found chiefly near the northeastern and southeastern corners of the county in tracts about one-fourth mile wide. They contain water in moderate amounts except near the outer edge of the terraces, from which it is drained into the adjacent valleys.

Except for the few outcrops near the Minnesota, Sibley County is wholly covered by drift. From exposures along the valley and the sections revealed by wells, its thickness in the eastern part of the county is known to be about 250 feet. Elsewhere the thickness is even greater, as shown by well sections, reaching 397 feet near the northeastern corner of the county, 275 feet at Gibbon, and 400 feet at Winthrop. (See the sections given below.)

The drift as a whole consists mainly of bowlder clay, some of the wells reporting this material (with almost no sand or gravel seams) for the entire depth to the rock. Below the surface soil is found the characteristic yellow oxidized clay to a depth of 12 or 15 feet, and below this, in most localities, a great thickness of grayish blue clay derived largely from Cretaceous material brought in from the northwest, and including some carbonized wood or lignite. At one point very near the northeastern corner of the county there was found a small amount of red clay, representing material brought from the northeast.

Until the last few years the water supplies throughout Sibley County have been obtained mainly from shallow surface wells, but in recent years many deep wells have been bored, the present number probably being not less than 200. It has been found, however, that, notwithstanding the great thickness of the drift, sandy or gravelly layers are relatively uncommon, and it is often necessary to drill several hundred feet in search of water supplies. In some wells no water zones are encountered in the drift, but a thin porous stratum is generally found at the contact of the drift with the underlying rock. By far the greater number of wells can obtain supplies sufficient for domestic, farm, and industrial purposes, and even for public supplies, without penetrating the rock.

ROCK FORMATIONS.

The Jordan sandstone probably occurs in the southeastern extremity of the county but is absent elsewhere.

The St. Lawrence formation consists of thin layers of pink magnesian limestone alternating with beds of shale that are in many parts characterized by a green color. It outcrops at a number of points in the Minnesota Valley north of Henderson and underlies a belt several miles wide parallel to the river. It gives rise, along the stream mentioned, to a large number of springs, many of which are used in the rapidly developing dairy industry. Six streams fed by springs are reported in T. 113 N., R. 26 W., and one in sec. 2, T. 112 N., R. 26 W. Some of the springs are said to form streams large enough to furnish water power. Beneath the uplands the St. Lawrence, though probably containing moderate amounts of water in its bedding planes, joints, etc., is not likely to yield more than the overlying drift and is not to be considered as a promising source of supply.

The Dresbach sandstone and underlying shales have not been observed in Sibley County, but were encountered below the St. Lawrence formation in the deep well at Henderson and probably lie immediately beneath the drift in the central part of the county. The successive beds of sandstones, which are separated by shale, are good water bearers and will yield abundant supplies to deep wells both in the valleys and uplands, but the water will rise to the surface in the Minnesota Valley only.

Outcrops along Minnesota River make it clear that 50 feet or more of red conglomerate and at least 250 feet of red or gray quartzite intervene between the rocks just described and the granite. They are of little or no value as a source of water supply.

The western part of the county is underlain by granitic rocks which yield no water except near the top, where they may be fissured or decayed.

To supplement the above statements in regard to the character and distribution of the formations found in this county, the following logs of deep wells with their hypothetical interpretations are here given:

Section at Henderson.

[City well sunk in 1896. Altitude of the surface is about 750 feet above sea level. Authority, H. P. Pfeiffer.]

	Thickness.	Depth.
	Feet.	*Feet.*
Alluvium: Gravel	20	20
Glacial drift: Sand, gravel, and bowlders	25	45
St. Lawrence formation:		
Gray and yellow limestone	10	55
Pink limestone	9	64
Green clay and limestone	250	314
White water-bearing sand	13	327
Red limestone	117	444
Gray limestones and sandstones	30	474
Red limestone	10	484
White sandstone	35	519
Coarse white sand	55	574
Coarse yellow sand	35	609
Green sandstone and limestone	15	624
Coarse sandstone	20	644
Fine-grained yellow sandstone	62	706

Section at Green Isle.

[Minneapolis and St. Louis Railroad well. Authority, chief engineer Minneapolis and St. Louis Railroad Company.]

	Thickness.	Depth.
	Feet.	*Feet.*
Artificial filling	3	3
Glacial drift:		
Blue clay	177	180
Sand and gravel (water)	24	204
Dresbach sandstone (?) and underlying beds:		
Soft white sandstone (water)	25	229
Red clay or shale	15	244
Blue shale	15	259
Hard white sandstone	87	346

Section at Winthrop.

[Well drilled for the Minneapolis and St. Louis Railroad Company in 1903. The surface altitude is about 1,018 feet above sea level. Authority, H. G. Kelly, chief engineer Minneapolis and St. Louis Railroad Company.]

	Thickness.	Depth.
	Feet.	*Feet.*
Clay	212	212
Fine-grained sand (water)	8	220
Clay (glacial)	150	370
Coarse sand	21	391
White sand	8	399
Red shale	9	408
Red shale with white sand	4	412
Granite (entered)	2	414

UNDERGROUND WATER CONDITIONS.

Yield of water.—Near the surface the drift contains considerable water but the yield is not generally large and the supply is frequently affected by drought. The bulk of the drift is relatively barren of water-bearing beds, as has already been explained, but at or near the base one or more beds usually exist which will yield generously. In the eastern portion of the county the rock formations will furnish large supplies, but farther west these are absent. The 8-inch city artesian well at Henderson is reported to flow 300 gallons a minute; the 10-inch railway well at Green Isle has been pumped at the rate of 150 gallons a minute; and the 10-inch village well at Winthrop has been tested at the rate of 75 gallons a minute.

Head of the water.—On the uplands flowing wells can not be obtained from the deeper beds, but in the Minnesota Valley the water from the sandstones will generally rise above the surface. The following table gives the head of the water from the deeper drift and sandstone zones at various localities in this county or adjacent to it:

Depth and altitude of the head of the water at localities in and near Sibley County.

Locality.	Distance of water level above (+) or below(−) surface.	Head above sea level.
	Feet.	*Feet.*
Buffalo Lake (Renville County)	− 10	1,055
Stewart (McLeod County)	− 13	1,045
Brownton (McLeod County)	− 24	995
Glencoe (McLeod County)	− 90	905
Hamburg (Carver County)	− 90	909
Fairfax (Renville County)	− 80	960
Gibbon	− 80	964
Winthrop	−121	897
Henderson	+ 60	810
Lesueur (Lesueur County)	+ 18	778

WATER SUPPLIES FOR CITIES AND VILLAGES.

Winthrop.—The village of Winthrop has a system of public waterworks supplied from a 10-inch well which is 239 feet deep. As is shown by the stratigraphic section of this well given on page 344, the Archean granite was struck 412 feet below the surface. Most of the inhabitants use water from private wells.

Henderson.—The section and other data in regard to the city well at Henderson are given on pages 343–344. The system of waterworks is used chiefly for fire protection, the domestic supply being taken principally from other wells.

Gibbon.—The village of Gibbon is provided with a system of waterworks which draws from a well 210 feet deep, but private wells are relied on for domestic supplies.

SUMMARY.

At nearly all points in this county beds of sand or sandstone which will yield adequate supplies occur within several hundred feet of the surface. The water from these depths will generally be found to be more satisfactory for domestic and boiler uses than that from shallow sources. It is under sufficient pressure to give rise to flows in the Minnesota Valley, but will everywhere stand below the upland level. In the western part of the county granitic rock will be encountered at depths of several hundred feet. It should not be penetrated, as it is not water-bearing.

STEELE COUNTY.

By C. W. Hall and M. L. Fuller.

SURFACE FEATURES.

The upland surface of Steele County, which stands between 1,100 and 1,200 feet above sea level, is interrupted only by two morainal belts and by the shallow valleys of Straight River and its tributaries. Of the morainal belts the more eastern is the narrower, ranging from one-half mile to 5 miles in width and generally standing not more than 100 feet above the surrounding plateau surface. It crosses the county from north to south a little west of its eastern border and is characterized by groups of irregular hills and basins. The other belt, which is somewhat lower, is seen along the western edge of the county, south of the Chicago and Northwestern Railway, where a width of about 4 miles falls within the county with an equal or greater width in Waseca County to the west. The intermediate area, though slightly undulating, is relatively flat and is characterized in places by lakes and swampy tracts of considerable size, some of which have been artificially drained. Straight River rises in the southern part of the county and flows northward between the moraines, eventually joining Cannon River. Throughout most of its course its valley is shallow, but near the border of Rice County the valley deepens to about 100 feet.

SURFACE DEPOSITS.

The glacial drift, which everywhere mantles the surface, varies in depth from a few feet in the valley of Straight River to 50 or 100 feet along its edges, 100 to 150 feet in the uplands of the central part of the county, and 150 to 200 feet in the morainal areas of the eastern and western parts of the county.

Near Deerfield a number of wells have encountered a bluish-black clay underlain by gravel and sand and some lignite, the material resembling the deposits which have been referred to the Cretaceous in other counties in southeastern Minnesota.[a] While there is no definite evidence as to the age of these beds, a late suggestion by Leverett and Sardeson is that they belong to a pre-Kansan deposit of the glacial drift. Practically no water occurs in the clays, but the sands beneath generally contain considerable amounts.

PALEOZOIC FORMATIONS.

The Devonian sandstone is a fine-grained gray to white sandstone with a few shaly limestone layers. It underlies a small area near the southeast corner of the county and probably reaches as far north as Owatonna, where a sandstone is known to rest upon the shaly limestone strata that are regarded as Galena. The formation generally yields water in rather large amounts and in some places under considerable artesian pressure.

The Galena limestone, Decorah shale, and Platteville limestone doubtless underlie the entire county, and from well records and other evidence they appear to have an aggregate thickness of nearly 200 feet. The uppermost formation is at many places broken and fissured and contains water under more or less artesian pressure. In some wells abundant supplies are obtained, but in others the yield is not satisfactory.

The St. Peter sandstone underlies the Platteville limestone throughout the entire county and is reached at 300 feet or more below the surface. It generally contains abundant water and yields strong supplies.

Below the St. Peter the following water-bearing beds occur:

List of water-bearing beds lower than the St. Peter sandstone.

	Approximate thickness.	Approximate depth below the bottom of the St. Peter.
	Feet.	*Feet.*
New Richmond sandstone	10 to 20	50
Jordan sandstone	80	150
Dresbach sandstone	90	500
Cambrian sandstone and shale	200	650

All these formations contain large quantities of water under sufficient pressure to cause them to enter the wells freely. They may be expected to furnish supplementary supplies of importance if the St. Peter fails through overdraft or otherwise.

[a] Harrington, M. W., Final Rept. Geol. and Nat. Hist. Survey Minnesota, vol. 1, 1882, p. 398.

The following log of the well drilled for the city of Owatonna in 1878 gives a section of the strata to the bottom of the St. Peter:

Well section at Owatonna.[a]

	Thick-ness.	Depth.
Glacial drift:	*Feet.*	*Feet.*
Gravel and sand	20	20
Blue, stony clay	14	34
Gravel and bowlders with much water	5	39
Devonian(?):		
White quartz sand	21	60
Soft limestone, decayed	2	62
Yellow clay, making the water very yellow	1	63
Hard white sandstone	35	98
Galena, Decorah, and Platteville formations (?):		
Blue compact limestone	20	118
Blue sandstone, "like grindstone grit"	10	128
Blue shale	10	138
Light-gray shale	10	148
Shale, "full of specks of iron pyrites, very hard to drill"	3	151
Blue shale	20	171
Light-gray shale	5	176
Blue clay	12	188
Hard yellow rock	2	190
Blue clay and shale	50	240
Lead-colored clay, making the water dark blue	3	243
Hard yellow rock	7	250
Blue arenaceous shale	3	253
Blue shale	8	261
A cherty layer	1	262
Blue limestone	28	290
St. Peter sandstone:		
White sandstone	80	370
Similar to the last, but very hard; thought to contain iron pyrites	8	378
White sandstone	9	387

[a] Upham, Warren, Final Rept. Geol. and Nat. Hist. Survey Minnesota, vol. 1, 1882, pp. 398-399. The interpretation here given is by C. W. Hall and is somewhat different from that given by Mr. Upham.

UNDERGROUND WATER CONDITIONS.

Wells.—Except along the valley of Straight River the drift is everywhere of considerable thickness, and wells sunk to sandy or gravelly layers 10 to 40 feet below the surface are common. In general the shallow supplies are less satisfactory than the deeper ones, and have the disadvantages of being liable to pollution and of failing in times of drought. For these reasons many relatively deep wells have been drilled. In the valley of Straight River, as at Owatonna, some of the wells penetrate to the underlying sandstones.

Head of the water.—Although Steele County contains some of the highest land in the southeastern portion of the State, there are many flowing wells within its area. These occur in the shallow valleys through the central part of the county and obtain their head from the high morainic belts on either side. The area in which flows can be obtained is shown in Plate IV.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Owatonna.—The public supply at Owatonna is taken from five wells 95 feet deep, and one 640 feet deep. Shallow wells are the common source for private water supplies, but in recent years drilling has been carried in a number of wells to depths of 200 to 250 feet. Several flowing wells are reported, ranging in depth to 250 feet.

Blooming Prairie.—The village of Blooming Prairie has a system of public waterworks supplied from a drilled well 245 feet deep, which ends in Galena or Platteville limestone.

Ellendale.—More than one-half of the people of Ellendale depend on the public supply which is obtained from a well 212 feet deep.

SUMMARY AND ANALYSES.

Adequate supplies can usually be obtained from the glacial drift or creviced portions of the Galena limestone, but if a larger yield is required than these formations will furnish drilling should be continued to the sandstones which everywhere underlie the county and which will provide generous and permanent supplies.

Mineral analyses of water in Steele County.

[Analyses in parts per million.]

	1.	2.	3.	4.	5.	6.	7.	8.
Depth .... feet	....	....	....	....	....	....	28	35
Silica (SiO_2)	10	17	33	33	19	18	17	11
Calcium (Ca)	69	233	216	237	56	42	123	98
Magnesium (Mg)	26	23	24	22	15	15	48	36
Sodium and potassium (Na+K)	6.2	5.5	5.8	4.8	12	16	35	27
Bicarbonate radicle (HCO_3)	339	....	391	....	277	248	593	481
Sulphate radicle (SO_4)	3.9	....	Tr.	Tr.	3.3	2	49	31
Chlorine (Cl)	6.7	....	1.7	2.1	1.8	.9	29	18
Total solids	290	294(?)	678	304(?)	392	348	594	459

	9.	10.	11.	12.	13.	14.	15.	15.	17.
Depth .... feet	25	29	29	28	29	15	14	640	640
Silica (SiO_2)	....	....	....	....	....	....	....	16	9.9
Calcium (Ca)	102	71	127	122	122	103	132	96	97
Magnesium (Mg)	32	31	40	39	38	34	42	35	26
Sodium and potassium (Na+K)	16	16	21	37	34	13	27	5	8
Bicarbonate radicle (HCO_3)	399	396	356	353	350	375	452	467	496
Sulphate radicle (SO_4)	61	11	233	219	238	88	128	2.9	6.3
Chlorine (Cl)	20	19	....	19	....	20	42	5.5	6.1
Total solids	429	426	592	609	605	453	608	....	....

1. Straight River at Owatonna. April, 1889.
2. Spring at Owatonna. January, 1905.
3. Spring at Owatonna. January, 1905.
4. Spring at Owatonna. January, 1905.
5. Morford Spring at Owatonna. 1875.
6. Flowing Spring at Owatonna. 1875.
7. Chicago and Northwestern Railway well at Owatonna. January, 1889.
8. Chicago and Northwestern Railway well at Owatonna. March, 1890.
9. Chicago, Milwaukee and St. Paul Railway well at Owatonna. August, 1890.
10. Chicago, Milwaukee and St. Paul Railway well at Owatonna. December, 1899.
11. Chicago, Milwaukee and St. Paul Railway well at Owatonna. March, 1900.
12. Chicago, Milwaukee and St. Paul Railway well at Owatonna. April, 1900.
13. Chicago, Milwaukee and St. Paul Railway well at Owatonna. July, 1900.
14. Chicago, Milwaukee and St. Paul Railway well at Blooming Prairie. August, 1890.
15. Chicago, Milwaukee and St. Paul Railway well at Blooming Prairie. December, 1893.
16. City well at Owatonna. 1890.
17. City well at Owatonna. 1891.

Analyses 2, 3, and 4 were made by H. C. Carel, and analyses 5 and 6 by Gustave Bode. Analyses 1 and 7 were furnished by G. M. Davidson, chemist Chicago and Northwestern Railway Company; analyses 8 to 17 by G. N. Prentiss, chemist Chicago, Milwaukee and St. Paul Railway Company.

SWIFT COUNTY.

By O. E. Meinzer.

SURFACE FEATURES.

Most of Swift County consists of a very gently undulating prairie, characterized by marshy areas through which sluggish streams meander, but containing few definite drainage channels and few well-defined lakes. Near the northeastern and northwestern corners, however, the topography is more morainic and there are numerous lakes. A small morainic area also occurs in the vicinity of Danvers near the center of the county. Two rivers flow southward and empty into the Minnesota—the Pomme de Terre in the western and the Chippewa in the central part. The valleys of both are small where they enter the county, but become wider and deeper as they progress. Their few tributaries have not yet dissected the prairie surface to an important extent. The Minnesota Valley borders the county for a few miles on the southwest.

SURFACE DEPOSITS.

Description.—The surface deposits include ordinary glacial drift, glacial outwash materials, and recently deposited alluvium. The drift covers the entire county and constitutes by far the greatest part of the surface deposits. The materials washed out from the ice sheet were in large measure laid down along the principal streams, forming extensive sheets of stratified sand and gravel. Alluvial deposits made by the streams since the last glacial epoch are of trivial importance.

The thickness of the surface deposits ranges from less than 100 to more than 300 feet and averages somewhat more than 200 feet. In general it is least in the southwestern part and increases toward the northeast. At Appleton underlying formations have been struck at a depth of 65 feet, and in the northwestern portion of the county at 185 to 240 feet, but in the morainic area of the northeast drilling has gone to depths of at least 300 feet without reaching the bottom of the drift.

Yield of water.—Wherever the outwash materials are found at the surface they provide relatively copious supplies from depths commonly ranging between 10 and 40 feet. The sand and gravel deposits intermingled with the bowlder clay of the glacial drift are generally saturated with water, and in nearly every locality beds of this type are sufficiently thick and coarse to afford supplies adequate for ordinary purposes. As a rule the deepest beds yield the most water and are least affected by drought. The two city wells at Benson are 6 and 8 inches in diameter and end in a gravel bed in the drift at a depth of 167 feet. Pumping at the rate of 160 gallons a minute from the two wells lowers the water 25 feet, but they will yield at this rate for an indefinite period.

Head of the water.—Throughout most of Swift County, especially the central and eastern portions, the water from the drift beds comes nearly to the surface. There are flowing wells in a number of localities and they could without doubt be obtained on the lowest places adjoining Chippewa River and its tributaries, and probably in other depressed areas. Flows are reported (1) in the vicinity of Swift Falls, on East Branch of Chippewa River; (2) on the lowest ground in the vicinity of Lake Hassel, north of Benson; and (3) along Shakopee Creek. They are also found along Chippewa River south of this county. In the city wells at Benson the water rises within 13 feet of the surface, which is virtually to the level of the river; at Danvers it is said to stand only 2 feet below the surface, but no flows are reported; and at Clontarf and Murdock it is reported to rise within 6 to 12 feet of the surface. The head is obtained largely from the high morainic belt northeast of this county.

Quality of the water.—The water from the lower portion of the glacial drift is softer than that from the upper. The latter contains much calcium and magnesium (the constituents that produce hardness), and these elements are associated to a large extent with the sulphate radicle and are deposited as hard scale in boilers. The deepest water, on the contrary, contains less calcium and magnesium, and only small quantities of sulphate radicle, and hence is better for boiler purposes. In the accompanying table compare analyses 1 to 4 with analysis 5. Though only one analysis (No. 5) is given of water from the lower portion of the drift, this one is known to be representative.

CRETACEOUS SYSTEM.

Description.—Cretaceous sedimentary rocks probably underlie most of this county, but in some localities, especially near Minnesota River, they are absent. But little deep drilling has been done and nearly all the wells end in the surface deposits. In the unsuccessful well drilled for the city of Benson glacial drift extended to a depth of at least 170 feet and the granitic rocks were entered at about 400 feet. Between these levels some shale was reported, but no reliable section is at hand. Shale was also reported in several wells in the western part of the county, the sections of two of which are given below. As shale has been encountered in all the counties bordering on Swift, it is safe to assume that it occurs generally in this county, but the Cretaceous must everywhere be thin, perhaps rarely reaching 100 feet in thickness. Although it consists chiefly of soft gray-blue shale ("soapstone"), there are probably also beds of sand or sandstone in some localities.

The following is the approximate section of an unsuccessful well on the farm of Philip Weise, sec. 28, T. 122 N., R. 42 W.:

Section in western Swift County (Weise well).

[Authority, Mr. Lawler, driller, Morris.]

	Thickness.	Depth.
Glacial drift:	*Feet.*	*Feet.*
Yellow bowlder clay	30	30
Blue bowlder clay	170	200
Cretaceous: Shale or "soapstone"	50	250
Archean: Granite	....	....

The following is the approximate section of a well on the farm of Philip Schreck, NE. ¼ sec. 8, T. 121 N., R. 43 W.

Section in western Swift County (Schreck well).

[Authority, Lewis Johnson, driller, Appleton.]

	Thickness.	Depth.
Glacial drift:	*Feet.*	*Feet.*
Soil and yellow bowlder clay	30	30
Quicksand	10	40
Blue bowlder clay	145	185
Cretaceous: Shale (a good yield of rather soft water at the depth of 248 feet)	63	248

Yield of water.—West of this county, where the Cretaceous is much thicker, it contains sandstone strata that yield large quantities of water, but in this county the granite comes nearer the surface and generally interrupts these water-bearing beds. The only successful well known to end in the Cretaceous is that of Philip Schreck, the section of which is given above. This well furnishes the farm supply and is said to have a good yield. On the other hand, a number of unsuccessful attempts at finding water in the Cretaceous are reported in this county and in Stevens County to the north.

Quality of the water.—The water from Philip Schreck's well is reported to be rather soft, but no analysis was made. The Cretaceous water immediately north, west, and south of Swift County is soft but rich in the alkalies, and if any truly Cretaceous water exists in this county it is probably of the same character. This water is entirely different from that obtained from the lower portion of the glacial drift. It contains less calcium and magnesium and much more alkali.

ARCHEAN ROCKS.

Granitic rocks were encountered in the village of Benson at a depth of about 400 feet,[a] in the northwestern part of the county

[a] The most reliable information was obtained from Mr. R. R. Johnson, who was president of the village council at the time the deep well was drilled. Mr. Johnson stated that drillings were submitted to Prof. N. H. Winchell, state geologist, and were pronounced by him to be granite. Mr. Johnson also stated that indications of decayed granite began at a depth of about 400 feet.

(sec. 28, T. 122 N., R. 42 W.) at a depth of 250 feet, and in the village of Appleton at a depth of 65 feet; they have frequently been reached in drilling on all sides of this county. In general the depth to granite increases toward the northeast, but it varies within short distances owing to irregularities of the present surface and of the surface of the rock itself. Throughout most of the county the depth is probably more than 300 but less than 500 feet.

Where the upper surface was not eroded by glacial action it appears to be greatly altered. Thus at Benson the decomposed material was entered at a depth of about 400 feet, but drilling was continued to about 700 feet, and for much of this distance the rock seems to have been more or less altered.

The granite is not water bearing except that very rarely small supplies are derived from the decomposed upper portion.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Benson.—The city of Benson is situated on a level plain on the east bank of Chippewa River, which has formed almost no valley at this point. At the surface there is outwash sand and gravel, which is water bearing, and beneath this lies the unstratified glacial drift, containing a bed of gravel between the depths of 160 and 190 feet, which constitutes the best water zone available.

The public supply is taken from two wells that end with screens at a depth of 167 feet. The yield and head of these wells are given above (pp. 350–351). The water has little permanent hardness and is relatively good for use in boilers. (See the analysis given in the table on p. 355.) It is used by about 800 people, and 25,000 gallons is consumed daily. Approximately 60 per cent of the inhabitants rely on private wells, nearly all of which are either dug or driven into the outwash sand and gravel and end at depths ranging from about 10 to 35 feet. The water is harder than that from the deep zone, as is shown by the analysis in the table (p. 355). The railway company uses water from the river.

Appleton.—The surface deposits at Appleton consist of unstratified glacial drift and outwash sand and gravel. In the drilling of a well at the brewery granite was struck, according to the report, at a depth of 65 feet. If any Cretaceous rocks exist in this locality they are probably thin and of no value as a source of water.

Most of the supply for the public waterworks is taken from Pomme de Terre River without filtering, but a part is obtained from a well 20 feet in diameter and 40 feet deep, situated on the bank of the river. Very few people use the public supply for drinking or cooking, but it is utilized for other purposes, and about 6,000 gallons is consumed daily. The private wells are for the most part either dug or driven and few are more than 35 feet deep. Water from the river is used at the mill.

FARM WATER SUPPLIES.

Virtually the entire farm supply is derived from wells that end in the surface deposits. These are of three types—driven, bored or dug, and drilled. The driven wells are confined to the areas where the outwash sands and gravels lie at the surface. Here they are the predominant type and usually furnish large and permanent supplies from depths rarely exceeding 40 feet. Outside of the areas of outwash deposits nearly all the wells were at one time of the bored or dug type, but many of these failed to stand the test of severe droughts, and hence have been replaced to a great extent by drilled wells. In the morainic districts the bored or dug wells are likely to give better satisfaction than those on the more gently undulating prairies where the drift includes less sand. Nearly all the drilled wells are 2 inches in diameter, and have a wide range in depth, most of them being between 75 and 150 feet deep. They afford ample quantities of water and are but slightly affected by drought.

SUMMARY AND ANALYSES.

Deep drilling should not be undertaken in this county, because the granitic rocks are everywhere within a few hundred feet of the surface, and no adequate supply of water will be found after they are entered. As the granite is generally expected to be very hard and difficult to drill, the decomposition of the upper portion has led to much popular confusion. There need be, however, very little difficulty in recognizing the decomposed granite. It has brilliant colors (red, green, yellow, white, etc.), which seldom fail to attract attention, and some of the unaltered constituents, such as grains of transparent quartz or silvery flakes of mica, usually remain. Frequently, too, hard quartzose veins are encountered before drilling has progressed far.

Though deep drilling should be out of the question, sinking to a depth of several hundred feet is recommended, especially for industrial purposes, because the water from the lower beds of the drift is generally softer and better for boiler use than that from shallow sources. The following procedure may be adopted where the quality of the water is of sufficient importance to warrant the expense involved:

1. Continue drilling until the granitic rocks are penetrated.
2. Keep a record of the materials passed through, noting for each layer the exact thickness and depth beneath the surface.
3. Whenever a water-bearing bed is encountered, determine also its yield and the quality of the water.

When the granitic material is reached, complete exploration of the underground water resources has been made, and all that remains is to finish the well at the most desirable horizon.

Mineral analyses of water in surface deposits (glacial drift, etc.) in Swift County.

[Analyses in parts per million.]

	Upper portion.				Lower portion.
	1.	2.	3.	4.	5.
Depth .... feet..	30	32	40	20	167
Diameter of well .... inches..	....	....	....	2	6 and 8
Silica (SiO_2)	26	....	....	26	30
Iron (Fe)	.2	....	....	Trace.	1.2
Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	4.5	....	....	4.6	3.6
Calcium (Ca)	145	214	161	175	71
Magnesium (Mg)	62	47	41	47	44
Sodium and potassium (Na+K)	50	5	46	56	16
Carbonate radicle (CO_3)	.0	....	....	.0	.0
Bicarbonate radicle (HCO_3)	493	402	414	492	430
Sulphate radicle (SO_4)	249	262	170	159	39
Chlorine (Cl)	33	95	109	120	2
Nitrate radicle (NO_4)	25	....	....	16	Trace.
Total solids	847	821	732	861	425

1. Well at Mr. Schoepf's blacksmith shop at Appleton. September 4, 1907.
2. "Storle's well" at Appleton. November 24, 1907.
3. "Stillwell's well" at Appleton. November 29, 1907.
4. Well at Hotel Columbia at Benson. September 25, 1907.
5. City wells at Benson. September 25, 1907.

Analyses 1, 4, and 5 were made for the United States Geological Survey by H. A. Whittaker, chemist Minnesota state board of health. Analyses 2 and 3 were furnished by G. N. Prentiss, chemist, Chicago, Milwaukee and St. Paul Railway Company.

WABASHA COUNTY.

By C. W. Hall and M. L. Fuller.

SURFACE FEATURES.

The surface of Wabasha County forms a relatively level plateau cut by deep stream valleys. This plateau has an elevation varying from 1,100 feet above the sea along the northern border of the county to 1,150 in the western portion, and 1,200 in the south and east, where it is approximately 525 feet above the Mississippi. It is cut into two parts near the center of the county by the valley of the Zumbro, which in its lower portion is 500 feet below the upland surface. The eastern edge of the county is further cut by numerous tributaries of the Mississippi, which extend back only a few miles from the river. The valleys of these tributaries, as well as that of the Zumbro, are sharp and canyon-like. The lower part of the Zumbro Valley is 1 to 2 miles in width and is marked by terraces.

An interesting physiographic feature is found at the mouth of Zumbro River, where the material transported by this stream, intermingled with that brought down by Chippewa River from central Wisconsin, has formed a broad alluvial dam stretching into the channel of the Mississippi and ponding the waters to form Lake Pepin.

SURFACE DEPOSITS.

The surface formations include alluvium, terrace, and outwash gravels, loess, and ordinary glacial drift.

The alluvium occurs in the valleys of the Mississippi and its tributaries where these have formed flood plains. Its thickness is unknown, but presumably averages between 25 and 50 feet. The coarser alluvium of the smaller streams and of the fan formed at the mouth of the Zumbro generally contains abundant water, the supplies being available to shallow wells and furnishing sufficient quantities for domestic and farm purposes. The alluvial deposits of the Mississippi include a considerable amount of silt, and the supplies of water are consequently smaller.

Terrace gravels are found at Kellogg and other points along the Mississippi, where they reach a height of 65 feet above the flood plain. Owing to the fact that the water readily escapes from the terraces into the adjacent valleys, it is generally necessary for wells to penetrate to the drainage level.

The loess forms a coating over the uplands 15 feet or less in thickness. Owing to its thinness it is of little consequence as a water-bearing bed, but it is important in collecting the rainfall and feeding it to the underlying formations.

The glacial drift is relatively thin, occurring mainly in patches beneath the loess over the flat uplands. In places, however, along the western border of the county, it seems to reach a thickness of 50 to 70 feet. A deposit of modified drift, occurring as a sort of outwash plain, lies in the western portion of the county, stretching eastward from the morainal accumulations. Water is found in various sandy and gravelly layers of the drift in sufficient quantities to supply domestic and farm wells.

ROCK FORMATIONS.

Of the upper formations of the Ordovician system only the Platteville limestone, here about 10 feet thick, is represented in the county. It caps the elevation known as Lone Mound and occurs on the highest uplands southwest of Plainview along the southern border of the county. It carries very little water and is to be considered as a source of supply only for "wet weather open wells."

The St. Peter sandstone, which in this county is about 100 feet thick, lies beneath the Platteville limestone on Lone Mound and on the high land near Plainview and outcrops over a considerable area of the uplands in the vicinity of this village. Owing to the fact that it occurs only on the higher lands, where its waters can escape to lower levels, it is not commonly a source of water supply in Wabasha County, though it would furnish water in moderate amounts to wells on the upland about Plainview and in parts of Mount Pleasant Township.

The Shakopee dolomite underlies a considerable part of the uplands, especially in the west and south. It has a thickness of about 35 feet and is generally less than 50 feet and rarely over 100 feet below the surface. It is reached by domestic and farm wells, to which it will yield small supplies.

The New Richmond sandstone, which is about 20 feet thick, outcrops on the uplands several miles back from the bluffs of the Mississippi and the Zumbro. It affords small supplies of hard water to the wells penetrating it.

The Oneota dolomite, which is very similar to the Shakopee, forms the upland crests and upper parts of the cliffs along the Mississippi and Zumbro valleys. It carries some water in its joints, bedding planes, and solution channels, and at a distance from its outcrops usually yields enough for farm purposes.

The Jordan sandstone, which in this region is a buff or yellow sandstone 100 to 120 feet thick, outcrops in the lower parts of the cliffs. It forms an important water-bearing bed and will yield good supplies to deep wells almost anywhere in the county. The water from this formation fails to rise to the surface, except perhaps in the Zumbro Valley.

The St. Lawrence formation, which consists of shales and limestones with some sandstone beds, is exposed at the base of the cliffs and lies beneath the flood plains of the Mississippi and the lower portion of the Zumbro, having a maximum thickness of about 230 feet. It will yield only small amounts of water.

The Dresbach sandstone is estimated to be about 50 feet thick in this county. It will yield large quantities of water, which is confined by the St. Lawrence formation under pressure sufficient to lift it nearly or quite to the surface.

The underlying shales and sandy layers have a thickness, according to the section of the Wabasha well, of about 150 feet, and according to the section of the Lake City well considerably greater. These are not important as a source of water, but serve to confine under artesian pressure the water in the subjacent sandstone. The underlying porous Cambrian sandstone is 225 feet or more thick and will yield large volumes of water that rises nearly or quite to the surface.

Beneath the sandstone just described, according to the evidence of the Lake City well, there are 320 feet or more of red shale, sandstone, and quartzite which are not water bearing. Underlying these will be found the granite, which is likewise void of available water.

Below is given the section of the well drilled in 1882 at Lake City for the Chicago, Milwaukee and St. Paul Railway Company. At this early date the statement was emphatically made by Mr. Swan, the driller, that the red clastic series was never known to add materially to the water supply furnished by the overlying beds, and he advised the withdrawal of the drill whenever it was reached.

Section of railway well at Lake City.

[W. E. Swan, driller.]

	Thickness.	Depth.
	Feet.	*Feet.*
Sand and gravel (alluvium)	207	207
Blue sand and shale (lower part of St. Lawrence?)	68	275
Sandstone (Dresbach) and gray sandy shale	127	412
Yellow and gray sandstone	88	500
Red shale and quartzite	320	820

UNDERGROUND WATER CONDITIONS.

Wells.—Shallow wells dug into the surface deposits were at first the principal source of supply. The inferior quality of the water, the liability to pollution, and failure in dry seasons eventually led to the general substitution of deeper drilled wells. In those parts of the uplands remote from the river valleys the wells are commonly from 100 to 150 feet deep, but near the edges of the plateau many go to depths of 250 to 350 feet, or even more. In the valleys driven wells sunk into the alluvium to a depth of 20 to 75 feet afford the most common source of supply, but when large volumes are required drilled wells are sunk to the underlying sandstones.

Head of the water.—Back from Mississippi and Zumbro rivers water stands in wells at a considerable depth below the surface, and as lower supplies have been tapped the head has gradually been lowered. In the valley of Mississippi River the water rises nearly to the surface, but it does not flow either in Lake City or in Wabasha, though flows are obtained at Red Wing to the north and at Winona to the south. It is improbable that flows can be obtained by new wells at either of the cities mentioned, but it is possible that they could be procured along the Mississippi south of the Zumbro.

Springs.—Springs emerge at numerous points along the base of the cliffs bordering the rivers, both from the limestones and the sandstones. Some are of considerable size and are important sources of domestic and farm supplies. Springs also issue from the limestone on the uplands, but their volume is generally small.

Springs usually emerge from the top of an outcrop of an impervious formation. Thus the top of the St. Lawrence, essentially a shale formation, and the top of the Shakopee, a compact dolomite, mark the situation of most of the springs of the county.

Quality of the water.—An inspection of the analyses shows no great difference in the quality of the underground water from different formations. The water from the Plainview well, which comes largely from the Jordan sandstone, is better than that from the alluvium of Lake City, Wabasha, and Weaver. Only one analysis of water from a deep well has been obtained.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Wabasha.—The city of Wabasha has no public supply. The people depend mainly on driven wells sunk from 15 to 70 feet into the alluvium. A deep well was drilled for the R. E. Jones Company, the section of which is reported to be as follows:

Well section at Wabasha.

	Thickness.	Depth.
	Feet.	*Feet.*
Alluvium	165	165
Shale (lower part of St. Lawrence?)	35	200
Sandstone (Dresbach and shale?)	200	400
Red sandstone	40	440
Granite (entered)	6	446

Lake City.—Twenty 4-inch wells, driven into the alluvium, supply the public waterworks of Lake City and provide water for about 90 per cent of the population. They yield about 100,000 gallons daily.

Plainview.—There are at Plainview two village wells; one, 325 feet deep, ends in the Jordan sandstone; the other, 692 feet deep, extends to the Dresbach sandstone. The stratigraphic section is as follows:

Well section at Plainview.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil, with remnants of St. Peter sandstone	70	70
Shakopee: Limestone	40	110
New Richmond: Sandstone	30	140
Oneota: Limestone	180	320
Jordan: Sandstone (water)	120	440
St. Lawrence:		
Limestone	50	490
Green clay (very sticky)	180	670
Dresbach: Sandstone (water)	22	692

Elgin.—The waterworks in Elgin village are supplied from a well 275 feet deep which taps the Jordan sandstone.

Mazeppa.—The village well at Mazeppa is 90 feet deep. Most of the people have private supplies.

ANALYSES.

Mineral analyses of water in Wabasha County.

[Analyses in parts per million.]

	Streams.		Surface deposits.					Jordan sandstone.
	1.	2.	3.	4.	5.	6.	7.	8.
Depth ... feet	....	....	24	20	40	40	49	325
Silica (SiO_2)	7.9	8.9	2	8	9.7	27	4.6	20
Calcium (Ca)	49	56	96	96	76	81	61	57
Magnesium (Mg)	15	21	29	35	27	27	28	26
Sodium and potassium (Na+K)	....	8.9	....	22	11	15	10	3
Bicarbonate radicle (HCO_3)	213	293	394	468	358	286	289	289
Sulphate radicle (SO_4)	9.9	4.8	26	20	29	35	48	16
Chlorine (Cl)	....	1.2	6.2	20	2.6	11	3.6	1.7
Total solids	187	244	395	431	332	315	298	260

1. Mississippi River and Wabasha. January, 1896.
2. Whitewater Creek at Weaver. December, 1891.
3. Chicago, Milwaukee and St. Paul Railway well at Weaver. November, 1891.
4. Chicago, Milwaukee and St. Paul Railway well at Lake City. January, 1894.
5. City filtration well at Lake City. November, 1891.
6. City supply well at Lake City. November, 1906.
7. Chicago, Milwaukee and St. Paul Railway well at Wabasha. November, 1891.
8. Village well at Plainview. November, 1906.

Analyses 6 and 8 were made for the United States Geological Survey by H. S. Spaulding. Analyses 2, 3, 4, 5, and 7 were furnished by G. N. Prentiss, chemist Chicago, Milwaukee and St. Paul Railway Company. Analysis 1 was furnished by the Dearborn Drug and Chemical Company, Chicago.

WASECA COUNTY.

By C. W. Hall and M. L. Fuller.

SURFACE FEATURES.

Nearly all of this county stands between 1,050 and 1,200 feet above sea level. Its surface throughout all but its eastern portion is flat or only gently undulating, but along the eastern edge there is an irregular morainal belt 3 to 8 miles wide, which rises about 50 feet above the surrounding region. Lakes are numerous both in the depressions of the moraine and in the shallow sags of the adjoining plain. The county lies within the drainage basin of Minnesota River, its waters entering that stream by way of Lesueur River, which flows through a shallow valley and has nowhere cut into rock.

SURFACE DEPOSITS.

The glacial drift mantles virtually the entire county, varying in thickness from 125 to more than 200 feet. In the extreme northeastern portion and in the central and southwestern portions its thickness is generally less than 150 feet; along the eastern border and toward the northwest it is nearly everywhere greater; and along a belt bordering the Chicago and Northwestern Railway from the county line to a point beyond Janesville it appears to be commonly great, possibly owing to the existence of a buried channel extending to the Minnesota at Mankato. The drift contains sandy and gravelly beds which commonly yield water and will afford adequate supplies to domestic and farm wells and probably enough for small industrial purposes.

PALEOZOIC FORMATIONS.

The Galena, Decorah, and Platteville formations are not seen at the surface, but from well records and from their occurrence in adjacent regions they are known to underlie at least the southeastern half of the county. Several hundred feet of strata belonging to these formations were found in a well at Freeborn, a few miles south of the county boundary, from which point the thickness gradually decreases northwestward.

Beneath the drift in the northwestern half of the county, and beneath the Platteville limestone in the southeastern half, the St. Peter sandstone is struck in drilling. It is white and is apparently about 120 feet thick. It carries much water, which rises considerably when encountered, yielding supplies sufficient for all ordinary purposes.

About 75 feet below the St. Peter lies the New Richmond sandstone, which is probably 15 or 20 feet thick; about 250 feet below the St. Peter lies the Jordan sandstone, which is approximately 70 feet thick, and about 500 feet below the St. Peter occurs the Dresbach sandstone, which is 90 feet or more thick. All these formations contain large supplies of water under sufficient pressure to cause it to enter the wells freely.

The following record of the city well at Waseca gives a good section of the deep-lying rocks in this region:

Well section at Waseca.

[Authority, J. P. McCarthy.]

	Thickness.	Depth.
	Feet.	*Feet.*
Glacial drift, mostly blue clay	185	185
Galena, Decorah, and Platteville formations:		
Limestone	6	191
Shale and "slate rock"	87	278
Limestone	16	294
St. Peter sandstone, mingled sandstone and shale	121	415
Shakopee dolomite: Limestone, reddish in color	100	515
New Richmond sandstone and Oneota dolomite, limestone (like above, but separated from it by a seam of different material, probably the New Richmond sandstone)	155	670
Jordan sandstone:		
White sandstone (water)	20	690
Reddish sandstone	30	720
White sandstone (water)	20	740
Red sandstone, probably iron-stained	25	765
St. Lawrence formation:		
Limestone	6	771
Green shale	3	774
Hard red limestone	65	839
Green shale	3	842
Blue shale	20	862
Red shale	85	947
Yellow shale	33	980
Dresbach sandstone and underlying shale:		
Sandstone mixed with shale (water)	44	1,024
Yellow sandy shale	133	1,157

UNDERGROUND WATER CONDITIONS.

Wells.—As has already been stated, the greater part of the county is underlain by 100 to 200 feet of glacial drift. Unlike most regions where such conditions prevail, this county contains relatively few shallow dug or bored wells. Their absence is apparently due to the fact that but little sand or gravel occurs in the upper part of the drift, and hence there is so little available water that in dry seasons a large proportion of the shallow wells failed. As a result deeper drilled wells were substituted, obtaining their supplies from sandy layers in the lower part of the drift or, more rarely, in the underlying formations. Perhaps nine-tenths of the wells draw from the drift and one-tenth from rock.

Head of the water.—In most of the wells the water stands considerably below the surface; but in the lowlands along the streams a considerable number of flowing wells are reported, apparently belonging to the same general field as the flowing wells in Faribault County. They are not deep and the water is under only slight pressure at the surface.

Quality of the water.—Several mineral analyses are given in the accompanying table. The water is in general similar to the typical Paleozoic waters; but it has a somewhat greater content of alkalies and sulphates, in which respects it shows a tendency to resemble the Cretaceous waters farther west.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Waseca.—The formations underlying the city of Waseca are shown in the section of the deep city well, which was given above. This well, together with another 600 feet deep, furnishes the public supply, on which about two-thirds of the inhabitants depend, consuming approximately 50,000 gallons daily. Analyses are given in the table (p. 363) of water from the deep city well and from the railway well, which penetrates the St. Peter sandstone.

New Richland.—The public water at New Richland is drawn from a well 150 feet deep, which extends into the Galena limestone.

SUMMARY AND ANALYSES.

Throughout most of the county drilled wells which penetrate the lower portion of the glacial drift form a satisfactory source of water. However, if a larger yield is required than the drift will afford, drilling should be continued to the sandstones, which will be encountered in every part of the county and which will always furnish water generously. No advantage in regard to the head of the water is to be expected from deep drilling.

Mineral analyses of water in Waseca County.

[Analyses in parts per million.]

	Lakes.		Glacial drift.	St. Peter sandstone.		Deep formations.
	1.	2.	3.	4.	5.	6.
Depth .... feet..	....	....	84	439	439	1,157
Silica (SiO_2)	4.1	2.2	2.1	22	25	21
Calcium (Ca)	5.7	32	94	101	87	96
Magnesium (Mg)	1.0	18	30	42	29	28
Sodium and potassium (Na+K)	5.8	29	20	78	95	27
Bicarbonate radicle (HCO_3)	22	188	450	500	525	411
Sulphate radicle (SO_4)	6.7	20	28	172	101	63
Chlorine (Cl)	4	29	4.7	4.9	6.7	7.3
Total solids	38	226	420	669	604	436

1. Water from Clear Lake. January, 1901. [This is apparently from melted ice. C. W. H.]
2. Water from Loon Lake. June, 1889.
3. Jennison Brothers & Co. well at Janesville. January, 1894.
4. Chicago and Northwestern Railway well at Waseca. March, 1891.
5. Chicago and Northwestern Railway well at Waseca. June, 1896.
6. City well at Waseca. April, 1896.

Analyses 1, 2, 4, and 5 were furnished by G. M. Davidson, chemist Chicago and Northwestern Railway Company. Analyses 3 and 6 were furnished by Edgar & Mariner, chemists.

WASHINGTON COUNTY.

By C. W. HALL and M. L. FULLER.

SURFACE FEATURES.

Washington County ranges in elevation from 700 feet on the bottom lands in the south to more than 1,000 feet on the morainic summits in the central and northern parts. The northern and western portions are in general markedly morainic, the surface being characterized by rough and irregular hills with intermediate depressions abounding in lakes; but in the extreme northwest there is a considerable area that is nearly flat. At an elevation of 800 to 850 feet above sea level and 100 to 150 feet above Mississippi and St. Croix rivers is a terrace extending the entire length of the St. Croix Valley from the northern end of the county to the southern, there joining a similar but wider one in the valley of the Mississippi. The width of the St. Croix terrace is rather uniform, averaging about 1½ miles; the width of the Mississippi terrace varies from about 1 mile, near Newport, to 4 miles, near Cottage Grove, beyond which it narrows to 1½ miles at its junction with the St. Croix terrace. The flood plains of these two valleys are, in general, very narrow within the limits of this county. The smaller streams are mainly tributary to the St. Croix, but their valleys are of no great width or depth.

As Washington County lies on the border of the so-called driftless area, its topography is typical neither of the glaciated region, as represented in the central part of Minnesota, nor of the driftless region typically developed 50 to 100 miles farther southeast.

SURFACE DEPOSITS.

Alluvium occurs along the Mississippi and also in the valleys of the large creeks. It carries considerable water and affords supplies that are generally sufficient for domestic and farm purposes.

The terrace deposits consist of sands and gravels laid down by streams flowing at distinctly higher elevations than those of the present rivers. The upper level stands in places more than 200 feet above the river level and the deposits are at least 150 feet thick. They occur along St. Croix River from the northern boundary of the county to the Mississippi and also cover extensive areas along the northeast side of the Mississippi between St. Paul and Hastings. They are porous, but the water level is low at many points near the exposed edges.

Outwash deposits consist of sands and gravels deposited by the glacial floods issuing from the ice sheet and flowing over the upland surfaces. They are generally flat or gently undulating, but in some places, where deposited very near the ice margin, they are rolling and have a morainic aspect. Their thickness is commonly between 25 and 50 feet. They are extensively developed in the northeastern corner and especially for several miles along the Anoka County line. The water fills the pores of the material and is prevented from sinking deeper by the underlying impervious clay. In most places it accumulates up to the level of the stream valleys and affords abundant supplies.

The glacial drift proper has a thickness of probably 80 to 100 feet or more in the north and northwest, but less in the southern part of the county. Water is found in the sandy and gravelly portions wherever these are not drained by adjacent valleys or other depressions.

ROCK FORMATIONS.

The Platteville limestone is the uppermost hard rock formation represented in this county. It occurs along the western border and in isolated hills north of Cottage Grove and south of Stillwater. From the few openings that quarrymen and farmers have made it appears as a thin bed of blue limestone weathering yellowish, interbedded with layers of shale, the whole thickness being not more than 10 or 15 feet.

The St. Peter sandstone has a total thickness of more than 100 feet, but in many localities the upper portion has been removed by erosion. The formation outcrops or lies immediately below the surface deposits in a strip that borders the Platteville limestone in the southwestern portion of the county and widens to the north, where it covers many square miles. It is a satisfactory source of supply in the flat areas in the northwestern part of the county, but is not so good a source in the south, where its waters are drained to the lower land farther east.

The Shakopee dolomite is represented in this county by a buff to gray magnesian limestone interbedded with shale partings and having a thickness of 25 to 65 feet. It lies at the surface or beneath the drift in a broad belt over the eastern half of the county, constituting an intermediate level between the Platteville outcrops and the valley of the Mississippi. Water occurs only in small amounts.

The New Richmond sandstone is a thin calcareous sandstone that outcrops along the sides of the valley of the Mississippi and is nowhere far below the surface. It yields moderate quantities of water in the central and western portions of the county, except near the river, where drainage toward the valley materially reduces the supply.

The Oneota dolomite is a buff or pink magnesian limestone similar to the Shakopee, except that it is thicker and more free from concretionary structures. It occurs in the lower part of the Mississippi Valley, in the southern half of the county, and is believed to lie beneath the surface deposits near the northeastern corner. In general the supply of water within this formation is no greater than in the overlying glacial drift.

The Jordan sandstone, which is between 50 and 90 feet thick, outcrops in the St. Croix Valley below Stillwater and in the lower portions of the valley slopes above this city. It yields large supplies of water at points back from the river, especially where covered by the Oneota and Shakopee in the northern third of the county.

The St. Lawrence formation consists essentially of a magnesian green sand and associated green shale layers. It has a considerable thickness, but only a few feet of the top is exposed, and that only in the bottom of the St. Croix Valley at Stillwater and northward. Small quantities of water are found in the sandy layers, but the supply is far less than in the overlying and underlying sandstones.

The Dresbach sandstone and underlying shales are not exposed at the surface, but are reached by the deep well at Stillwater and have a combined thickness of several hundred feet. The yield of water from the porous sandstones, at least in the deep well at Stillwater, is abundant and sufficient for all ordinary industrial purposes and for the water supplies of cities of considerable size. They afford in fact, a large portion of the water used in the city of Stillwater.

The red clastic series consists of a remarkable thickness of red sandstone alternating with shales of the same color. It contains some water, but its yield is insignificant compared with that of the overlying formations.

The deep well sunk at Stillwater in 1888 and 1889 by a stock company in search of natural gas is one of the deepest and most notable wells in the Northwest. From a set of samples furnished to Mr. A. D. Meeds, of the University of Minnesota, the following record has been compiled. Because of the importance of this well in the elucidation of the stratigraphic history of the early Paleozoic in Minnesota the section is given in considerable detail.

Section of Stillwater deep well.[a]

	Thickness.	Depth.
	Feet.	*Feet.*
Glacial drift: Coarse, yellow sand (much rusted)	18	18
Oneota: Gray limestone	85	103
Jordan:		
Fine grained quartz sand	39	142
Fine-grained pure white sand	27	169
St. Lawrence(?):		
Light-green shale with some sand and limestone	41	210
Very fine white sand	12	222
Light-green shale with grains of sand	56	278
Dresbach sandstone and underlying beds:		
Fine-grained white sand (grayish owing to coating of lime)	31	309
Coarse-grained gray sand with some green material	10	319
Coarse-grained white sand (some pyrite and some pieces of shale)	10	329
Gray sand with green grains (effervesces slightly)	27	356
Gray shale or limestone with quartz (effervesces)	31	387
Impure sandstone with much broken dark material, some red and yellow grains (effervesces)	70	457
Fine-grained quartz sand	10	467
Pink shale with streaks of white and green quartz grains (effervesces strongly)	80	547
Coarse quartz sand (some grains very large)	148	695
Red clastic series:		
Dark-red shale with sand grains (effervesces)	13	708
Coarse quartz sand	5	713
Fine-grained dark-red shale (effervesces)	11	724
Fine-grained dark-red sandstone (effervesces)	175	899
Same as last (very fine grained)	31	930
Same as last in general appearance (a small amount of salt water was struck at 1,950 feet)	1,327	2,257
Material same as last, mixed with calcite and pink grains of feldspar, giving a mottled appearance (at a depth of 2,450 feet a salt pocket was encountered and a small amount of brine continued to flow into the well to the close)	650	2,907
Darker than last	46	2,953
Fine-grained dark-red sandstone (effervesces)	4	2,957
Keweenawan diabase:		
Dark-brown diabasic rock with kaolinized feldspar and some green grains	225	3,182
Dark-brown diabase similar to last, with some kaolin, calcite, and a notable amount of a green mineral found in long slender fibers	100	3,282
Fine-grained slate-colored diabase with pieces of native copper	25	3,307
Same as last but mixed with white material	5	3,312
Fine-grained slate-colored diabase with pieces of native copper	96	3,408
Fine-grained drab-colored rock with green material	39	3,447

[a] Meeds, A. D., Bull. Minnesota Acad. Nat. Sci., vol. 2, No. 2, pp. 274-277.

UNDERGROUND WATER CONDITIONS.

Head of the water.—The head of the water in Washington County varies greatly, owing to the topography. In the southern end, where Mississippi and St. Croix rivers are only 10 to 12 miles apart and the nearly horizontal Paleozoic rocks rise between them, forming a plateau 200 to 300 feet high, the drainage of the successive layers is sufficient to lower the water to a great depth. At Newport, St. Paul Park, Pullman avenue, and on the St. Croix side of the county wells are drilled to considerable depths before a permanent supply of water is reached in the Paleozoic sandstones; but in the northern portion of the county, away from the St. Croix gorge, the water from these formations is generally lifted near the surface, and in the Valley of the Mississippi they give rise to flowing wells. Upon the plateau, even in the southern part, water stands in the sandy deposits at 15 to 30 feet below the surface, held there by the underlying impervious clay of the glacial drift.

Springs.—There is a series of springs which issue from the rock walls all along St. Croix and Mississippi rivers. Scores of them are used by the farmers and occupants of summer cottages.

WATER SUPPLY AT STILLWATER.

The system of waterworks in the city of Stillwater is owned by the Stillwater Water Company, a private corporation. The supply is obtained (1) from the deep well the section of which is given above, (2) from a spring flowing from a sandstone (probably the Jordan), and (3) from Lake McKusick. The deep well yields 1,250,000 gallons a day from the sandstone formations between 650 and 750 feet below the surface, the overlying Jordan and Dresbach being cut off by the casing, which is carried to 650 feet. The spring yields about 250,000 gallons a day. Lake McKusick will furnish 2,000,000 gallons or more a day, but unfortunately is polluted and unsatisfactory. Only the spring and well waters are used for drinking purposes. The water is distributed from three reservoirs, the aggregate capacity of which is approximately 300,000 gallons. About three-fourths of the people use the public supply, and over 1,000,000 gallons of water are reported to be consumed each day. Owing to its situation near a large and rapidly growing community, the spring should be carefully watched if its use as a drinking supply is continued. In the state-prison yards there are several springs, some of which have been utilized for many years.

SUMMARY AND ANALYSES.

The surface deposits in this county contain an uncommon amount of sand, and hence constitute an important source of water wherever they have a reasonable thickness. The underlying formations are utilized along Mississippi River and where the drift is thin. The formations available for water supplies within the county are the St. Peter sandstone in the higher hills near the western boundary, the New Richmond sandstone, the Jordan sandstone, and the Dresbach and underlying sandstones. Flows can be obtained in the Mississippi Valley, but not on the uplands, though in the northwest the water will rise near the surface.

Mineral analyses of water in Washington County.

[Analyses in parts per million.]

	1. Alluvium.	2. Glacial drift.
Depth ... feet..	20	....
Calcium (Ca)	44	68
Magnesium (Mg)	20	49
Sodium and potassium (Na+K)	8.3	....
Bicarbonate radicle (HCO_3)	226	452
Sulphate radicle (SO_4)	25	....
Chlorine (Cl)	1.5	....
Total solids	215	375

1. Chicago, Milwaukee and St. Paul Railway well at Afton. November, 1891. G. N. Prentiss, chemist.
2. Spring at Forest Lake. 1897. N. Lehman, chemist.

WATONWAN COUNTY.

By O. E. Meinzer.

SURFACE FEATURES.

The surface of Watonwan County slopes gradually from an elevation of about 1,300 feet above sea level at the southwestern corner to slightly above 1,000 feet at the northeastern corner, but so gradual is the descent that is is quite unnoticeable. The topography is for the most part that of a gently undulating plain, almost unaffected by erosion and covered with numerous ponds and swamps. But this comparatively level surface is broken near the northwestern corner by a ridge of Sioux quartzite, which rises 50 to 100 feet above the surrounding prairie, and in other localities by shallow stream valleys. North Fork of the Watonwan flows through the northern part of the county and South Fork through the southern and eastern. Two miles east of Madelia the two unite to form the Watonwan, which flows eastward into Blue Earth River. Where the Watonwan leaves the county its valley is about 50 feet deep, but farther upstream it is much shallower.

SURFACE DEPOSITS.

Description.—The glacial drift constitutes a blanket that conceals the older formations in all parts of the county except in one small area, where rock appears at the surface. Because of the irregularities of the underlying quartzite near the western margin, the drift sheet has here a correspondingly irregular thickness and in a few localities is extremely attenuated. Farther east, however, where the quartzite is not present, the drift attains a greater and more uniform depth, probably reaching a maximum of nearly 300 feet and an average of somewhat less than 200 feet.

Yield of water.—The water-bearing members of the drift may be divided into two groups—(1) the gravelly portions of the surficial yellow clay layer and (2) the seams of sand and gravel either interbedded with the blue bowlder clay or lying at its base. The surficial gravelly beds yield supplies which are frequently small and readily affected by drought, though because of the flat surface and poor drainage the ground-water level stands near the surface and is not as readily lowered in dry seasons as might be supposed. The seams in the bowlder clay generally furnish generous and permanent supplies. Mr. James Weisher, a driller at Madelia, reports that it is his practice to test the farm wells which penetrate to this zone at 25 gallons a minute, and that the wells included in the following table were submitted to this test:

Wells in Watonwan County tested at 25 gallons a minute.

Owner.	Location.	Diameter.	Depth.	Date.
		Inches.	*Feet.*	
Franklin Investment Company	S. ½ sec. 17, T. 107 N., R. 30 W	6	114	1907
W. W. Murphy	SE. ¼ sec. 21, T. 107 N., R. 30 W	6	155	1907
F. Teighe	SE. ¼ sec. 5, T. 106 N., R. 30 W	6	212	1906
R. Sargent	SW. ¼ sec. 21, T. 106 N., R. 30 W	6	64	1907
D. Griffin	NW. ¼ sec. 10, T. 106 N., R. 30 W	4½	182	1907
A. Bocock	NE. ¼ sec. 35, T. 107 N., R. 31 W	4½	88	1907
S. D. Whiting	SW. ¼ sec. 9, T. 106 N., R. 31 W	6	255	1907

Head of the water.—The surface is so flat and so little dissected by valleys that there is little opportunity for the ground water to escape. Hence all the porous parts of the drift have become saturated and the water from all depths rises nearly to the surface. On the other hand, there are few abrupt differences in elevation, and therefore few low-lying areas in which flows can be obtained. There is, however, a group of flowing wells in the valley of Spring Branch Creek, southeast of Madelia, and a few others are found in different parts of the county, two very shallow ones in the southern portion of the city of St. James and one in the NW. ¼ sec. 32, T. 106 N., R. 31 W. In all these the water overflows with but very slight pressure. In the higher areas in the western part of the county the water does not always rise near the surface.

Quality of the water.—The water from the glacial drift is all hard, most of it being rich in calcium sulphate and hence forming hard scale in boilers. In general the hardness decreases toward the east. Moreover, the water from very shallow sources is commonly not so hard as that from deeper beds. As shallow water in the zone of oxidation contains much less iron than that from greater depths, and as iron is much more noticeable than other dissolved minerals, the deep water is often mistakenly believed to be "harder" than the shallow water, although in fact the amount of iron present is no indication of the degree of hardness.

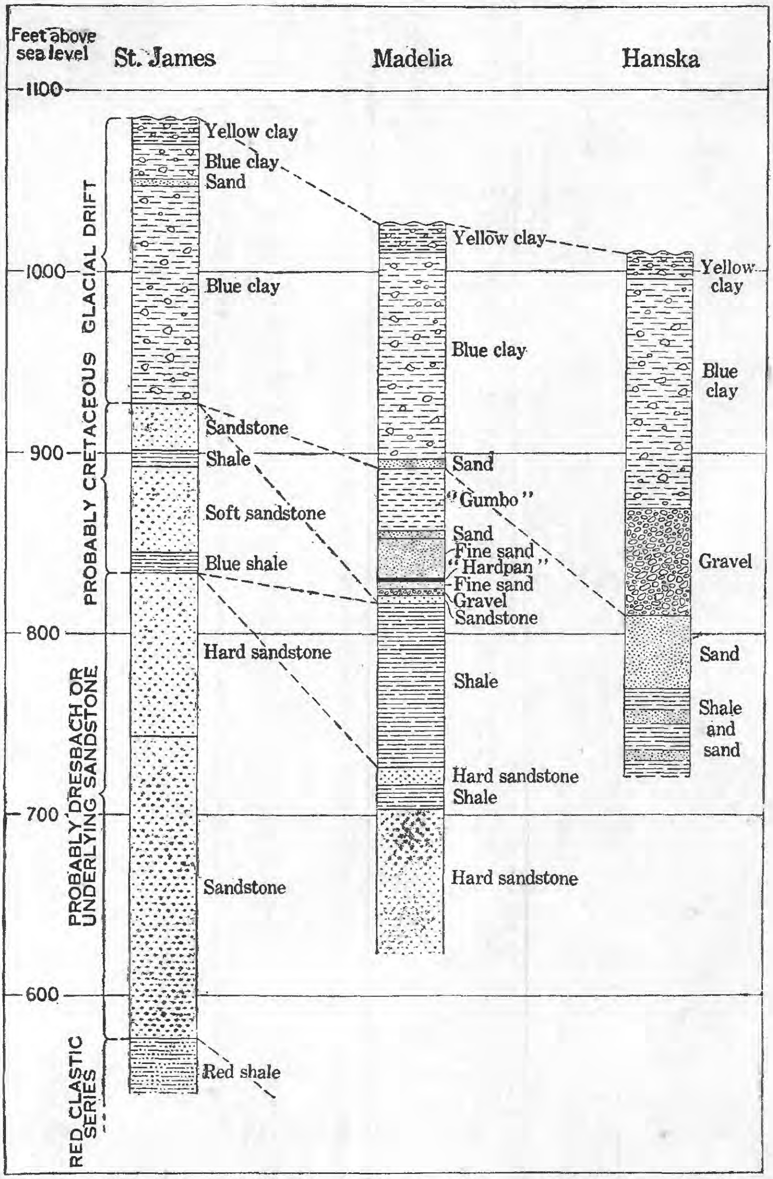
UNDERLYING FORMATIONS.

Description.—Above the Archean granite lies the Algonkian Sioux quartzite, which is probably hundreds of feet thick. In the eastern part of the county this quartzite is deeply buried beneath younger formations, but in the western tier of townships it comes close to the surface, and near the northwestern corner it outcrops at an elevation of about 1,250 feet above sea level. Lying upon the Algonkian surface, probably with an unconformable relation, is a series of Paleozoic strata that dip southeast. Hence if the formations younger than the Paleozoic were removed the quartzite would be exposed over a considerable area in the western part of the county, and toward the southeast successively younger Paleozoic rocks would be found outcropping. Spread over much, but not all, of this Algonkian-Paleozoic surface appears to lie a thin series of Cretaceous shales and sandstones. In preglacial times the quartzite to the west must have projected rather conspicuously above the surrounding Cretaceous surface, but it is now nearly buried under the mantle of drift.

The approximate sections at St. James, Madelia, and Hanska (Brown County), together with their probable correlations, are shown in Plate XVI. It is perhaps superfluous to state that in a situation such as is here presented, where several unconformable rock systems, not distinctly different in lithologic character, exist everywhere concealed from view, it is impossible to make any close correlations. There appears, however, to be little reason for doubting that the indurated sandstones and shales in the lower portions of the St. James and Madelia sections belong to the Paleozoic formations that are known to occur throughout southeastern Minnesota, and that the strata of incoherent sand and soft shale and lignite encountered between the glacial drift and the indurated rocks belong to the Cretaceous, which is generally recognized in western Minnesota and Iowa.

The Algonkian possesses such distinctive lithologic characters that there is but little uncertainty in regard to its interpretation from well records. The greatest depth to which it has been penetrated in this county is at Butterfield, where a well 520 feet deep was drilled for the Chicago and Northwestern Railway Company. At 325 feet below the surface the drill entered a "hard red sandstone," in which it continued to the depth of 500 feet, the last 20 feet being reported to consist of light-colored sandstone. No doubt all the rock below 325 feet belongs to the Sioux quartzite.

Yield of water.—The thick beds of sand and sandstone that occur beneath the glacial drift in the central and eastern portions of the county will yield inexhaustible supplies of water. The 6-inch creamery well at St. James, which is finished with an open end in a stratum of sandstone at a depth of 327 feet, was tested at 90 gallons a minute for many hours of continuous pumping without lowering the water perceptibly; the new city well at St. James, which is also finished with an open end and is reported to be supplied from a depth of 380 feet, has been tested at 400 gallons a minute; the old city well, which likewise gets its supply from the sandstone formations, has been



GEOLOGIC SECTIONS IN WATONWAN AND SOUTHEASTERN BROWN COUNTIES.

By O. E. Meinzer.

St. James.—Deep well drilled for city in winter of 1892-93. Authority, C. F. Loweth, civil engineer, St. Paul.

Madelia.—Upper 200 feet generalized; lower portion approximate section of well drilled for C. F. Christianson Milling Company in 1906, reported by engineer of mill.

Hanska (Brown County).—Well at flouring mill. Authority, James Weisher, driller, Madelia.

pumped at 200 gallons a minute for twenty-four hours continuously. The mill well at Madelia is 404 feet deep, is 6 inches in diameter at the bottom, and is not cased below the 324-foot level. Pumping from this well at the rate of 120 gallons a minute for six days is reported not to have lowered the water more than 2 feet.

The quartzite in the western part of the county will furnish moderate supplies, the water coming chiefly from the less firmly cemented portions, as in the Butterfield railway well described above (p. 370). The deeper the drilling is carried into the rock the greater is the number of water-bearing layers encountered, each of which will contribute something to the yield.

Head of the water.—The water from the Cretaceous, Paleozoic, and Algonkian formations is lifted to essentially the same altitude as that from the deeper beds of the drift. In the Madelia mill well it is reported to rise to a level 42 feet below the surface or 985 feet above the sea; in the creamery well at St. James, to a level 14 feet below the surface, or 1,080 feet above the sea; in the two city wells at St. James, to a level 32 feet below the surface, or 1,053 feet above the sea; and in the railway well at Butterfield, within a few feet of the surface, or approximately 1,170 feet above the sea. Thus the head above sea level increases toward the west, and though in all parts of the county the water will come nearly to the surface it is not probable that flowing wells can anywhere be obtained from deep zones.

Quality of the water.—At St. James the water from the upper sandstone strata contains very large quantities of calcium and magnesium and is harder even than the water from the glacial drift and from the beds at the base of the drift, as becomes evident upon comparing analyses 1, 2, and 8 with 9 and 10. According to analysis 12, the hardness also decreases somewhat when greater depths are reached, but unfortunately the wells from which samples 10 and 12 were obtained are old, and there is therefore some uncertainty as to the actual zone from which the water came. At Madelia the water is generally less mineralized than at St. James, but here also the sandstone water appears to be somewhat harder than that from the glacial drift (compare analyses 3, 7, and 11).

The only analysis of quartzite water at hand is No. 13, the sample having been taken from the railway well at Butterfield. The water from this well is remarkably soft, but high in chlorides, in these respects resembling the soft Cretaceous water farther northwest. However, not all of the quartzite water is soft.

WATER SUPPLIES FOR CITIES AND VILLAGES.

St. James.—The city of St. James lies upon a nearly level and poorly drained drift plain, the valley of St. James Creek being but slightly lower than the town site. Hence the ground-water level is virtually at the surface, and large supplies are obtained from shallow wells, especially in wet years. The geologic section and underground water conditions in this locality have already been discussed (p. 370). The public waterworks are supplied from two drilled wells, which extend into the sandstone formations. Their yield and head and the quality of water which they furnish are all given elsewhere (pp. 370–371). For culinary and drinking purposes nearly all the people depend on very shallow wells, which provide water that is not so extremely hard as the public supply. The railway company uses water from St. James Lake.

Madelia.—The village of Madelia is situated in part upon a terrace of Watonwan River and in part on the adjacent upland prairie. The approximate stratigraphic section to a depth of 400 feet is given in Plate XVI. The public supply is derived from two drilled wells, which are somewhat over 200 feet deep and end in a stratum of sand. The water is used by about 700 people, and approximately 12,000 gallons is consumed daily. More than half of the inhabitants depend on private wells, which range in depth from about 20 to 130 feet, 20 to 35 feet being common depths on the terrace, and 35 to 50 feet on the upland. The deepest well in the village is the 404-foot well recently drilled at the flouring mill. According to the analyses given in the table, the water from this depth is somewhat more highly mineralized than that from shallower sources.

FARM WATER SUPPLIES.

At one time nearly all farms were supplied from bored or dug wells ending in yellow clay or gravel above the blue bowlder clay, at depths not generally exceeding 30 or 40 feet. As these wells came to be severely tested by drought, as the amount of live stock to be watered increased, and as the farmers became more prosperous, many of them were abandoned, and deeper wells with more abundant and permanent supplies were drilled. However, much of this county is so flat and poorly drained that many very shallow wells were found to have a practically inexhaustible store of water even in the driest years, and consequently a large proportion of the farms are still supplied from shallow sources.

The drilled wells range from 2 to 6 inches in diameter and from only a few feet to more than 300 feet in depth. By far the greater number end in glacial drift but several penetrate older formations. The 6-inch drilled wells are the type recommended. They are superior to the bored and dug wells not only in the quantity and permanence of their yield but also in being more cleanly and sanitary, and they are more satisfactory than the 2-inch drilled wells because they do not require screens and hence do not become clogged.

SUMMARY AND ANALYSES.

The beds of sand and gravel occurring within the glacial drift and at its base form the most accessible and valuable source of water. Except in the western part of the county, still larger supplies can be obtained from the sandstones that lie at somewhat greater depths, but the water from these deep formations, though under good head, will not rise above the surface, and moreover is extremely hard and poor for use in boilers.

Along the western margin of the county it is sometimes necessary to drill into the quartzite, which will nearly always yield adequate supplies if penetrated to a sufficient depth. Drilling into quartzite should not, however, be undertaken except by those experienced in this kind of work, because it requires methods which one accustomed to drilling in softer rock may not understand.

Mineral analyses of water in Watonwan County.

[Analyses in parts per million.]

	Glacial drift.					
	1.	2.	3.	4.	5.	6.
Depth ... feet	30	40	45	86	136	168
Diameter of well ... inches	192	Large.	144	6–10	....	2
Silica (SiO_2)	29	31	39	31	49	14
Iron (Fe)	....	1.5	....	....	....	....
Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	1.0	4	32	....	1.6	4.5
Calcium (Ca)	111	146	103	240	233	236
Magnesium (Mg)	40	56	25	75	77	79
Sodium and potassium (Na+K)	17	28	6.5	85	117	120
Carbonate radicle (CO_3)	....	.0	....	....	....	....
Bicarbonate radicle (HCO_3)	509	473	390	561	653	947
Sulphate radicle (SO_4)	49	237	53	603	591	376
Chlorine (Cl)	6	14	.8	4	2	5.5
Nitrate radicle (NO_3)	....	2.5	....	....	....	....
Total solids	502	763	452	1,315	1,393	1,302

	Intermediate zone.		Cretaceous and Paleozoic sandstones.				Sioux quartzite.
	7.	8.	9.	10.	11.	12.	13.
Depth ... feet	216±	255	325	380(?)	404	480(?)	520
Diameter of well ... inches	6 and 8	6	6	10	10–6	8	4½
Silica (SiO_2)	54	58	22	....	38	16	23
Iron (Fe)	2	5	3	8	2	3	....
Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	8.3	10	5	.2	4.4	9	7
Calcium (Ca)	107	162	327	324	162	228	27
Magnesium (Mg)	29	47	118	116	35	77	10
Sodium and potassium (Na+K)	81	29	83	146	127	117	532
Carbonate radicle (CO_3)	.0	.0	.0	.0	.0	.0	....
Bicarbonate radicle (HCO_3)	447	498	512	503	442	495	199
Sulphate radicle (SO_4)	168	250	1,026	1,121	408	698	389
Chlorine (Cl)	1	2	4	10	7	4	532
Nitrate radicle (NO_3)	.0	.0	.0	.0	.0	.01	....
Total solids	677	810	1,853	1,994	1,006	1,396	1,618

1. Railway well at St. James. October, 1895.
2. Well at pumping station and electric-light plant at St. James. November 16, 1907.
3. Well of the Chicago, St. Paul, Minneapolis and Omaha Railway Company, at Madelia. April 8, 1901.
4. Well at Odin. July 6, 1901.
5. Railway well at Odin. October 9, 1901.
6. Creamery well at Butterfield. April 7, 1899.
7. Mixture of water from the two city wells at Madelia. July 12, 1907.
8. Well near St. James, on the farm of S. D. Whiting, SW. ¼ sec. 9, T. 106 N., R. 31 W. July 16, 1907.
9. Creamery well at St. James. November 18, 1907.
10. West city well at St. James. November 16, 1907.
11. Well at the C. S. Christensen Company mill at Madelia. July 16, 1907.
12. East city well at St. James. July 16, 1907.
13. Well of the Chicago and Northwestern Railway Company, at Butterfield. June 8, 1900.

Analyses 2, 7, 8, 9, 10, 11, and 12 were made for the United States Geological Survey by H. A. Whittaker, chemist Minnesota state board of health. Analyses 1, 3, 4, 5, 6, and 13 were furnished by G. M. Davidson, chemist Chicago, St. Paul, Minneapolis and Omaha Railway Company.

WINONA COUNTY.

By C. W. Hall and M. L. Fuller.

SURFACE FEATURES.

Winona County is among the most rugged in the State. Deep sharp valleys alternating with narrow but flat-topped ridges characterize the topography of the greater part of the county. The ridges constitute the remnants of a once continuous plateau that extended over the region, large areas of which are still found south of Lewiston and St. Charles. The upland surface has an elevation of about 1,200 to 1,300 feet above sea level and of more than 500 feet above the valley of the Mississippi. The remnants of Platteville limestone in the southwestern corner of the county form a distinct topographic feature. It is more resistant to erosion than the surrounding rocks, and the areas in which it occurs at the surface are therefore bounded by more or less well-defined escarpments. In these areas sink holes due to the caving of underground passages are abundant.

SURFACE DEPOSITS.

The surface deposits of Winona County include alluvium, terrace gravel, loess, and glacial drift.

The alluvium, which occurs in the principal valleys, generally ranges in thickness between 25 and 100 feet, but in some localities, as in the vicinity of Winona, the thickness is greater. Owing to the frequent overflow of the streams, only the higher parts of the flood plains are inhabited, and hence in most instances only small demands are made on the alluvium for water supplies. Water can be obtained in moderate amounts, but the supplies are not sufficient for large industrial plants.

The terraces of the valleys of the Mississippi and its tributaries reach a maximum height of about 60 feet above the flood plain. Owing to the ease with which their water supplies can escape into the valleys, they do not yield much water to wells, except those that penetrate below the level of the adjacent drainage.

The mantle of loess, which covers the uplands to a depth at few points exceeding 15 feet, is rarely a source of water supply, but it serves to collect the rainfall and to feed it to underlying rocks.

The glacial drift is found in small patches throughout the upland area, but appears to form a continuous sheet only along the western and southwestern borders of the county. Generally it is too thin to be of value as a water zone, but locally considerable amounts of water may occur in the gravelly portions.

ROCK FORMATIONS.

The Decorah shale is present in this county with a thickness of about 50 feet. It consists of green and gray shales and contains no water, but serves to collect the water in the overlying drift or loess, which supply numerous shallow wells and feed many small springs.

Beneath the Decorah shale is a massive layer of Platteville limestone about 25 feet thick, which may yield small supplies of water where it is not drained by lower land in the vicinity.

The St. Peter sandstone has a maximum thickness in this county of more than 90 feet. At a number of points it carries ferruginous layers, which, by their resistance to weathering, have given rise to mounds. Owing to the presence of numerous valleys, its supplies are not as large as in many localities, but most wells penetrating to the bottom of the formation will obtain sufficient water for domestic and farm use, but not generally enough for industrial or public purposes.

The Shakopee dolomite, which is about 25 feet thick, outcrops below the St. Peter in the southwestern part of the county and forms the country rock in the higher portions of the uplands in the southeastern and northern parts of the county. It carries some water in the joints, bedding planes, and solution passages, and its yield is adequate for domestic and farm supplies, but generally insufficient for industrial or public supplies.

The new Richmond sandstone outcrops about the margins of the Shakopee areas several miles back from Mississippi River and its tributaries. It carries a moderate amount of water which it will yield to rock wells on the higher uplands, but the supplies will generally be found insufficient except for domestic and farm uses.

The Oneota dolomite has a maximum thickness of about 175 feet. It constitutes the rock in the upper portion of the cliffs bordering Mississippi River and its tributaries and forms the upland surface for several miles back from the streams. It contains small quantities of water in joints, bedding planes, and solution passages and furnishes the supplies for shallow wells throughout a large portion of the upland area, but fails near the edge of the bluffs where the water is free to escape into the valleys.

The Jordan sandstone outcrops in the cliffs of the Mississippi Valley and its tributaries. Near its outcrops it furnishes little water, but elsewhere it is saturated with water and yields abundant supplies. In the wells on the uplands the water stands many feet below the surface.

The St. Lawrence formation consists of green and blue shales with interbedded layers of limestone and sandstone. It has a total thickness of about 170 feet and outcrops near the base of the cliffs. The sandy layers contain some water but the amount is less than in the underlying Dresbach sandstone.

The Dresbach sandstone is about 100 feet thick. Generally it underlies the alluvium of the valley of the Mississippi but rises slightly above the valley level at Dresbach and other points in the southeastern part of the county. It carries considerable water and wherever it is below drainage level will yield large supplies to wells penetrating it.

Beneath the Dresbach sandstone is a series of blue and green shales and white sandstone having a combined thickness of more than 200 feet. The shales, which form the upper portion of the series, serve to confine the water in the underlying sandstone, thus giving rise to flows in the valleys.

Beneath the white sandstone just described there is a series of sandstones, shales, etc., which are predominantly red in color and are called the red clastic series. They yield little water and rest on an indefinite thickness of granite which is likewise destitute of available water.

A careful record of the drillings from the city well at Winona was kept by the late C. H. Berry and is presented below. A general section of material penetrated at Winona and vicinity, reported by C. A. Wood, a practical well driller, is also given. The first 150 feet consists of alluvium, below which is the shale and sandstone series which underlies the Dresbach sandstone.

Section of the city artesian well at Winona.

[Authority, C. H. Berry. This well was drilled in 1889.]

	Thickness.	Depth.
	Feet.	*Feet.*
Gray sand	75	75
Sharp green sand	5	80
Bluish gray sand	10	90
Green sand containing minute shells	6	96
Quicksand	4	100
Coarse sand without shells	8	108
Gravel	41	149
Blue clay changing into white sand	9	158
Clean coarse white sandstone	252	410
A streak of brick-red color changing to a pink or red sandstone	27	437
Another streak of reddish color	33	470
"Still more red"	30	500
Soapstone rock, sandstone at bottom	10	510
Granite (entered 5 feet).		

Generalized well section at Winona.

[Authority, C. A. Wood, driller, Winona.]

	Thickness.	Depth.
	Feet.	*Feet.*
Sand and gravel	150	150
Blue shale and sandstone	50	200
White sandstone	150	350
Red sandstone	15	365
White sandstone	125	490
Blue shale	16	506
Granitic rocks (entered).		

UNDERGROUND WATER CONDITIONS.

Head of the water.—Owing to the great relief, the head of the water relative to the surface varies. On the upland the water from the deep zones stands far below the surface, but in the valley of the Mississippi flows can be obtained from these same zones where they are not exposed by erosion.

Quality of the water.—There is little difference in the chemical quality of the water from the different zones except that the water from the red sandstone series is somewhat harder and has a higher content of chlorine than that from other formations. In general the water is moderately mineralized, the principal constituents being calcium, magnesium, and the bicarbonate radicle. (See the accompanying table, p. 279, and also Pl. V.)

Springs.—There are numerous springs along the lower parts of the valley cliffs. They generally emerge from sandstones or limestones immediately above a layer of shale, many of those issuing from the limestone being large. On the uplands the springs are less numerous and smaller, but are not rare where limestones exist near the surface. In sec. 15, T. 107 N., R. 8 W., near Minnesota City, a spring was developed which some years ago attracted considerable attention as a medicinal water.[a] The composition of the water is given in analysis 2 in the table on page 379.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Winona.—The city of Winona is built on an island formed between the main channel of Mississippi River and Lake Winona, which is a nearly abandoned channel of the stream. The general level of the island is only a few feet above the high-water mark of the river. The alluvium that constitutes the island has a depth, according to well records, of 150 feet and consists of gravel, sand, clay, "hardpan," and other flood-plain débris. Wherever sufficiently porous it is water bearing, the ordinary shallow wells of the city procuring their supplies at an average depth of 30 or 35 feet. Occasionally a well is sunk to a depth sufficient to penetrate the underlying Paleozoic formations, which yield water that is wholesome, but considerably harder than that from the Mississippi. (See analyses 3 to 8 in the table.) A number of the deep wells at Winona overflow at the surface. The best supplies, both in quantity and quality, are obtained at depths not exceeding 350 feet. (See the well sections given above, and also Pls. IV and V.)

The public supply of Winona is derived from several sources—(1) two flowing wells over 500 feet deep, obtaining water from the shale and sandstone series which underlies the Dresbach sandstone and possibly from the red clastic series; (2) two cement-lined dug

[a] Winchell, N. H., Final Rept. Geol. and Nat. Hist. Survey Minnesota, vol. 1, 1882, p. 264.

wells 60 feet in diameter and 28 to 38 feet deep, deriving their water from the alluvium and from the infiltration from the river; (3) an emergency intake from the river, used only in case of fire. The capacity of the artesian wells is calculated at 600 gallons a minute. A test of the water from the different sources shows the following relative composition:

Composition of public supply at Winona.

[Parts per million.]

	Artesian well.	Infiltration well.	River intake.
Total carbonates (alkalinity) (as $CaCO_3$)	395	175	155
Sulphates (SO_4)	76	29	23
Chlorine (Cl)	67	45	29
Iron (Fe)	1	.5	Trace.

The system has not proved altogether satisfactory, the artesian water being hard and the infiltration well water liable to contamination. Hence a plan is at present (August, 1908) under consideration to install a filtration plant and obtain a supply drawn wholly from the river.

On the Doty and Reinke sheep farm north of the city a flowing well, which has a head of 8 feet and a yield of about 50 gallons a minute, is used to operate a turbine that pumps the water to higher levels. The use of turbines together with rams promises to add greatly to the usefulness of flowing wells by distributing the water and lifting it to points higher than the head. The well of George Fifield, about 3½ miles above Winona, is only 280 feet deep. The water, which is known as "Fifield's Artesian Mineral Water," is sold in the city and shipped to other points.

St. Charles.—The public supply at St. Charles is derived from a well 942 feet deep, which taps the Jordan, Dresbach, and basal Cambrian sandstones. The water stands about 150 feet below the surface. An analysis is given in the table (p. 379).

Lewiston and Utica.—The villages of Lewiston and Utica draw their permanent supplies from the Jordan sandstone, which is about 300 feet below the surface. Many private wells are sunk into the New Richmond.

Rolling Stone.—Most of the people of Rolling Stone use the public supply, which is derived from a drilled well 340 feet deep.

SUMMARY AND ANALYSES.

The strongest water zones are the Jordan, Dresbach, and basal Cambrian sandstones. The water in the basal Cambrian sandstones is confined beneath a layer of shale and has sufficient head to rise above the surface in the deepest valleys. As the red series yields only small quantities of hard water, drilling should always be discontinued when it is encountered.

Mineral analyses of water in Winona County.

[Analyses in parts per million.]

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
Depth ... feet	......	......	23	22	35	24	30	34	70	90	120	350
Silica (SiO_2)	12	16	......	16	10	......	16	......	......	1.3	9.5	16
Iron (Fe)	......	......	......	......	......	......	......	......	2.9	8.6	8.5	.7
Calcium (Ca)	60	73	78	55	59	57	65	62	......	82	78	46
Magnesium (Mg)	32	30	22	24	28	22	27	25	16	32	19	21
Sodium and potassium (Na+K)	5.2	3.6	15	7.6	2.6	......	6	1.2	4.3	18	7.7	5.4
Bicarbonate radicle (HCO_3)	340	376	307	291	323	217	262	300	321	378	331	227
Sulphate radicle (SO_4)	4.6	5.7	38	8.2	24	53	57	19	......	30	7.1	22
Chlorine (Cl)	4.7	.3	18	5.9	21	......	9	12	6.7	27	7.9	2.5
Total solids	289	316	323	260	327	313	303	284	266	392	292	219

	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.
Depth ... feet	82	28	500	942	942	376	350	350	375	325	462	462
Silica (SiO_2)	9.9	16	10	11	18	12	8.3	......	......	......	5.1	14
Iron (Fe)	1.1	1.5	.2	1.0	.8	......	4.0	......	......	......	.2	......
Calcium (Ca)	54	69	68	84	99	53	51	47	64	52	67	85
Magnesium (Mg)	26	29	28	14	24	21	18	13	26	20	20	29
Sodium and potassium (Na+K)	4.3	5.6	13	9.8	11	60	41	28	171	120	24	50
Bicarbonate radicle (HCO_3)	266	339	325	317	280	193	183	193	630	301	199	386
Sulphate radicle (SO_4)	26	21	14	6.5	74	89	109	12	42	78	82	56
Chlorine (Cl)	20	4.4	21	15	18	70	64	42	54	96	37	47
Total solids	255	314	314	298	407	405	388	436	519	519	336	471

1. Spring at the quarry at Stockton.
2. Spring of F. C. Bryan near Minnesota City. October, 1881. Hydrogen sulphide and a trace of lithium were also reported.
3. Chicago, Milwaukee and St. Paul Railway well at Winona. March, 1905.
4. Chicago and Northwestern Railway well at Winona. March, 1889.
5. Chicago and Northwestern Railway well at Winona. March, 1890.
6. Chicago, Milwaukee and St. Paul Railway well at Winona. June, 1900.
7. Well at the Chicago and Northwestern Railway shops in Winona. February, 1904.
8. Chicago, Milwaukee and St. Paul Railway well at Dakota. November, 1881.
9. Chicago and Northwestern Railway well at St. Charles. September, 1887.
10. Creamery well in St. Charles. May, 1904.
11. Chicago and Northwestern Railway well at St. Charles. November, 1888.
12. Village well at Lewiston. December, 1906.
13. Chicago and Northwestern Railway well at Stockton. August, 1892.
14. Chicago and Northwestern Railway well at Stockton. June, 1892.
15. City well at St. Charles. January, 1896.
16. City well at St. Charles. December, 1895.
17. City well at St. Charles. December, 1906.
18. Well at the Winona Malting Company brewery.
19. Well at the Park brewery in Winona.
20. Well at the Peter Bub brewery.
21. Artesian well at Winona. April, 1906.
22. C. W. Miller's artesian well at Winona. March, 1905.
23. City well at Winona, a mixture from the depths of 36 and 462 feet.
24. City well at Winona. 1903.

Analyses 12 and 17 were made for the United States Geological Survey by H. S. Spaulding. Analyses 1, 4, 5, 7, 9, 11, 13, 14, and 16 were furnished by G. M. Davidson, chemist Chicago and Northwestern Railway Company. Analyses 3, 6, 21, and 22 were furnished by G. N. Prentiss, chemist Chicago, Milwaukee and St. Paul Railway Company. Analyses 10, 15, and 23 were furnished by the Dearborn Drug and Chemical Company, Chicago. Analysis 2 was made by W. A. Noyes for the geological survey of Minnesota; analysis 20 was made by Wahl & Hennis; and analysis 24 was made by H. C. Carel.

WRIGHT COUNTY.

By O. E. Meinzer.

SURFACE FEATURES.

Wright County can be divided into three physiographic provinces[a]—(1) the irregular morainic tract occupying most of the county, (2) the gently undulating area lying in the south-central part, and (3) the level plain bordering Clearwater and Mississippi rivers along the northern margin of the county. The Mississippi has cut a narrow gorge into this plain, and its tributaries have accomplished a small amount of erosion, but the surface of the county is still imperfectly drained and remains covered with numerous lakes and swamps.

SURFACE DEPOSITS.

Description.—There are two distinct types of bowlder clay, the blue and the red. The red clay occurs chiefly in the northeastern part of the county, but has been found as far southwest as Waverly. Where both are present the blue lies above the red. The red is apparently derived from the rocks in the Lake Superior region, and the blue comes for the most part from the Cretaceous formations to the west. These two varieties of drift have been discussed by the state geologists, N. H. Winchell[b] and Warren Upham.[c] In addition to the sand and gravel that is interbedded with the bowlder clay, extensive deposits lie at the surface, forming the level plain referred to above.

The glacial drift ranges in thickness from a scant layer to perhaps about 400 feet. It reaches its greatest development in the central and southwestern parts and is somewhat thinner in the northern and northeastern, but there are considerable variations within short distances. The following specific data will give some conception of the thickness in the different localities: (1) In the vicinity of Cokato depths of 150 to 300 feet have been reached without passing out of the drift; (2) in the village of Howard Lake one well is reported to have struck rock at a depth of 135 feet and several others in the same district at depths of 170 to 218 feet, but on the other hand many wells in this region end in drift at depths of more than 200 feet; (3) at Waverly "rock" was encountered in one well at 190 feet below the surface, but in the mill well in the same village the drift deposit may be deeper; (4) near Delano (in the NE. ¼ sec. 24, T. 118 N., R. 35 W.) sandstone was found at a depth of 211 feet, but there are deeper wells in the locality which do not reach this for-

[a] Upham, Warren, Final Rept. Geol. and Nat. Hist. Survey Minnesota, vol. 2, 1885, Pl. 41.

[b] Fifth Ann. Rept. Geol. and Nat. Hist. Survey Minnesota, 1876, pp. 156-174; Sixth Ann. Rept., 1877, pp. 84-87.

[c] Final Rept. Geol. and Nat. Hist. Survey Minnesota, vol. 2, 1885, pp. 254-256.

mation; (5) in the Buffalo railway well 385 feet may be drift; (6) in the vicinity of Mississippi River and Crow River near its mouth there are great and abrupt variations in the thickness of the surface deposits, the maximum probably being at least 300 feet.

Yield of water.—The numerous thick beds of sand and gravel provide ample and permanent supplies, and where they lie at the surface, as they do throughout a considerable section of this county, they commonly yield large quantities of water even to very shallow wells.

Head of the water.—Flowing wells are found in a number of localities (Pl. IV) and could without doubt be secured in other restricted tracts, such as stream valleys and depressions partly filled by lakes. The chances of obtaining flows are always best in low districts that lie close to high morainic belts.

In the following areas the water from the drift will rise above the surface: (1) Along the eastern and southern margins of Buffalo Lake and on the low ground southwest of this lake, the supply coming from sand and gravel beds at various depths. In the village of Buffalo the water is lifted fully 30 feet above the level of the lake. (2) Along both branches of Crow River and some of their affluents. A number of scattered flowing wells with slight head have been obtained here, and probably many more could be had on the lowest ground bordering these streams. (3) On the west side of Cokato Lake, north of the village. This is a small area and the wells thus far drilled are not more than 100 feet deep.

Flows are also obtained from the surface deposits in the valley of the Mississippi.

Quality of the water.—The mineral constituents of the water from the drift consist chiefly of calcium, magnesium, and bicarbonates, only small amounts of sodium, potassium, sulphates, and chlorides being present. This water therefore has a considerable temporary hardness (which can in large measure be removed by heating), but will not deposit much hard scale in boilers.

The water in this county is similar to that from the deeper portions of the drift farther west, but is less highly mineralized than the shallow drift water in that region. Thus there is both a horizontal and a vertical variation in the composition of the water, the mineralization (especially the content of calcium, magnesium, and sulphates) decreasing from west to east and from the surface downward.

CRETACEOUS (?) ROCKS.

About 15 miles beyond the northwestern edge of Wright County, in southern Stearns County, there is an exposure of shales, etc., in which Cretaceous fossils have been identified,[a] but it is not known

[a] Kloos, J. H., A Cretaceous basin in the Sauk Valley, Minnesota: Am. Jour. Sci., 3d ser., vol. 3, 1872, pp. 17-26.

that deposits of this age exist at any point within the county. Two outcrops of sandstone and conglomerate are described in the report of the state survey,[a] one on Crow River east of St. Michael and the other on North Branch north of Howard Lake (sec. 8, T. 119 N., R. 27 W.). The suggestion is made by the state geologist that these may be Cretaceous in age, but there is no proof that they are so. It has already been mentioned that a number of wells in the vicinity of Howard Lake and Waverly enter "rock," and a list of such wells is given below. This rock, which appears from the drillers' description to be light-colored water-bearing sandstone, may be the same formation as that which forms the outcrops, but this, too, is uncertain. The blue shales encountered in drilling along the Mississippi are certainly not Cretaceous.

PALEOZOIC AND OLDER FORMATIONS.

Description.—Most of Wright County is underlain by stratified formations which are Paleozoic and perhaps in part pre-Paleozoic in age. Their combined thickness is probably great in the southeast, but much less in the northwest. Because of the dip of these strata and their apparent tendency to change in character and thickness from one locality to another, great caution is necessary in the interpretation of well sections.

In the vicinity of Elk River, a village situated on the opposite bank of the Mississippi, numerous deep wells have been drilled, and these show the stratigraphic succession below the surface deposits to consist of blue shale, white water-bearing sandstone, and red shale and sandstone nearly destitute of water. The section in this locality is shown in Plate XVII. Both shale and sandstone are so hard that they do not require casing; in this respect they differ from most of the Cretaceous strata of southern Minnesota. The total thickness of the red clastic series is not known.

The same succession of blue shale, white sandstone, and red rock has been found in Monticello and at a number of points in the eastern extremity of this county. At Anoka drilling has gone to a depth of 420 feet without reaching the red clastic series; this fact indicates the general thickening of the overlying Paleozoic strata toward the southeast. Near Dayton, which is situated at the confluence of Mississippi and Crow rivers, sandstone was encountered in several wells at a depth of about 50 feet below the river level, and on the opposite side of the Mississippi limestone, which probably lies higher in the series, is reported 100 feet below the upland level.

At Buffalo the following section is reported for the railway well. The upper 386 feet is probably glacial drift.

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[a] Final Rept. Geol. and Nat. Hist. Survey Minnesota, vol. 2, 1885, pp. 250-251.

Well section at Buffalo.

[Authority, Joseph Greeninger, driller, Anoka.]

	Thickness.	Depth.
	Feet.	*Feet.*
Clay	35	35
Sand	2	37
Blue bowlder clay	245	282
Sand	37	319
Quicksand	6	325
Sand and gravel	31	356
Sand and large stones	30	386
Clean sand	9	395
Sandstone	158	553

Light-colored water-bearing rock, which was encountered in the southern part of the county, has already been alluded to as a possible Cretaceous formation. The following table gives a list of wells in which this rock was found:

Rock wells in southern Wright County.

Owner and location.	Depth to rock.	Depth rock was penetrated.
	Feet.	*Feet.*
J. Freden, NE. ¼ sec. 24, T. 118 N., R. 25 W	211	9
Doctor O'Hair, Waverly	190	7
——— Fleiner, Howard Lake	135	5
J. McKee, NE. ¼ sec. 34, T. 119 N., R. 27 W	218	7
F. Birkholz, NW. ¼ sec. 27, T. 118 N., R. 27 W	169	3
C. Dangers, SW. ¼ sec. 15, T. 118 N., R. 27 W	170	3

A few miles north of Wright County the granitic rocks come to the surface and form numerous outcrops in Sherburne and Stearns counties; in Meeker County they have been encountered in several wells. These facts indicate that in the northwestern part of Wright County the granite is not far below the surface, but the depth probably increases rapidly toward the southeast.

Yield of water.—The data given above show that water-bearing sandstone (perhaps belonging to more than one formation) occurs throughout the southeastern part of the county and may extend to the northwestern margin. It has been encountered at depths ranging from 80 to 400 feet and in all wells yielded generously. Neither the red clastic series, which lies beneath the white sandstone in the eastern part of the county, nor the granite, which may be reached in deep drilling in the northern part, is of any value as a source of water.

Head of the water.—The sandstone will produce flows in the valley and on the lower terraces of the Mississippi but not on the uplands (Pl. IV). In the village of Elk River the water is lifted about 60 feet above the river level, or 904 feet above the sea, and at Monticello it rises about 918 feet above sea level, a considerable height above the river.

Quality of the water.—The water from the Paleozoic sandstone is not highly mineralized. Its chief constituents are calcium, magnesium, and bicarbonates; in this respect it is similar to the water from the glacial drift. No. 9 in the accompanying table (p. 387) is a representative analysis. No. 6 is an analysis of water from one of the "rock" wells included in the above list.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Buffalo.—The village of Buffalo is picturesquely situated on the northeastern shore of Buffalo Lake. The glacial drift is here deep (see p. 383) and contains several sand and gravel layers, from which the water rises above the level of the lake. The section given above shows that a thick stratum of water-bearing sandstone lies beneath the drift. The village has no system of public waterworks. Several analyses of water from this locality will be found in the table.

Delano.—The glacial drift is here probably more than 200 feet deep. Below the drift there is believed to be water-bearing sandstone, but it has not been reached by drilling within the village. In the valley deposits of sand and gravel lie at the surface. The public supply is obtained from fourteen 3-inch wells, whose stratigraphic section is as follows:

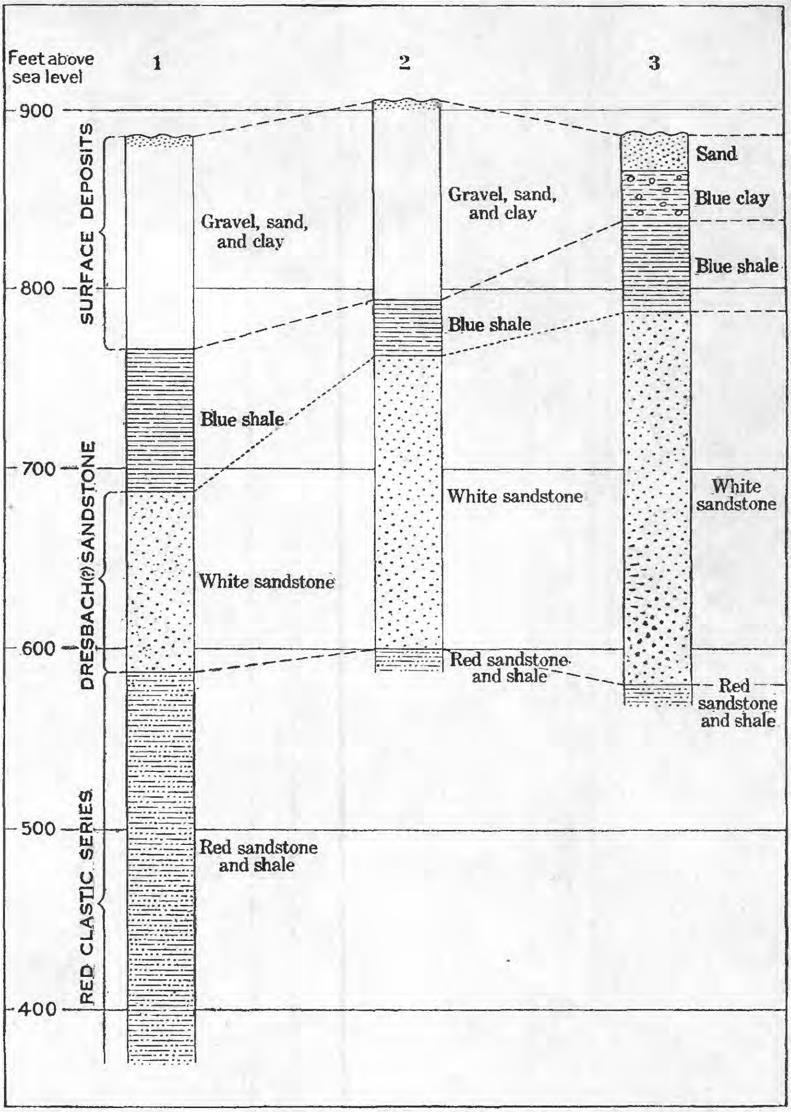
Section of village wells at Delano.

[Authority, T. B. Rader, driller, Delano.]

	Thickness.	Depth.
	Feet.	*Feet.*
Sandy loam	6	6
Blue clay	13	19
Sand (water)	17	36
Blue clay (containing sand and a little water)	4	40
Coarse sand (water) (penetrated 10 feet).		

The water rises virtually to the surface and is drawn simultaneously from all the wells by suction. Pumping at the rate of about 250 gallons a minute for several hours continuously has thus far produced no noticeable effect. The water, an analysis of which is given in the table, is only moderately hard and will not deposit much hard scale in boilers. It is used at the pumping station, mill, and printing house, and altogether about 30,000 gallons is daily consumed. The railway company takes water from the river. Most of the private wells are drilled and range between 50 and 150 feet in depth.

Monticello.—The village of Monticello is situated on the south bank of the Mississippi. The valley is narrow and nearly all the houses are built upon an elevated terrace. Alluvial deposits and glacial drift occur near the surface, beneath which lie the Paleozoic strata shown in Plate XVII. The thick beds of sand and gravel, as well as the



GEOLOGIC SECTIONS AT ELK RIVER.

1. Flowing well; furnished by the driller, T. S. Nickerson.
2. Well at the public school; furnished by William Norval, janitor.
3. Flowing well at Blanchett's Hotel; furnished by the driller, Smith Trask.

Paleozoic sandstone, yield large quantities of water. The well which furnishes the public supply is 8 inches in diameter and 237 feet deep. The water rises to a level 5 feet below the top of the well, which is about 30 feet above the river, or approximately 918 feet above the sea, and pumping at the rate of 275 gallons a minute for five hours continuously is reported to lower this level only 2 feet. As can be seen from the analysis in the accompanying table (p. 387), the water is only moderately hard and will not form much hard scale in boilers. About 25,000 gallons is consumed daily, but most of the people still use water from private wells.

Howard Lake.—The glacial drift has a considerable thickness and contains water-bearing deposits of sand and gravel. Beneath the drift there is a light-colored water-bearing sandstone which is reported to have been penetrated at 135 feet below the surface, though generally occurring at a greater depth. The public supply is pumped from the lake without filtering, through an intake which is about 800 feet from the shore. This water has a relatively low total hardness, and is used by more than one-half of the people, approximately 25,000 gallons being consumed daily. The glacial drift and underlying rock will yield ample supplies of water that is only moderately hard.

Cokato.—Drilling to a depth of 185 feet at Cokato has revealed nothing but glacial drift, as is shown by the following section of a well at the canning factory:

Section at Cokato.

[Authority, John Hammarlund, driller, Cokato.]

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow bowlder clay Blue bowlder clay	78	78
Sand, thin (a little water) Blue bowlder clay	50	128
Sand (water)	2	130
Blue bowlder clay (penetrated 55 feet).		

It is altogether probable that there are other water-bearing beds at greater depths. The public waterworks are supplied from a drilled well 3 inches in diameter and 125 feet deep, which ends with a screen in a bed of sand reported to be at least 6 feet thick. The water rises to a level about 45 feet below the surface or 1,020 feet above sea level. It is moderately hard but has not much permanent hardness, as the analysis in the table (p. 387) shows. Most of the people use water from private drilled wells, none of which is much more than 100 feet deep. The well at the canning factory, which is supplied from the sand layer 128 feet below the surface, has been tested at 15 gallons a minute. The head and quality of the water are similar to those of the village well.

Waverly.—The following section was reported for the well at Adam Berker's flouring mill, which is the deepest well drilled in the locality about Waverly:

Section at Waverly (Berker's mill).

[Authorities, William Jestus, driller, Howard Lake, and Adam Berker, owner of the mill, Waverly.]

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow and blue clay	117	117
"Hardpan"	8	125
Yellow sand (water)	85	210
Red clay	215	425
Coarse yellow sand (water) (entered 19 feet).		

In the table (p. 387) will be found analyses of the water from this well and also of water from Doctor O'Hair's well, which is 197 feet. The public waterworks are supplied from the lake, but all the people depend on private wells, most of which are of the 2-inch drilled type and have an average depth of about 125 feet.

FARM WATER SUPPLIES.

The most common type of farm wells found in this region are the 2-inch or 2½-inch drilled wells. These range from about 40 to 300 feet in depth, their average depth being slightly more than 100 feet in the southern part of the county and somewhat less in the northern. Nearly all stop in the surface deposits and are finished with screens. In the south the screens are liable to become clogged after several years of service, but farther north they seldom do. As a rule the water is harder in the southern than in the northern part and there appears to be a relation between the hardness of the water and the tendency of the screens to become incrusted.

Other types of farm wells are the driven, bored, or dug and drilled wells of larger diameter. In the past the bored and dug wells were the prevailing kind, but they are now gradually being replaced by the drilled types. Where 6-inch wells are not to be pumped faster than the rate at which a windmill operates they can be successfully finished with open ends, thus obviating all difficulties with screens.

SUMMARY AND ANALYSES.

The surface deposits contain large supplies of water that is only moderately hard, and in low areas they may give rise to flows with slight pressure.

The southeastern part of the county, and perhaps the entire county, is underlain by water-bearing sandstone, which has been encountered at depths ranging from 80 to 400 feet, and which will usually yield large quantities of water of about the same hardness as that from the surface deposits. Near the Mississippi the water from this sandstone is under sufficient pressure to rise to a level about 900 feet above the sea, and in the valley it will therefore be lifted above the surface.

The red clastic series and the granitic rocks, which occur at greater depths, are of no value as sources of water, and should not be penetrated in drilling.

Mineral analyses of water in Wright County.

[Analyses in parts per million.]

	Surface deposits (glacial drift, etc.).				Undetermined.				Dresbach (?) sandstone.
	1.	2.	3.	4.	5.	6.	7.	8.	9.
Depth ... feet..	46	89	125	290	237	197	444	....	307
Diameter of well ... inches..	3	2	3	....	8	2	2	....	....
Silica (SiO_2)	24	20	28	20	26	11	9.2	19	....
Iron (Fe)	.4	1.8	.6	.6	Trace.	.3	.4	....	.6
Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	1.6	1.6	2.4	4	2	2	1.6	11	1.6
Calcium (Ca)	102	51	96	42	57	104	76	101	55
Magnesium (Mg)	30	37	34	14	25	43	37	39	21
Sodium and potassium (Na+K)	29	79	19	6	3	15	21	5	9
Carbonate radicle (CO_3)	.0	.0	.0	.0	.0	.0	.0	....	.0
Bicarbonate radicle (HCO_3)	498	517	468	176	293	527	317	492	268
Sulphate radicle (SO_4)	31	16	40	29	12	37	124	13	20
Chloride (Cl)	1	3	1.5	2	2	2	1	5	2
Nitrate radicle (NO_3)	.0	.0	.0	.0	.0	.0	.0	....	.0
Total solids	471	469	455	208	276	485	431	435	260

1. Village wells at Delano. October 8, 1907.
2. Well of James Engstrom near Buffalo, SE. ¼ sec. 19, T. 120 N., R. 25 W. October 11, 1907.
3. Village well at Cokato. October 9, 1907.
4. Well of Dr. M. A. Lowe at Buffalo. October 11, 1907.
5. Village well at Monticello. October 11, 1907.
6. Well of Doctor O'Hair at Waverly. October 9, 1907.
7. Well at Berker's flouring mill at Waverly. October 9, 1907.
8. Railway well at Buffalo. Analysis furnished by C. W. Drew, chemist.
9. Flowing well at Blanchett's Hotel at Elk River, Sherburne County. October 11, 1907.

All of the above analyses, except No. 8, were made for the United States Geological Survey by H. A. Whittaker, chemist Minnesota state board of health.

YELLOW MEDICINE COUNTY.

By O. E. Meinzer.

SURFACE FEATURES.

Most of Yellow Medicine County is occupied by a plain, which in general is flat and featureless and descends very gradually toward the northeast. Immediately west of the county is the Coteau des Prairies, or prairie plateau, which stands approximately 500 feet above this plain; and in the western part of the county the surface slopes with relative abruptness from one level to the other. On the northeast the plain is interrupted by the Minnesota Valley, here about 150 feet deep. The county can thus be divided into three physiographic provinces—the slope, the lowland plain, and the valley (Pl. I).

The slope has an inclination sufficient to allow the water to drain off readily and to do effective erosion; hence it has become dissected by many ravines or small canyons. The descent of the plain is much more gradual, and its streams flow sluggishly through shallow valleys with few tributaries, thus leaving extensive interstream areas poorly drained but too flat to contain many lakes. The valleys of these streams are not in topographic adjustment with the Minnesota Valley. They have a slight gradient down to the part where, as they approach the river valley, they descend steeply to its level.

The general monotony of the topography is relieved by several parallel morainal ridges which extend across the county with a northwest-southeast trend. These are outlined on Plate II.

SURFACE DEPOSITS.

Description.—Glacial drift covers the entire county except parts of the Minnesota Valley and a few small areas in other places where older formations come to the surface (Pl. II). In the Minnesota Valley, near the granite outcrop midway between Canby and Clarkfield, and in the vicinity of Echo and the region south and southwest of that village, the drift commonly has a thickness of less than 50 feet, but near the southwestern corner it attains a maximum of more than 300 feet. Over most of the county it is not less than 50 and not more than 200 feet thick, but because of the irregular surface on which it rests it may range within these limits in the same locality. The average thickness for the county is at least 125 feet.

Yield of water.—The sand and gravel deposits, which constitute the water-bearing members of the drift, vary greatly within short distances and their yield varies likewise. In general, however, the probabilities of finding an adequate supply increase with the depth of the drift. Where the drift is thick, it will usually afford enough water for ordinary purposes, but where it is thin it does not everywhere contain a bed that will yield sufficient even for farm use. The 4-inch village well at Wood Lake, 186 feet deep, is pumped at the rate of 25 gallons a minute, and the village well at Canby, which draws from a depth of less than 100 feet, is pumped at the rate of 125 gallons a minute without lowering the water level greatly.

Head of the water.—Throughout the greater part of the county the water rises nearly but not quite to the surface, but near the western end several flowing wells are found. There is, however, no large or important area in which flows can be obtained. Within a few miles of the Minnesota the head is lowered by seepage into the valley, and here the water commonly stands 60 to 110 feet below the surface. There are many springs in the Minnesota Valley and along the streams that descend from the coteau, but very few elsewhere in the county.

Quality of the water.—According to the analyses given in the accompanying table (p. 393), all the water from the surface deposits is hard. No. 4, which is perhaps the most typical of the ordinary glacial-drift waters, contains large amounts of calcium, magnesium, and sulphates and will produce hard scale in boilers; Nos. 2 and 3 are still richer in these substances and are unfit for boiler use.

CRETACEOUS SYSTEM.

Description.—The Cretaceous is absent in much of the eastern and central sections of the county, where the granite lies immediately beneath the drift, but in the west it is believed to be present as a continuous deposit. It varies greatly in thickness within short distances, owing both to the uneven contour of the granitic surface on which it rests and to the irregularities of its own upper surface. It has a maximum thickness of at least 225 feet, but its average thickness is not great. It consists of alternate strata of soft gray-blue shale ("soapstone") and of sand or sandstone, the shale greatly predominating. In many localities the sandstone is absent and in some it is represented by beds of quicksand.

Shale has been encountered in numerous wells in the vicinity of Clarkfield, and has also been found at many localities in the region including Echo, Wood Lake, and Hanley Falls (Pl. XVIII). The thicker series of the western part of the county is represented by the Canby section given in Plate XII.

Yield of water.—The Cretaceous supplies a number of good wells in this county, but it is not a reliable source of water. It may be absent, may consist entirely of impervious shale, or may contain no water-bearing beds except quicksand, from which the water can not readily be separated. Moreover, it is so irregular in distribution and thickness that it is impossible to predict with confidence the probabilities of obtaining water from it in any given locality.

Head of the water.—The water from the Cretaceous (and the subjacent granitic residuum) is raised by artesian pressure to about the same level as that from the glacial drift. It generally comes nearly to the surface, but would probably not flow anywhere in the county. When the village well at Hanley Falls was completed the water rose within 10 feet of the surface, but at present it stands 40 feet below.

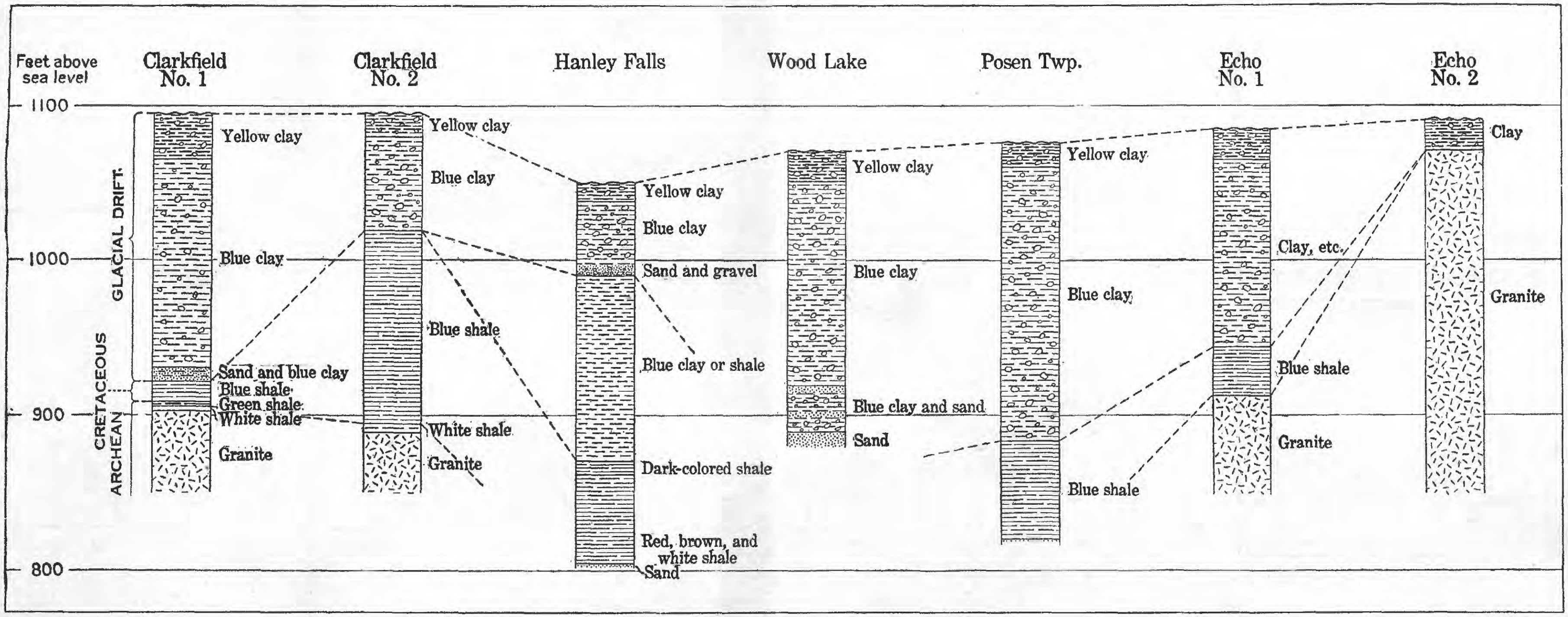
Quality of the water.—The water from this source generally contains only small quantities of calcium and magnesium, and hence is a truly soft water. In exceptional places, however, it is hard, probably owing to the mingling of water from the drift. It holds large amounts of alkali sulphates and chlorides, the latter commonly being present in sufficient quantities to give a distinctly saline taste. Analyses 5 and 6 in the accompanying table represent typical waters from this zone.

ARCHEAN ROCKS.

Description.—Outcrops of granitic rock are found (1) over large areas in the Minnesota Valley, especially in the vicinity of Granite Falls; (2) in a number of small areas south of Echo and Wood Lake, near the Redwood County line; and (3) in a small area midway between Canby and Clarkfield (Pl. III). In the country surrounding the exposures the granite is frequently encountered in drilling, and throughout the county it is not generally so much as 300 feet below the surface. At Echo it occurs locally within a few feet of the surface, but is generally at greater depth; at Wood Lake drilling has gone down 186 feet without reaching it; at Hanley Falls it is probably at a depth of about 250 feet; near Granite Falls it lies at 150 feet or less below the upland surface; and in the vicinity of Clarkfield it has been struck at depths of about 200 feet. In the western part of the county it is farther below the surface. At Canby white clay was found at 325 feet and granite at 385 feet.

As in other counties, the upper portion is generally much weathered, especially where it has been protected from glacial erosion by overlying Cretaceous sediments. A white clay, described in the reports on Redwood and Renville counties (pp. 309 and 316), is often the first warning that the granite is at hand. It is a decomposition product of the granite, but in some places was probably assorted and redeposited by water, as at Canby, where 60 feet of this material is reported immediately above the granite. Aside from the white clay, there is frequently a large amount of true residuum immediately above the unaltered rock, and in some places between the rock and the white clay. At the top it may be a soft clay, but downward it gradually merges into the hard undecomposed granite. It has brilliant colors—red, brown, yellow, green, etc.—which can not fail to attract the notice of drillers; the meaning of its presence can not be mistaken. Moreover, it may have a silvery appearance, given by the flakes of mica or allied minerals which it contains, and it is usually granular, owing to the quartz that was included in the granite and remains unchanged in the residual clay. The drill may also meet hard "glassy" layers, which are the quartzose bands of the original gneissic rock remaining unaltered while the softer minerals have decayed.

Yield of water.—In rare instances water is found in seams of grit associated with the granitic residuum, but the probabilities are against obtaining an adequate supply after the white clay or ordinary altered granite have been entered. The village well at Hanley Falls ends in what appears to be the contact zone between the Cretaceous shale and the granitic residuum. It is 5 inches in diameter and has been pumped for twenty-four hours continuously at the rate of 40 gallons a minute. The experience at Canby is more common; here both the white clay and the granite failed to furnish water.



GEOLOGIC SECTIONS IN EASTERN YELLOW MEDICINE COUNTY.

By O. E. Meinzer.

Clarkfield No. 1.—Village well; approximate. Authority, J. M. Haubris, driller, Montevideo.

Clarkfield No. 2.—Unsuccessful well drilled in this village for J. E. Afden; approximate. Reported by George Olson, driller, Clarkfield.

Hanley Falls.—Generalized section. Somewhat conflicting records have been reported.

Wood Lake.—Generalized section to depth that drilling has been carried in this village.

Posen Township.—Well south of Wood Lake, in sec. 11, T. 113 N., R. 39 W.

Echo No. 1.—Approximate section at creamery.

Echo No. 2.—Section at east end of village.

The last three sections are given on the authority of J. P. Peterein, driller, Echo.

WATER SUPPLIES FOR CITIES AND VILLAGES.

Granite Falls.—The city of Granite Falls is situated on the flood plain of Minnesota River about 150 feet below the upland level. At this point the river has cut its valley down to the granite and has developed rapids where it crosses the granite ledge. The rock is so near the surface that only very meager supplies of underground water can be obtained, but there are a few shallow wells ending in the alluvium above the granite. The analysis given in the table represents water from a very shallow well owned by the city and used largely for culinary purposes. Most of the water for the public supply is taken from Minnesota River and passed through a crude filter; but the reservoir into which the filtered water discharges also acts as a well, and thus a small amount of underground water is mingled with that from the river. The supply is used extensively for all purposes, and about 40,000 gallons are consumed daily.

Canby.—The best water-bearing beds at Canby are found in the glacial drift, which is here 100 feet deep. The sandy strata of the Cretaceous are so fine grained that there is difficulty in finishing wells in them. The well which supplies the public waterworks was drilled to a depth of 426 feet and entered granite, but at present it draws its water from sand between the depths of 70 and 100 feet (Pl. XII). At the time the well was visited (August, 1907), the water overflowed into the manhole, which is about 18 feet deep. When it was pumped at the rate of 125 gallons a minute it stopped overflowing, but water has been taken from it at this rate for sixteen hours continuously without lowering the water below the pumping limit. In dry seasons, however, the water does not rise to the manhole, and pumping at the above rate will lower it to a level from which it can not be lifted by suction. The water is hard, and hence poor for boiler feed. It is not used extensively for household purposes, but supplies the public schools, a total of about 10,000 gallons being consumed daily. The boiler water for the railway and mill is taken from the river.

Clarkfield.—At Clarkfield the granite lies at a depth of about 200 feet, above which there is Cretaceous shale and glacial drift, the latter being practically the only water-bearing formation (Pl. XVIII). No satisfactory boiler supplies have been found. The soft-water zone that occurs at Dawson and Hanley Falls has not been encountered here.

The public waterworks are supplied from a well which was drilled to a depth of 197 feet but obtains its water from a bed of sand nearer the surface. The water rises within 40 feet of the top of the well, but because of the fine sand which clogs the screen the yield is said to be limited to 13 gallons a minute. The water is not used for domestic purposes and very little is consumed except in case of fire. Virtually all the people depend on private wells, which are dug, bored, or drilled, and range in general between 20 and 140 feet in depth. The deepest penetrate the sand beneath the blue bowlder clay and provide adequate supplies.

Echo.—In the locality about Echo the granite lies near the surface, having been reached at depths of 19 feet at the east end of the village, 58 feet at the public pumping station, and 171 feet at the creamery, where 31 feet of shale intervenes between it and the drift. The well that supplies the public waterworks is 12 feet in diameter and 53 feet deep. It passes through yellow and blue bowlder clay and ends in gravel, from which the water rises to a level 35 feet below the surface. Its yield is not great and is easily affected by drought. The water is extremely hard, as is shown by the analysis given in the table (p. 393), and is not used for domestic purposes, very little being consumed except in case of fire. The private wells have an average depth of 20 or 25 feet and furnish small quantities of water, which is also very hard. An analysis of the water from a typical shallow well is given in the table. The mill is provided from an open well, and the creamery from a drilled well 150 feet deep.

Wood Lake.—The glacial drift at Wood Lake has been penetrated to a depth of 186 feet without reaching shale or granite, but a short distance south of the village granite has been struck at 175 feet. The well which supplies the public waterworks passes through yellow and blue bowlder clay and terminates with a screen at a depth of 186 feet, in a bed of sand from which the water rises within 36 feet of the surface. The test of the well has already been given (p. 388). The analysis in the table (p. 393) shows that the water is hard. Up to the present time it has not been used for domestic purposes. The private wells include shallow open wells and deeper drilled ones, all ending in drift.

Hanley Falls.—In the locality of Hanley Falls the glacial drift is underlain by blue shale, below which there is brown, red, and white clay or shale. The supplies for the waterworks, the creamery, and the Great Northern Railway are drawn from a bed that is at a depth of about 240 feet and affords water that is soft but rich in sodium. The data in regard to the village well are given above (pp. 389–390). Virtually the entire population depends on the public supply, which is furnished free of charge, about 12,000 gallons being consumed daily. The Minneapolis and St. Louis Railroad Company uses water from the river.

FARM WATER SUPPLIES.

Most of the farms are now provided with drilled wells. Formerly there were many of the shallow bored type, but these have generally proved unsatisfactory and have been replaced to a large extent by deeper and more permanent drilled wells. The latter range from about 50 to 250 feet in depth, a majority being between 100 and 200 feet. Nearly all terminate in the drift and yield hard water, which incrusts the screens that are used. In localities where soft water can not be obtained it is advisable to drill wells so large in diameter that screens will not be required.

SUMMARY AND ANALYSES.

Throughout the county granite occurs within a few hundred feet of the surface. Except in rare instances, this rock will not furnish water, and no water-bearing formation lies below it. For this reason all supplies must be drawn from beds relatively near the surface, and deep drilling should not be undertaken. Some flowing wells can be obtained near the western end of the county, but they are generally less than 200 feet deep, and any deep drilling project for the purpose of obtaining artesian water is certain to end in failure.

Where sandstone beds are found below layers of shale ("soapstone"), they will usually contribute soft water, but unfortunately in most localities these beds are wanting. Nevertheless prospecting for soft water is a reasonable undertaking in any region that has not yet been thoroughly explored. The cost of such an experiment is moderate because the depth to granite is never great, and if a soft-water bed exists at all it will be found before this rock is reached. At Hanley Falls a soft-water zone is known to be present, but at Canby, Clarkfield, and Echo granite has been encountered without finding such a zone, and at Wood Lake drilling has apparently never been carried below the drift.

Mineral analyses of water in Yellow Medicine County.

[Analyses in parts per million.]

	Surface deposits (glacial drift, etc.).				Cretaceous.	
	1.	2.	3.	4.	5.	6.
Depth ... feet	(a)	35	53	186	247	148
Diameter of well ... inches			144	6 and 4	5	6
Silica (SiO_2)	27	30	29	47	1.2	11.4
Iron (Fe)	.1	.1	2.2	.3		
Aluminum (Al)	5.4		4.3			
Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)		9.4		2.4	2.4	3.6
Calcium (Ca)	117	385	357	171	23	10
Magnesium (Mg)	67	173	138	65	10	7.5
Sodium and potassium (Na+K)	46	66	57	165	251	248
Carbonate radicle (CO_3)	.0	.0	.0	.0	.0	.0
Bicarbonate radicle (HCO_3)	405	689	483	407	229	483
Sulphate radicle (SO_4)	66	382	1,119	604	137	136
Chlorine (Cl)	173	615	10	51	215	27
Nitrate radicle (NO_3)	15	35	.5	.08	.0	.0
Total solids	729	2,053	1,971	1,353	759	697

a Very shallow.

1. Public street well at Granite Falls. This well has no connection with the city waterworks. September 5, 1907.
2. Well behind A. Matz's general store at Echo. August 29, 1907.
3. Village well at Echo. August 29, 1907.
4. Village well at Wood Lake. August 22, 1907.
5. Village well at Hanley Falls. August 21, 1907.
6. East village well at Dawson (Lac qui Parle County). August 29, 1907.

The above analyses were made for the United States Geological Survey by H. A. Whittaker, chemist, Minnesota state board of health.

INDEX.

C.

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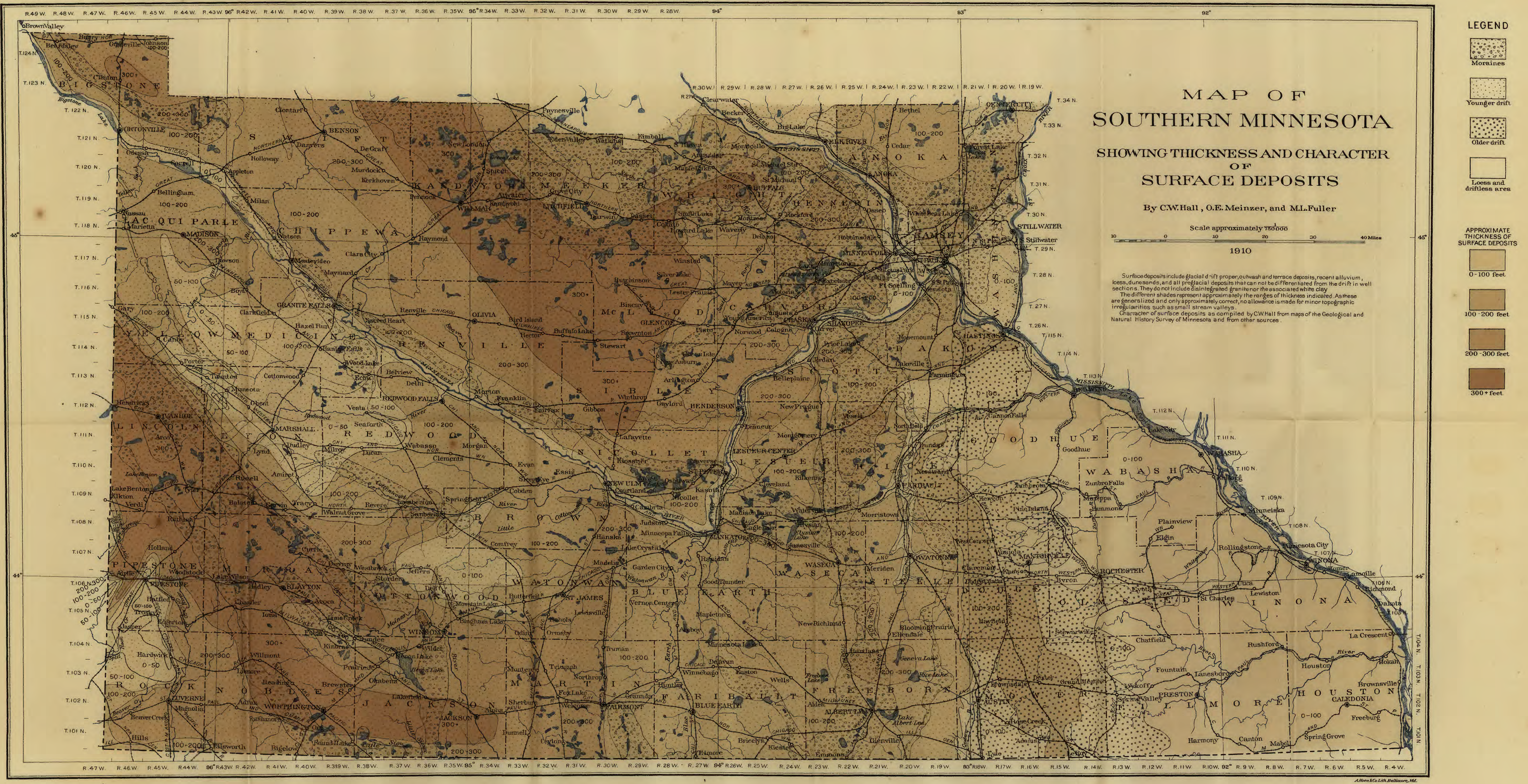
MAP OF
SOUTHERN MINNESOTA
SHOWING UNDERGROUNDWATER CONDITIONS
By C.W. Hall, O.E. Meinzer, and M.L. Fuller
Scale approximately 1/750000
10 0 10 20 30 40 Miles
Contour interval 100 feet
Datum is mean sea level
1910
Topographic contours compiled by O.E. Meinzer from railroad levels, maps of the Geological and Natural History Survey of Minnesota, maps of the Mississippi River Commission, topographic maps of the U.S. Geological Survey, and field notes.
LEGEND
Area underlain by water-bearing Cretaceous sandstone (in part of the area Paleozoic formations lie below the Cretaceous)
AREA UNDERLAIN BY WATER-BEARING PALEOZOIC SANDSTONES
Area generally underlain by the St. Peter sandstone and everywhere underlain by the Jordan, Dresbach, and underlying sandstones
Area generally underlain by the Jordan sandstone and everywhere underlain by the Dresbach and underlying sandstones
Area underlain by the Dresbach and underlying sandstones
Area in which the Sioux quartzite is the only water-bearing formation below the glacial drift
Area in which the Sioux quartzite probably occurs and other water-bearing formations may be present below the glacial drift
Area in which only meager supplies of water are found below the glacial drift; thin interrupted Cretaceous deposits, immediately overlying Archean rocks, occur throughout most of the area
Areas that yield flowing wells from the glacial drift
Areas that yield flowing wells from Cretaceous formations
Areas that yield flowing wells from Paleozoic formations
Area in which the lower portion of the glacial drift yields better boiler water than the upper portion
Area in which the water from the Cretaceous formations is predominantly hard
Area in which the water from the Cretaceous formations is predominantly soft
Isolated flowing wells supplied from the glacial drift
Cretaceous soft-water wells in the hard-water area


MAP OF
SOUTHERN MINNESOTA
SHOWING OCCURRENCE
OF
GRANITIC ROCKS AND SIOUX QUARTZITE
By O.E. Meinzer
Scale approximately 1/750000
10 0 10 20 30 40 Miles
Contour interval 100 feet
Datum is mean sea level
1910
Topographic contours compiled from railroad levels, maps of the Geological and Natural History Survey of Minnesota, maps of the Mississippi River Commission, topographic maps of the U.S. Geological Survey, and field notes.
LEGEND
Granitic rocks, generally less than 500 feet below the surface Under this term are here included granite, gneiss, diabase, schist, etc., their disintegrated products, and the associated white clay
Sioux quartzite, generally less than 500 feet below the surface
Both granitic rocks and Sioux quartzite, generally more than 500 feet below the surface
Granitic rocks at the surface
143
Granitic rocks encountered at the depth indicated (in feet). As at many points the upper limit of the granitic residuum is indefinite, some of the depths indicated are more or less arbitrary
Sioux quartzite at the surface
251
Sioux quartzite encountered at the depth indicated (in feet)
240
Points where drilling has gone to the depth indicated (in feet) without encountering either the granitic rocks or the Sioux quartzite
930
Elevation above sea level of the granitic surface
1483
Elevation above sea level of the quartzite surface
500
500-foot contours of the granitic surface
1000
500-foot contours of the quartzite surface. The position of contours below the 1000-foot level is not known
The contour lines are interpolations between the points where the elevations are known and for the most part are only roughly approximate. Their datum is sea level
BIG STONE
SWIFT
KANDIYOHI
MEEKER
CHIPPEWA
LAC QUI PARLE
YELLOW MEDICINE
RENVILLE
SIBLEY
CARVER
HENNEPIN
ANOKA
RAMSEY
WASHINGTON
DAKOTA
SCOTT
LINCOLN
LYON
REDWOOD
BROWN
NICOLLET
LESUEUR
RICE
GOODHUE
WABASHA
PIPESTONE
MURRAY
COTTONWOOD
WATONWAN
BLUE EARTH
WASECA
STEELE
DODGE
OLMSTED
WINONA
ROCK
NOBLES
JACKSON
MARTIN
FARIBAULT
FREEBORN
MOWER
FILLMORE
HOUSTON
MINNEAPOLIS
ST PAUL
MANKATO
ROCHESTER
WINONA
Granite more than 1640' below surface
Granite more than 645' below sea level
Granite more than 1160' below surface
Granite more than 480' below sea level
Granite more than 820' below surface
Granite more than 100' below sea level
Granite more than 2200' below surface
Granite more than 1200' below sea level
A.Hoen & Co. Lith. Baltimore, Md.


MAP OF
SOUTHERN MINNESOTA
SHOWING THICKNESS AND CHARACTER
OF
SURFACE DEPOSITS
By C.W. Hall, O.E. Meinzer, and M.L. Fuller
Scale approximately 1/750000
10 0 10 20 30 40 Miles
1910
Surface deposits include glacial drift proper, outwash and terrace deposits, recent alluvium, loess, dunesands, and all preglacial deposits that can not be differentiated from the drift in well sections. They do not include disintegrated granite nor the associated white clay
The different shades represent approximately the ranges of thickness indicated. As these are generalized and only approximately correct, no allowance is made for minor topographic irregularities such as small stream valleys.
Character of surface deposits as compiled by C.W. Hall from maps of the Geological and Natural History Survey of Minnesota and from other sources.
LEGEND
Moraines
Younger drift
Older drift
Loess and driftless area
APPROXIMATE THICKNESS OF SURFACE DEPOSITS
0-100 feet
100-200 feet
200-300 feet
300+ feet
A. Hoen & Co. Lith. Baltimore, Md.

A.Hoen & Co. Lith. Baltimore, Md.