GROUND WATER IN THE HOPE AREA, STEELE COUNTY, NORTH DAKOTA

BY

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CONTENTS

ILLUSTRATIONS

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ABSTRACT

Hope is in the south-central part of Steele County, North Dakota, about 30 miles west of Hillsboro. The glaciated plains of this area have been descriptively referred to as the Drift Prairie. The gently undulating land surface in the vicinity of Hope represents the surface of the sheet of glacial till (ground moraine) deposited by the most recent ice sheet that covered the area. That ice sheet overrode an outwash plain formed by the melt water from an earlier ice sheet. Surface drainage is poorly developed, and there are no large perennial streams. At the present time, water is obtained from numerous privately owned wells in Hope, and it is estimated that about 40,000 to 50,000 gallons of water a day might be required for a satisfactory municipal water supply.

The rock materials in descending order consist of glacial drift, the Pierre shale and other Cretaceous shales, the Dakota sandstone, and crystalline rocks. The drift is the only material likely to contain water of suitable quality and in sufficient quantity for a municipal supply. It consists of till of the ground moraine 0 to 35 feet thick, outwash gravel 4 to 26 feet thick, and well-indurated boulder clay 120 to 175 feet thick. The outwash gravel, which lies between the till of the ground moraine and the older boulder clay, is the only extensive drift aquifer in the Hope area.

Information obtained from existing wells and from 10 test holes suggests that the water in transient storage in 2 square miles of the glacial-outwash aquifer probably would be sufficient to furnish at least 40,000 gallons of water a day for about 40 years. Because the overlying till is thin and moderately permeable and is absent in places, and because the irregular topography prevents rapid surface runoff, considerable water is recharged to the aquifer from precipitation in the area. The mineral quality of the water varies considerably in different parts of the aquifer. Sixteen analyses of water from representative wells show a range of 482 to 2,640 parts per million of total dissolved solids. The least mineralized waters are in the thickest and most permeable parts of the aquifer, in the east part of the area in the vicinity of test holes 20, 21, and 13, and in the northwest part of the area in the vicinity of test hole 18.

INTRODUCTION

Scope and purpose of the investigation

This is a progress report on the general study of the geology and ground-water resources of Steele County being made by the U. S. Geological Survey in cooperation with the State Water Conservation Commission and the State Geological Survey. These general studies are being made to determine the occurrence, movement, discharge, and recharge of the ground water, and the quantity and quality of such water available for all purposes including municipal, domestic, irrigation, industrial, and others. However, the most critical need at the present time is for adequate and perennial water supplies for numerous towns and small cities throughout the State which are attempting to construct municipal water-supply systems for the first time. For this reason, the county studies are being started in the vicinity of those towns which have requested the help of the State Water Conservation Commission and the State Geologist. Progress reports are being released as soon as possible in order that the preliminary data may be available for use in connection with the solution of water-supply problems in the towns shortly after they are obtained and before the general studies can be completed. The study described in this report was confined chiefly to that part of Steele County which might be of interest to the village of Hope in its search for sources of municipal water supply.

Location and general features of the area

Hope is in the south-central part of Steele County, North Dakota, about 30 miles west of Hillsboro. It is on the branch line of the Great Northern Railway which runs from Fargo to Devils Lake. The town has a population of about 474 (1940 census) and serves as a shipping point and trading center for the farming area around it.

The part of the Central Lowland 1/ physiographic province in which Hope is located has been called the Drift Prairie by Simpson.2/ It is a plains area modified by little-eroded glacial drift which forms low, relatively rough hills along the lines of the end moraines and a gently rolling topography elsewhere. The Drift Prairie is bordered on the west by the Missouri Plateau and on the east by the Red River Valley. Hope is about 50 miles east of the escarpment which marks the eastern boundary of the Missouri Plateau and about 5 miles west of the highest (Herman) shore line of glacial Lake Agassiz which marks the western limit of the Red River Valley. 3/

The topography in the vicinity of Hope is gently rolling, with the hills and swales typical of ground moraines. No end moraines occur within the area covered by the present investigation, and on Upham's map4/ the nearest moraine is shown about 8 or 10 miles west of Hope. From this map it

1/ Fenneman, N. M., Physiography of eastern United States, pp. 559-588, McGraw-Hill Book Co., 1938.
2/ Simpson, H. E., Geology and ground-water resources of North Dakota: U.S. Geological Survey Water-Supply Paper 598, p.4, 1929.
3/ Upham, Warren, The glacial Lake Agassiz: U.S. Geol. Survey Mon. 25, 1896.
4/ Op. cit., pl. 19.

appears that a lobe of ice occupied the Hope area during the deposition of the Fergus Falls moraine, and extended southward beyond the latitude of the present U. S. Highway 10. The glacial drainage channels, which are the chief relief features of the area, were probably formed during the withdrawal of this ice lobe. The general course of the channels is southeastward, parallel to the front of the retreating ice. Most of the channels now carry only intermittent streams, but the Maple River, which is 3 miles west of Hope, has a very small perennial flow. Another glacial channel occurs about 1½ miles west of Hope. It is generally parallel to the Maple River, but about 2 miles south of Hope it turns abruptly eastward to join the South Branch of the Goose River. Several high-level cross channels connect the two glacial channels in the area in which they have parallel courses. They were probably formed when ice blocked the eastward flow of the second glacial channel, forcing it to drain into the Maple River.

Previous investigations and acknowledgments

The geology and ground water of the Hope region have been previously treated only in a very general way in connection with studies of broad areas. A general discussion of the ground water in Steele County, with mention of the average depth and character of wells at Hope, is contained in Simpson's paper on the ground-water resources of North Dakota.5/ Other works such as Upham's monograph6/ and the bulletins of the North Dakota Geological Survey are useful for their treatment of the general geology of the area.

5/ Op. cit., pp. 228-230.
6/ Op. cit.

The present study was facilitated by the ready cooperation of townspeople and farmers. Thanks are due especially to those who permitted measurement of water levels in their wells and drilling operations upon their land, and to Arthur Sorenson, the local well driller, for information concerning the numerous wells which he has bored in the vicinity.

Present water supply and future needs

The present water supply is obtained from numerous shallow wells in town, each of which generally serves from one to four families. The wells are of large diameter, being either bored or dug, and the water in them is generally withdrawn by means of a hand pump. Automatic pressure pumps have been installed on the well at the hotel and on a few of the wells serving private homes. Rain water caught from the roofs of buildings and stored in cisterns is used in many homes for washing and other purposes requiring soft water.

Two large dug wells were constructed for the City with W.P.A. labor in 1938. They are 5 feet in diameter, are curbed with concrete blocks, and are 34 and 42 feet deep, respectively. Because of the comparatively high mineralization of the waters in these wells, they are used infrequently for domestic purposes and serve primarily for fire protection.

It is estimated that about 40,000 to 50,000 gallons of water a day might be required for a satisfactory municipal water supply for the town, although probably less than one-half that amount is used at the present time.

GEOLOGY AND HYDROLOGY

General

Essentially all ground water is derived from precipitation. The water may enter the ground by direct penetration from rainfall or from melting snow, and by percolation from streams which cross the area concerned. In some areas a part of the ground water comes from adjacent regions, entering the ground at higher elevation and moving slowly to lower elevations.

The amount of water that a rock can hold is measured by its porosity. The unconsolidated rocks such as clay, sand, and gravel are generally more porous than consolidated rocks such as sandstone and limestone, although in some areas the consolidated rocks are highly porous.

If the pore spaces are large and interconnected, as they commonly are in sand and gravel, the water is transmitted more or less freely and the rock is said to be permeable, but where the pore spaces are very small, as they are in clay, the water is transmitted very slowly or not at all and the rock is said to be impermeable. Below a relatively shallow depth in practically all regions the pore spaces in the rocks are filled with water and the rocks are said to be saturated. This is true of the clay as well as the sand and gravel, but because of the difference in permeability it is possible to obtain wells only in the coarser materials. Where some part of the water-transmitting bed (aquifer) is exposed at the surface or comes in contact with another aquifer that is so exposed, the water discharged naturally or through wells has an opportunity to be replenished each year in this "recharge area." Where the aquifer is more or less completely surrounded by clay, natural recharge may be very slow and the water taken by wells from storage in the aquifer may not be fully replenished each year. The initial yield of wells in aquifers which are virtually cut off from natural recharge may be as large as that from wells in aquifers having adequate recharge areas, thereby giving an erroneous impression that an abundant perennial supply is avaiable.

As ground water moves through an aquifer it dissolves a part of the more soluble materials present and the length of time the water is in contact with them. Therefore, the waters which have been underground longest and have traveled the greatest distance are commonly more highly mineralized than those which are relatively near the recharge area.

The rock materials and their water-bearing characteristics

The surface rock in the Hope area is glacial drift of Pleistocene age. It covers the underlying shale bedrock, which is the Pierre shale of Cretaceous age. Beneath the Pierre are other shale formations and the Dakota sandstone, all of Cretaceous age, and pre-Cambrian crystalline rocks. Only the glacial drift and the Dakota sandstone are of interest as possible aquifers in this area.

Information concerning the rock materials of the glacial drift was obtained from logs of existing wells and from 10 test holes drilled in the area. Information concerning the bedrock formations is inferred from deep wells in adjacent areas.

Glacial drift

The glacial drift may be divided conveniently into three units: (1) The ground moraine lying at the surface and consisting chiefly of till (boulder clay), (2) outwash gravel, which underlies the ground moraine at shallow depths, and (3) older till, which underlies the gravel to a total depth of 150 to 200 feet below the surface.

Till of the ground moraine:-The ground moraine in the Hope area generally ranges in thickness from 10 to 35 feet, though it is absent in a few places. In general, the thickest parts occur beneath the hills and the thinnest parts beneath the swales. In other words, the surface upon which the ground moraine was deposited appears to have been nearly flat in the Hope area, and the present differences in topography have resulted from the differences in the amount of till deposited at various points by the melting ice.

The till of the ground moraine is a compact clayey material composed chiefly of shale detritus with occasional boulders and pebbles of limestone and crystalline rocks. A few beds of glacio-fluvial sand and gravel are contained within the till, but those encountered in test holes lie above the water table, are thin, and are composed almost entirely of grains and pebbles of shale. Therefore, the materials of the ground moraine are essentially non-water-bearing.

Outwash gravel: All wells and test holes drilled in the Hope area encountered gravel and sand at depths ranging from 10 to 35 feet below the surface. Most farm wells within 5 miles of Hope also obtain water from gravel which they penetrated at depths ranging from 15 to 60 feet below the surface, indicating that the outwash gravel may occur over an area much larger than that covered in this report. The top of this gravel body lies at an elevation of about 1,200 feet above mean sea level in the 10 test holes drilled in the Hope area, and the reported depths of wells in surrounding townships suggests a nearly uniform altitude in those areas also.

The thickness of the gravel and sand body as determined from the test holes ranges from 4 to 26 feet. The top is generally at or below the water table, and the full thickness is therefore saturated. There is considerable variation in the character of the gravel from place to place, and much of it contains from 10 to 15 percent of clay. In all test holes, pebbles and grains of shale constitute a large part of the gravel and sand, but in some holes hard rock materials, chiefly limestone, quartz, and crystalline rocks, compose about one-half of the materials of the gravel bed.

The origin of the gravel body is not definitely determinable in the area covered by the present investigation. It is evident that at least a local advance and retreat of the ice must have occurred after the gravel was deposited, for it is everywhere covered by the latest ground moraine. The upper surface of the gravel probably was nearly flat or sloped gently to the south or southeast. The presence of shallow farm wells in surrounding sections suggests that the gravel plain may have been rather extensive. This thin blanket of gravel of highly variable character covering a relatively flat surface is most readily explained as an outwash plain formed at some time prior to the last advance and retreat of the ice. No information was found during the present investigation to indicate where the ice margin may have stood during the formation of such an outwash plain.

Older till:-A compact, stony till encountered in all test holes below the outwash gravel is believed to be a deposit of an older ice sheet, and hence is called older till. It rests unconformably on the Pierre shale. Only three of the 10 holes penetrated the entire thickness of the older till, but from these it appears that the total thickness is about 120 to 175 feet in the Hope area. The material is well-indurated and very stony, and is therefore very difficult to drill. Sand and gravel beds are rarely encountered in it, and it is not likely to contain important aquifers in this area.

Pierre shale

The Pierre shale, of Cretaceous age, underlies the older till and overlies other shale formations and the Dakota sandstone, also of Cretaceous age. It was encountered at a depth of 160 to 210 feet below the surface in three of the test holes, and no other test holes or wells had been drilled previously as deep as the shale in the immediate vicinity of the town. No wells are known to obtain water from the shale in or near Hope, although in other parts of the State some wells, which yield small amounts of highly mineralized water, derive their supply from sandy beds and other permeable zones in this formation. One well near Hope is reported to have been drilled deeply into the shale without finding any appreciable amount of water.[7] It is located in the E$\frac{1}{2}$ sec. 29, T. 145 N., R. 56 W. The owner is given as Simon Neilson and the total depth as 925 feet. This depth would have carried the hole nearly through the complete section of Cretaceous shales in this area, and it probably ended near the top of the underlying Dakota sandstone. The shale appears

7/ Works Projects Administration official project No. 665-73-3-48. Report on file with the State Geologist, University of North Dakota, Grand Forks, North Dakota.

to contain no important water-bearing beds over a wide area in this region. Near Aneta the Edgar Gutormson farm well is reported by Simpson [8] to have been drilled to a depth of 744 feet without finding water. Several wells at the old O'Keeffe flour mill at Sharon are reported to have been drilled as much as 700 feet into the shale without finding appreciable quantities of water. Simpson[9] also reports a well at Finley, about 18 miles north of Hope, to be 800 feet deep. This well also is reported to have been a "dry hole."

Dakota sandstone

The Dakota sandstone underlies the Cretaceous shales in this area, and so far as is known no wells deep enough to encounter it have been drilled in the vicinity of Hope. According to Simpson,[10] the upper artesian horizon of the Dakota sandstone is encountered about 900 feet below the surface at Dazey, Barnes County, which is about 25 miles southwest of Hope. The probably depth to this aquifer at Hope would be about 1,000 or 1,100 feet. In this part of North Dakota, the water from the Dakota sandstone is highly mineralized and is generally considered unsuitable for drinking and culinary purposes.

Test holes

Much of the information concerning the rock materials and their water-bearing characteristics in the Hope area was obtained from 10 test holes drilled with the State-owned hydraulic rotary machine to depths ranging from 31 to 218 feet. The location of these test holes is shown on figure 1, and logs of the holes are given on page 30.

8/ Op. cit., p. 179.
9/ Op. cit., p. 230.
10/ Op. cit., p. 70.

The first test hole, Steele County 12, was located on the curve of Carpenter Boulevard at the northwest corner of town. The hole penetrated 36 feet of weathered till of the ground moraine, 8 feet of clayey outwash gravel, 122 feet of very tough bouldery clay (older till), and 4 feet of shale bedrock. The outwash gravel in this hole was relatively thin and clayey, and no other aquifers were encountered. The second hole, Steele County 13, was located about 8 blocks east of the first one in city-owned land now used as a dump ground. The till of the ground moraine was rather sandy in this hole, and the outwash gravel was 17 feet thick and fairly clean. In order to obtain complete data across this part of the area, holes 14 and 15 were drilled about a quarter and three quarters of a mile east of No. 13. The outwash gravel was 12 feet thick in hole 14, and only 6 feet thick and very clayey in hole 15. No other aquifers were encountered in these three holes.

In order to determine the character and thickness of the aquifer from which the J. L. Thompson well obtains water, hole 16 was drilled on Steele Avenue at the west edge of town to a depth of 70 feet. The area of the Thompson well held special interest because chemical analysis had indicated that the water from this well is considerably less mineralized than that from most wells in town. (See analysis, p. 24.) However, the test holes showned only 4 feet of rather clayey sand and gravel; and in hole 17, which is about 3 blocks southeast of 16, the aquifer was also thin, consisting of about 4 feet of coarse sand.

Hole 18 was drilled about a quarter of a mile west of town, opposite the Thorsland farm. It encountered about 10 feet of sand and gravel in the drift of the ground moraine and 22 feet of outwash gravel. However, the upper gravel is above the water table and the outwash gravel below contains considerable clay.

Test holes 19, 20 and 21 were drilled east and southeast of town, 19 being opposite the Germundson farm, 21 opposite the Oxton farm, and 20 at the section corner between these two farms. The drift of the ground moraine contained two sandy beds at hole 19, but the outwash gravel was only 13 feet thick and contained considerable clay. At hole 21 the outwash gravel was 20 feet thick and fairly clean. In this hole there were two other aquifers, 8 and 12 feet thick, at depths of 42 and 58 feet, respectively. In hole 20 the outwash gravelwas 26 feet thick, extending to a total depth of 40 feet below the land surface. The base of the gravel in holes 20 and 21 lies at a lower elevation than it does in the other test holes. The sand and gravel in this hole was relatively well rounded, was well-sorted, and consisted of about equal amounts of shale and hard-rock materials. Most of the other holes contained a considerably higher percentage of shale pebbles and grains.

Existing wells

General

There are more than 50 wells in Hope, about half of which are being used at the present time. So far as could be determined, all wells put down in town yielded sufficient water for domestic purposes. The depth of most wells is between 20 and 40 feet, although a few are as deep as 60 feet. All the wells were either bored with a large power-driven auger or were dug, and according to the driller many of the wells do not penetrate the full thickness of the gravel. The differences in depths of the wells results chiefly from the differences in their surface elevations and it would found that practically all wells bottom at elevations between 1,180 and 1,200 feet above mean sea level. Therefore, it appears probable that the wells all draw from the same aquifer.

Many farm wells in the vicinity of Hope are reported by the local well driller to bottom in a shallow gravelsimilar to that which supplies the wells in town. His observation is substantiated by a comparison of the depths of arm wells in the surrounding area with the depths of wells at Hope. The town is located at a township corner and records of depths of farm wells in all four townships surrounding it were tabulated from W.P.A. county records.[11] In T. 145 N., R. 55 W., most wells ranged in depth from 16 to 35 feet and the deepest was 60 feet; in T. 145 N., R. 56 W., most wells were 24 to 50 feet deep and the deepest producing well was 74 feet; in T. 144 N., R. 55 W., most wells ranged in depth from 18 to 24 feet and the deepest was 90 feet; and in T. 144 N. R. 56 W., most wells were 20 to 30 feet deep and the deepest was 45 feet. From these data it appears that the outwash gravel aquifer may be generally present within a radius of several miles of Hope.

Water table

The depth of water in 37 wells in the Hope area was measured on September 3 to 6, 1946. Elevations of the measuring points on these wells were established later, and from these data the contour map of the water

11/ Op. cit.

surface given in figure 1 was constructed. The contours show that the water table has a gentle slope to the southeast corresponding in general with the slope of the land surface. The slope is most pronounced in the western part of the area and becomes nearly flat in the eastern part. None of the numerous water levels measured was more than a few tenths of a foot higher or lower than would be expected from the contours as drawn. This is further evidence that the wells all draw from the same aquifer.

Fluctuations in water levels

According to reports of well owners and the local well driller, there is little variation in the water levels in the wells of the Hope area from season to season and from year to year. The reported water level obtained when the well was bored is, in most cases, within a foot of the present water level. These reports are substantiated by measurements made in some of the wells between September 1946 and August 1947. In most cases the range in fluctuations was only a few hundredths or a few tenths of a foot, and in only one instance was the fluctuation greater than a foot.

The water levels are reported to recover rapidly after a period of pumping. This was substantiated during the round of measurements on September 3-6, 1946, by the almost identical elevations obtained both in wells which had been recently pumped and on unused wells. None of the wells when pumping has drawdowns great enough to break suction.

Storage, recharge, movement, and discharge of water in the outwash gravel

The thickness and extent of the outwash gravel would indicate that a considerable amount of water is stored in this aquifer in the Hope area. The information obtained from existing wells and test holes makes it reasonably certain that the aquifer is present throughout an area of at least 2 square miles, and information from farm wells in the surrounding area suggests its probable presence over a much wider area. The average thickness of the aquifer in the 10 test holes is 13.7 feet.

The effective porosity, or specific yield, of sand and gravel--the volume of water yielded from storage in a given volume of material when the water level is lowered--varies between wide limits and no data are available for the determination of the specific yield of this aquifer. However, a specific yield of 20 to 40 percent is common in materials of this type, 12/ and if calculations are based on an assumed specific yield of 15 percent the results should be a conservative figure for the amount of water in storage. Not all the water in storage could be withdrawn by means of a single well or even a number of wells. However, if as much as two-thirds of the estimated 15 percent could be so withdrawn over an area of 2 square miles, and assuming that the aquifer averages 13.7 feet thick and that there is no recharge to it, storage would be sufficient to last for about 40 years if the average withdrawal were at the rate of 40,000 gallons a day. However, this is an oversimplification, because water could not be withdrawn from any given area of 1 square mile without withdrawing water from adjacent areas. On the other hand, it would require a considerable number of wells to withdraw water to the indicated extent from the full 2 square-mile area. On the favorable side is the probability that there is considerable annual recharge to the aquifer, so that withdrawals would not depend entirely on storage. All in all, an estimate of not less than 40,000 gallons a day from several widely spaced wells appears to be reasonable. More definite information concerning the amount of water in

12/ Meinzer, O. E., The occurrence of ground water in the United States: U.S. Geol. Survey Water-Supply Paper 489, pp. 50-76, 1923.

storage in the aquifer can be obtained when test wells are constructed to penetrate the entire thickness of the gravel, and when controlled pumping tests can be made upon the aquifer to determine transmissibility.

Much of the recharge to the outwash gravel is probably from local precipitation. The irregular topography of the ground moraine prevents rapid surface runoff of precipitation in the immediate vicinity of Hope, and in adjacent areas runoff occurs only after numerous depressions have been filled. At the locations of the test holes the gravel is covered by 10 to 35 feet of weathered till, but the till cover is so variable in thickness it seems likely that the gravel may be at or very near the surface in the areas of the major depressions. The thinnest till cover was encountered in test holes located at the lowest elevations, and the nearly uniform elevation of the top of the gravel in all the holes suggests a fairly level outwash plain upon which varying thicknesses of till was deposited. Thus it appears that the ponds and marshes are the most likely areas of recharge, although the weathered till would probably permit some recharge over the entire area during very wet seasons. The gravelly character of the till covering in the vicinity of holes 13, 18, and 19 indicates that considerable recharge might occur in those areas. Relatively high water levels in wells near the northwest part of town probably indicates considerable recharge from the ponds in and adjacent to that area.

With respect to recharge of the aquifer from rainfall, a very conservative estimate can be made as follows: The mean annual rainfall at Hope is about 20 inches. If an average of only 2½ percent of this amount, or 0.5 inch, penetrated to the aquifer and was not otherwise disposed of, it would be sufficient to replenish a withdrawal of more than 40,000 gallons a day from wells located so as to draw on an area of about 2 square miles. Thus, following the lowering of water levels and withdrawal from storage required to establish the necessary water-table gradients to the wells, the pumpage would be supported by recharge and not from storage.

The water in the outwash gravel is in motion toward the southeast, as indicated by the water-table contours of figure 2, but the rate of movement is very slow when compared to surface-stream velocities, being measurable in terms of feet per year rather than feet per second. Nevertheless, the water in the gravel is not static and, despite the quantities of water withdrawn from wells in town, the water levels are still higher in town than they are to the southeast, indicating that water moves in that direction towards points of natural discharge. With regard to the rate of movement, the amount of clay and fine sand in samples of the out--wash gravels obtained from the test holes varied considerably from hole to hole and from bed to bed within each hole. Movement of water would be greatly retarded in those portions of the aquifer which contain large amounts of these fine materials, and would be considerably more rapid in those portions which are relatively free of clay and fine sand.

The general movement of the ground water to the southeast indicates that the principal areas of natural discharge are in that direction. Marshes and ponds on both sides of the railroad from 0 to 2 miles southeast of town may be important areas of natural discharge through evaporation and transpiration. On the other hand, most of the natural discharge may be into the glacial drainage channel which changes the direction of its course from southerly to easterly about 2 miles south of Hope, and ultimately joints the South Branch of the Goose River.

In the absence of long-period water-level records, pumping records, and pumping tests, only very general conclusions can be drawn concerning the storage, recharge, movement, and discharge of water in the aquifer. More definite information as to the quantities of water perennially available from the aquifer can be obtained only after such data have been collected and analyzed.

QUALITY OF THE GROUND WATER

Water samples from 16 representative wells in the Hope area were collected and submitted to the State Department of Health and the State Laboratories Department for mineral analysis. The locations of the wells sampled are shown by double circles on figure 2. The results of these analyses are given in the following table, together with an earlier analysis of water from one of the W. P. A. City wells, made about 1937.

The waters show a rather wide range in the concentration of the dissolved mineral load. The total solids range from 482 to 2,640 parts per million and the total hardness from 424 to 1,750 parts per million. There is a correspondingly wide range in the concentration of the various radicals. It is not known why there should be such a wide range in the amount of dissolved mineral matter in wells so closely spaced and drawing water from the same aquifer, but a number of factors which probably contribute in a greater or lesser degree to this condition are as follows: It is likely that the materials of the outwash aquifer vary considerably from place to place in the amounts of soluble mineral matter which they contain. Potholes and other undrained depressions in which dissolved minerals might have been concentrated by evaporation of waters may have been present on the old outwash plain, causing the amount of soluble material in the gravels to be higher in those places. Similar undrained depressions are now present over the area, and some of these may contribute highly mineralized water to the aquifer during wet periods when water from rainfall accumulates in them and forces water previously concentrated by evaporation to move back into the aquifer. Movement of water through the more clayey portions of the gravel is very slow, so that the waters remain in contact with the soluble constituents of the rock materials for long periods of time. Hence, in some portions of the aquifer the more highly mineralized character of the water is due to this condition of relative stagnation.

Seven of the nine samples of water collected from wells in town showed a mineral content of more than 1,000 parts per million of dissolved solids. The water from the well on the C. S. Braisted farm, near the southwest corner of town, also belongs to this group of relatively highly mineralized waters. On the other hand, water from the J. L. Thompson well in the extreme western part of town, and the "Poppie" well and W. T. Newell well in the northwest corner of town, was considerably less highly mineralized, as was water from six wells at farms northwest, north, northeast, east, and southeast of town. Thus it appears that the relatively highly mineralized waters may be the result of local conditions in and southwest of town.

The analyses (page 24) show that there is more or less complete gradation from the least mineralized to the most mineralized waters in the area. Furthermore, several of the more highly mineralized waters are extensively used and are considered to be reasonably satisfactory by their users. Any well drawing large quantities of water from the aquifer in or near the town would cause water to flow toward it from a fairly large surrounding area, and the average quality of the water quite likely would be somewhere between the least and most highly mineralized waters given in the table. However, it appears that the least mineralized waters generally occur in the more permeable parts of the aquifer, and a well located in such an area would likely draw most of its water from adjacent permeable areas and a comparatively small amount from the less permeable and more highly mineralized areas. Nevertheless, periodic checks on the mineral quality of any municipal supply well would seem to be necessary.

SUMMARY AND CONCLUSIONS

Only one aquifer of imporatance occurs in the Hope area and this is everywhere present at Shallow depths throughout the area covered by the present investigation. It is composed of sand and gravel ranging in thickness from about 4 to 26 feet and is covered by weathered till ranging in thickness from about 10 to 35 feet. Although apparently present everywhere, the thickness and permeability of the aquifer vary from one part of the area to another. The mineral quality of the water from wells in different parts of the area also varies considerably. For example, the 16 analyses show a range of 482 to 2,640 parts per million for total dissolved solids.

Information obtained from existing wells and from 10 test holes drilled in the area indicates that the amount of water in transient storage in the aquifer is large in comparison with the daily requirements of a town the size of Hope. On the basis of conservative estimates concerning the average specific yield of the materials of the aquifer and the percentage of stored water which might be recovered from it economically, there appears to be sufficient storage in 2 square miles of the aquifer to furnish at least 40,000 gallons a day for about 40 years, disregarding recharge during that time. Because the overlying drift is weathered, is locally sandy, and is thin or possibly even absent in the topographic depressions, a perceptible amount of recharge to the aquifer probably occurs from precipitation on the area. It is estimated that the recharge from this source is sufficient to supply at least 40,000 gallons a day to wells drawing on an area of 2 square miles.

The most permeable, as well as the thickest, sections of the aquifer were encountered in test holes 20,21, 13, 18, and 19, in that order. The quality of the water in the vicinity of these holes is probably better than that in most of the wells in town, as indicated by analyses of water from farm wells in the vicinity of the test holes. The base of the gravel in holes 20 and 21 lies at a lower elevation than it does in the other test holes. This would permit withdrawing relatively large quantities of water in this area because of the larger practicable drawdown and wider area of influence.

More definite information as to the quantities of water perennially available from the aquifer, as well as the probable average mineral quality of the water, can be obtained from: (1) Controlled pumping tests on test wells constructed to penetrate the full thickness of the aquifer in those areas which appear to be most favorable; (2) periodic analysis of the waters pumped; (3) periodic water-level measurements on observation wells; and (4) wider field studies of the extent of the aquifer.

Owner	Location number	Date collected	Source of analysis 1/	Depth of well (ft.)	Iron (Fe)	Calcium (Ca)
Obert Germundson	144-55-6bcb	9/6/46	A	23	0	118
Frank Oxton	144-55-7bda	5/3/47	B	24	.7	170
City of Hope (WPA) at 5th & Hubbard	144-56-1bad2	9/6/46	A	34	0	291
City of Hope (WPA) at 5th & Hubbard	do.	1937	C	34	3	173
W. T. Newell	144-56-1bbb	9/6/46	A	45	0	204
Community well known as Poppie Well	144-56-1bbd3	9/6/46	A	36	0	157
City of Hope (WPA) at 2nd & Small	144-56-1bca1	9/6/46	A	42	0	560
J. L. Thompson at Service Station	144-56-1bca2	9/6/46	A	65	0	383
J. L. Thompson	144-56-1acb	9/6/46	A	40	0	160
H. J. Wemerstrom	144-56-1caa	9/6/46	A	37	0	450
C. S. Braisted	144-56-2add	5/3/47	B	50	.4	228
Winston Wennerstrom	145-55-31caa	9/6/46	A	50	0	229
Arthur Hogeback	145-55-31dad	5/3/47	B	16	.2	71
Bill Kainz	145-55-31dcc1	9/6/46	A	34	Trace	460
Ted McCullaugh	145-55-31ddd	9/6/46	A	24	Trace	251
T. Thorsland	145-56-36[illegible]	5/3/47	B	40	.8	77
School Well	144-56-1acb	9/6/46	A	--	0	400

1/ A - North Dakota State Dept. of Health, Bismarck, N. Dak.
B - State Laboratories Department, Bismarck, N. Dak.
C - Abbott, G. A. and Voedisch, F. W. The Municipal ground-water supplies of North Dakota. North Dakota Geol. Survey Bull. 11, 1938, p. 78.

IN HOPE AREA, IN PARTS PER MILLION

Magnesium (Mg)	Sodium and potassium (Na K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Total dissolved solids	Total hardness, as ($CaCO_3$)
23	6.8	---	330	125	5	482	480
40	0	98	150	250	0	767	588
22	45	---	373	555	26	1,240	818
96	115	---	484	483	99	1,330	833
60	10	---	346	412	14	870	956
53	0	---	271	360	13	788	612
85	5.1	---	495	1,060	182	2,640	1,750
109	0	---	499	810	100	1,930	1,410
10	16	---	371	161	3	570	442
85	0	---	410	906	136	2,040	1,480
85	200	186	239	847	31	2,100	920
32	13	---	435	342	15	944	705
60	18	41	51	316	22	863	424
91	0	---	400	1,110	41	2,170	1,530
20	27	---	413	395	22	990	708
68	55	67	88	394	---	935	470
110	25	---	417	1,060	31	2,340	1,450

Location number	Owner or Name	Depth of well (ft.)	Diameter (inches)	Type	Date completed
144-55-6bcb	Obert Germundson	23	24	Bored	1944
144-55-7baa	USGS test hole 21	190	5	Drilled	5/3/47[4]
144-55-7bda	Frank Oxton	24	30	Bored	1935
144-56-1abc	Florence Winless	19	24	Bored	Old
144-56-1abb1	Evdyn Eggert	25	24	do.	1945
144-56-1abb2	Fred Cole	25	24	do.	1944
144-56-1abc	Henry Paine and J. L. Emmerich	60	24	do.	Old
144-56-1abd	Wm. Splittstosser	--	--	---	do.
144-56-1acb1	Sam Smith	28	18	Dug	do.
144-56-1acb2	Grace Wood	25	--	do	Before 1931
144-56-1acc	Harold Anderson	31	48	do.	Old
144-56-1ada	USGS test hole 19	50	5	Drilled	5/1/47[4]
144-56-1bab	Mary Baker	60	--	---	Old
144-56-1bac1	F. W. Willmert	32	24	Bored	Before 1920
144-56-1bac2	Wm. Sussex	33	--	---	---
144-56-1bac3	Anne Jefferson	35	--	Bored	Old
144-56-1bac4	Alvie Strathe	34	24	do.	1944
144-56-1bad1	J. W. Stanley	33	36	Dug	1904
144-56-1bad2	City of Hope (WPA) at 5th and Hubbard	34	60	do.	1937
144-56-1bbb	W. T. Newell	45	36	do.	Old
144-56-1bbd1	Anne Roy	40	24	---	Before 1926
144-56-1bbd2	H. H. Lindeman	43	24	Bored	---
144-56-1bbd3	Community well, known as Poppie well	36	24	do.	Old
144-56-1bca1	City of Hope (WPA) at second and Small	42	60	Dug	May 1938
144-56-1bca2	J. L. Thompson (at Service Station)	40	--	Bored	1945
144-56-1bcb1	USGS test hole 16	70	5	Drilled	4/29/47[4]
144-56-1bcb2	J. L. Thompson	65	30	Dug	---

1/ Land-surface datum.
2/ Mean sea level datum.
3/ D-Domestic, S-Stock, U-Unused, Ind.-Industrial.
4/ Test holes were drilled and refilled. Date given is date of refilling.

Depth to water (ft.)1/	Elevation of water surface (ft.)2/	Date of measurement	Use3/	Remarks
11.34	1,201.2	9/6/44	D.S	Analysis.
---	---	---	U	Log.
---	---	5/3/47	D	Analysis.
15.11	---	9/3/46	U	---
20.99	1,200.8	9/4/46	D	Reported to have bad taste.
22.18	1,201.2	9/3/46	D	Bored to top of sand.
24.49	1,201.2	9/3/46	D	
21.13	1,199.5	9/3/46	D	
22.38	1,201.6	9/5/46	D	
19.88	1,200.1	9/5/46	D	
24.63	1,201.2	9/5/46	-	
---	---	---	U	Log.
33.63	1,202.0	9/5/46	D (U)	
27.90	---	9/6/46	U	
29.23	1,202.0	9/6/46	D	
29.65	---	9/6/46	D	
31.93	1,203.6	9/4/46	D	Bored to top of sand.
26.10	1,202.9	9/6/46	D	
27.90	1,203.6	9/5/46	D.S	Analysis.
41.70	1,202.3	9/4/46	D.S	Do.
36.89	1,201.9	9/5/46	U	
42.21	1,202.2	9/5/46	D.P	
31.08	1,202.4	9/4/46	D	Analysis.
35.10	1,202.5	9/5/46	U	Do.
37.68	1,200.7	9/5/46	D	Do.
---	---	---	U	Log.
38.95	1,203.6	9/5/47	D	Analysis.

Location number	Owner or Name	Depth of well (ft.)	Diameter (inches)	Type	Date completed
144-56-1bda1	Mrs. Clara Kraabel	35	12	Bored	1906
144-56-1bda2	Geo. Thilmony	26	24	do.	1943
144-56-1bdb1	Mrs. Elsie Johnson	43	30	Dug	Old
144-56-1bdb2	Orin Chance	35	24	Bored	1946
144-56-1bdc	Oliver Vierkandt	48	20	do.	Old
144-56-1bdd	P. Bowen (?)	37	24	do.	---
144-56-1caa	H. J. Wennerstrom	37	247	do.	1906
144-56-1cab1	Harvey Cockle	90	---	do.	1941
144-56-1cab2	C. S. Braisted	39	---	Dug	Old
144-56-1cba	USGS test hole 17	56	5	Drilled	4/30/47[4]
144-56-1ddd	USGS test hole 20	50	5	do.	5/1/47 [4]
144-56-2aba	USGS test hole 18	60	5	do.	5/1/47 [4]
144-56-2add	C. S. Braisted	50	36	Dug	Old
145-55-31caa	W. Wennerstrom	50	24	Bored	1940
145-55-31ccd	USGS test hole 12	170	5	Drilled	4/23/47[4]
145-55-31cdb	Arthur Hogeback	45	---	Dug	1942
145-55-31cdc	C. G. Fosdick	44	24	Bored	1944
145-55-31dad	Arthur Hogeback	16	24	do.	1945
145-55-31dcc1	Bill Kainz	34	24	do.	---
145-55-31dcc2	Fred Hoageson	33	24	Dug	---
145-55-31ddc	USGS test hole 13	180	5	Drilled	4/23/47[4]
145-55-31ddd	Ted McCullaugh	24	24	Bored	1945
145-55-32ccc	USGS test hole 14	31	5	Drilled	4/25/47[4]
145-55-32dcc	USGS test hole 15	136	5	do.	4/29/47[4]
145-56-36ddd	T. Thorsland	40	24	---	---

1/ Land-surface datum.
2/ Mean sea level datum.
3/ D-domestic, S-stock, U-unused, Ind-industrial.
4/ Test holes were drilled and refilled. Date given is date of refilling.

Depth to water (ft.)[1]	Elevation of water surface (ft.)[2]	Date of measurement	Use[3]	Remarks
30.46	1,201.4	9/6/46	U	
21.45	1,201.4	9/5/46	D	
35.13	1,202.4	9/5/46	D	
31.38	1,201.5	9/5/46	D	
37.20	1,202.1	9/6/46	D	
31.23	1,202.2	9/5/46	U	
30.85	1,201.9	9/5/46	U	Analysis.
33.75	1,201.1	9/5/46	D	Well deepened for greater storage.
33.83	1,202.1	9/5/46	U	
---	---	---	U	Log.
---	---	---	U	Do.
---	---	---	U	Do.
30.51	---	9/5/46	--	Analysis--sample from new well.
38.60	1,210.1	9/6/46	D.S.	Analysis.
---	---	---	U	Log.
43.92	1,201.4	9/[illegible]/46	D.S.	Bottomed in sand at 30 feet.
34.73	1,203.9	9/3/46	D.S.	
11.52	1,200.1	9/6/46	Ind.	Analysis (well at slaughter house).
27.77	1,202.3	9/3/46	S	Analysis.
29.27	1,201.4	9/3/46	U	
---	---	---	U	Log.
15.98	1,200.5	9/3/46	--	Analysis.
---	---	---	U	Log.
35.03	1,210.3	9/6/46	S	Analysis.

Logs of test holes near Hope, Steele County, N.Dak.

N. 12, 145-55-31ccd

Material	Thickness	Depth
Till, weathered, yellow	36	36
Gravel with some clay	8	44
Till, unweathered, gray, bouldery	122	166
Shale	4	170

No. 13, 145-55-31ddc

Till, weathered, yellow	6	6
Sand, with some clay	4	10
Till, weathered, yellow	7	17
Sand, coarse	5	22
Gravel	12	34
Till, gray, bouldery	131	165
Shale	15	180

No. 14, 145-55-32ccc

Till, weathered, yellow	15	15
Sand and gravel with some clay	12	27
Till, gray, bouldery	4	31

No. 15, 145-55-32dcc

Till, weathered, yellow	12	12
Gravel, with considerable clay	6	18
Till, unweathered, gray very bouldery	118	136

No. 16, 144-56-1bcb

Till, weathered, yellow	25	25
Till, unweathered, gray	11	36
Sand and gravel	4	40
Till, gray, bouldery	30	70

No. 17, 144-56-1cba

Material	Thickness	Depth
Till, weathered, yellow	4	4
Sand, coarse	2	6
Till, weathered, yellow	18	24
Till, unweathered, bouldery	6	30
Sand, coarse	4	34
Till, gray, bouldery	22	56

No. 18, 144-56-2aba

Till, weathered, yellow	8	8
Sand and gravel, with considerable yellow clay	10	18
Sand and gravel, with considerable gray clay	22	48
Till, gray, bouldery	12	60

No. 19, 144-56-1ada

Till, weathered, gray	5	5
Sand, coarse, with considerable clay	2	7
Till, weathered, yellow	6	13
Gravel and sand, with some clay	5	18
Till, unweathered, gray	3	21
Gravel and sand, with some clay	13	34
Till, gray	16	50

No. 20, 144-56-1ddd

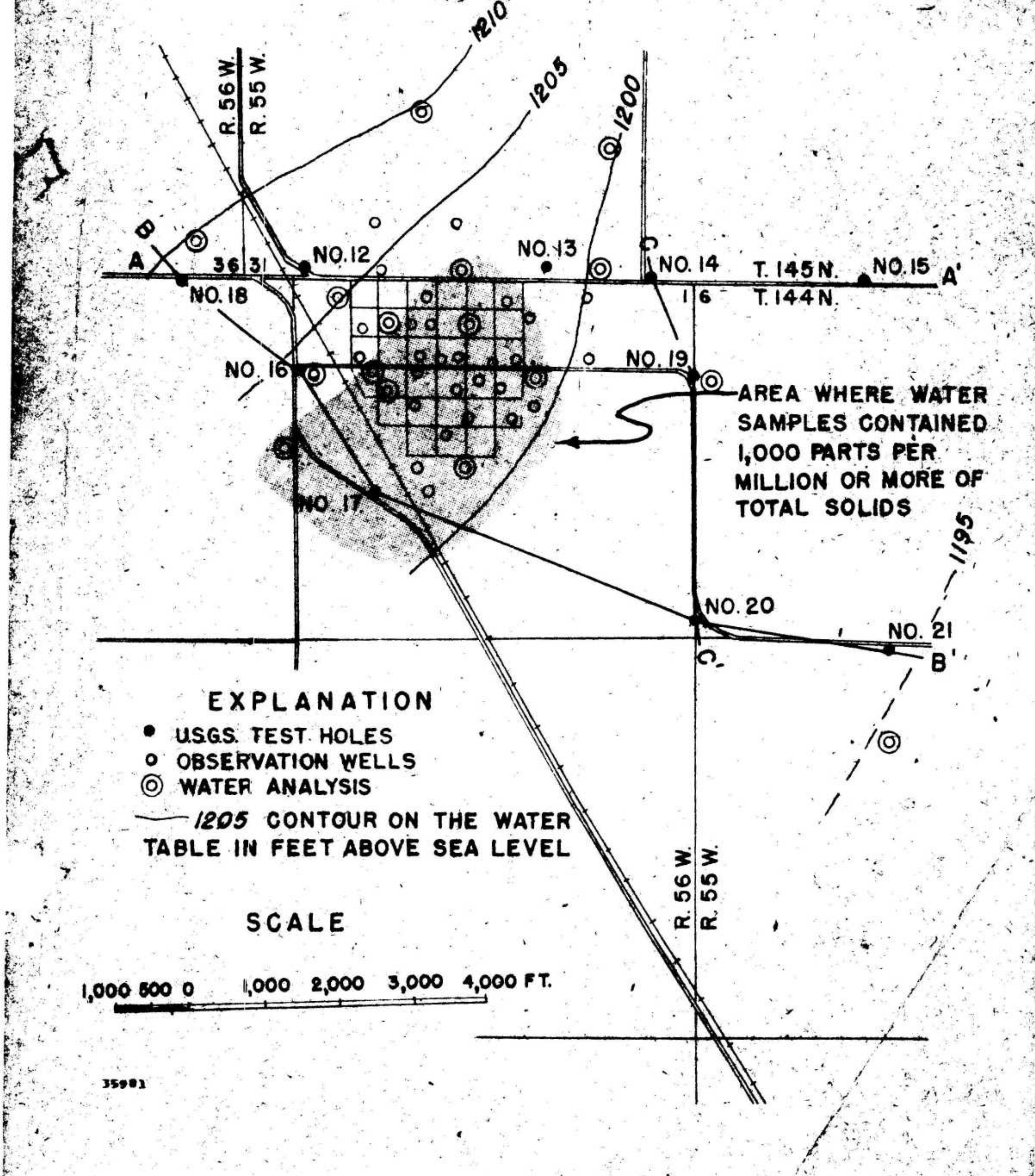
Till, weathered, yellow, bouldery	14	14
Sand and gravel	26	40
Till, unweathered, gray	10	50

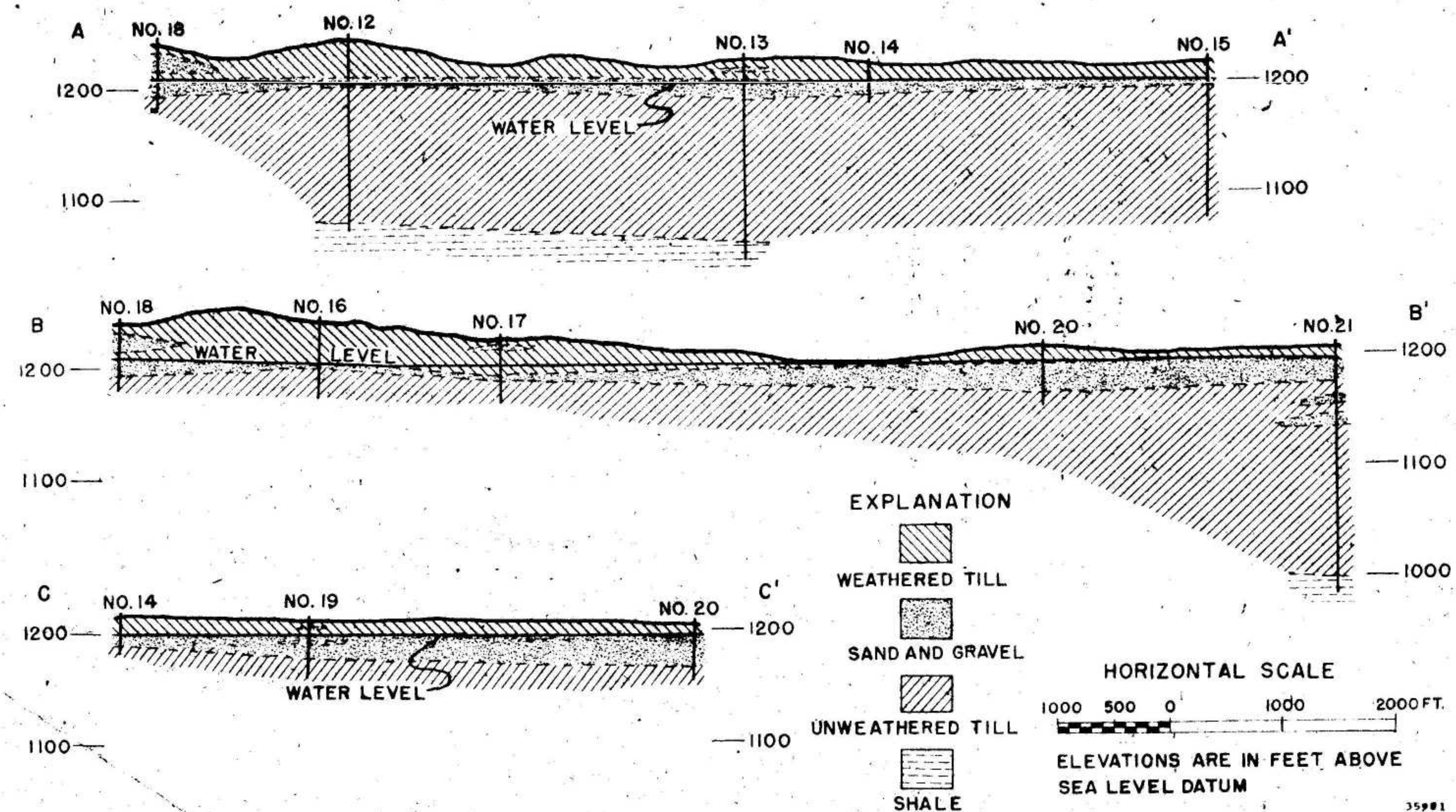
No. 21, 144-55-7baa

Material	Thickness	Depth
Till, weathered, yellow	10	10
Sand and gravel	20	30
Till, gray, bouldery	12	42
Sand, with some clay	8	50
Till, gray	8	58
Sand and gravel, with some clay	12	70
Till, gray, bouldery	135	205
Shale	13	218

FIGURE I

MAP OF HOPE AREA SHOWING GEOLOGIC AND HYDROLOGIC FEATURES




A
NO. 18
NO. 12
NO. 13
NO. 14
NO. 15
A'
1200
1100
WATER LEVEL
B
NO. 18
NO. 16
NO. 17
NO. 20
NO. 21
B'
WATER LEVEL
1200
1100
1000
C
NO. 14
NO. 19
NO. 20
C'
1200
1100
WATER LEVEL
EXPLANATION
WEATHERED TILL
SAND AND GRAVEL
UNWEATHERED TILL
SHALE
HORIZONTAL SCALE
1000 500 0 1000 2000 FT.
ELEVATIONS ARE IN FEET ABOVE SEA LEVEL DATUM