Ground-Water Resources of the Alma Area Michigan

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1619-E

Prepared in cooperation with the Michigan Geological Survey and the city of Alma

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By KENNETH E. VANLIER

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1963

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

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By Kenneth E. Vanlier

ABSTRACT

The Alma area consists of 30 square miles in the northwestern part of Gratiot County, Mich. It is an area of slight relief—gently rolling hills and level plains—and is an important agricultural center in the State.

The Saginaw formation, which forms the bedrock surface in part of the area, is of relatively low permeability and yields water containing objectionable amounts of chloride. Formations below the Saginaw are tapped for brine in and near the Alma area.

The consolidated rocks of the Alma area are mantled by Pleistocene glacial deposits, which are as much as 550 feet thick where preglacial valleys were eroded into the bedrock. The glacial deposits consist of till, glacial-lake deposits, and outwash. Till deposits are at the surface along the south-trending moraines that cross the area, and they underlie other types of glacial deposits at depth throughout the area. The till deposits are of low permeability and are not a source of water to wells, though locally they include small lenses of permeable sand and gravel.

In the western part of the area, including much of the city of Alma, the glacial-lake deposits consist primarily of sand and are a source of small supplies of water. In the northeastern part of the area the lake deposits are predominantly clayey and of low permeability.

Sand and gravel outwash yields moderate and large supplies of water within the area. Outwash is present at the surface along the West Branch of the Pine River. A more extensive deposit of outwash buried by the lake deposits is the source of most of the ground water pumped at Alma. The presence of an additional deposit of buried outwash west and southwest of the city is inferred from the glacial history of the area. Additional water supplies that may be developed from these deposits are probably adequate for anticipated population and industrial growth.

Water levels have declined generally in the vicinity of the city of Alma since 1920 in response to pumping for municipal and industrial supplies. The declines are not excessive, and during the late 1950's water levels in parts of Alma have risen slightly, because of dispersion of the pumping stations.

The ground water in the Alma area generally is very hard and high in iron. Locally, the buried outwash that underlies the city of Alma is contaminated by phenolic substances. This limits the amount of ground water available for municipal supply within the city, although reclamation of the contaminated part of the aquifer is considered feasible.

INTRODUCTION

PURPOSE AND SCOPE OF STUDY

In 1945 the city of Alma requested that the Geological Survey Division of the Michigan Department of Conservation expand its cooperative program of water-resources investigations with the U.S. Geological Survey to include a study of the Alma area. Interest in an overall ground-water-resource appraisal of the area was prompted by a water shortage that resulted from contamination by phenol of one of the city's wells. When the affected well was removed from service, the remaining wells were not able to provide enough water to meet, demands. The city reasoned that a study of the ground-water resources of the area would aid in obtaining additional water supplies and in planning for future needs. The city agreed to share the costs of the investigation, which was started in 1946.

The objectives of the investigation were (1) to define the principal aquifers in the Alma area and to determine whether these aquifers could yield supplies adequate for the needs of the city and other water users; (2) to define the extent of phenol contamination, and (3) to describe the deficiencies of existing data and the scope and nature of further work necessary for sound planning of future water-resource development.

The immediate problem of the city, locating an additional source of municipal water supply, was met by a city test-drilling and aquifer-testing program. This program furnished the basis for selection of sites and specifications for 2 new production wells, and the problem was resolved with the construction of these 2 wells.

The results of early investigations by the U.S. Geological Survey were summarized in an informal preliminary report to the city of Alma. The present report, which supersedes the earlier one, is designed to make data collected during the investigation and interpretations made therefrom readily available to the public. In addition, data collected in the period since the study was completed, and an evaluation of the effects of continued use of ground water through the spring of 1960, are included.

PREVIOUS INVESTIGATIONS

The first study of the water resources of the Alma area was an investigation of flowing wells in Alma made by a student at Alma College under the direction of Prof. C. A. Davis. The results of the investigation were reported in the September 10, 1897, edition of the Alma Record, a local newspaper. In the summer of 1904, Davis (1907) made a detailed study of the flowing wells in Alma and the water supplies of Gratiot County, as part of a larger regional study by Leverett and others (1907). Since 1946, measurements of water levels in observation wells in Alma and adjacent areas have been made as part of a statewide cooperative program, and these records have been published in the annual series of Water-Supply Papers of the U.S. Geological Survey entitled "Water Levels and Artesian Pressures in Observation Wells in the United States" (table 1) and in Water Supply Reports 1, 2, and 3 of the Michigan Geological Survey (Giroux 1957, 1958, and Giroux and Thompson, 1960).

TABLE 1.—*Length of water-level records for observation wells in the Alma area published in U.S. Geological Survey Water-Supply Papers, 1946–57*

WELL NO.	FORMER NO.	WATER-SUPPLY PAPER NO. AND YEAR OF RECORD										
		1071 1946	1096 1947	1126 1948	1156 1949	1165 1950	1191 1951	1221 1952	1265 1953	1321 1954	1404 1955	1537 1956, 1957
12N 3W 28-1	GrPr-16		—	—	—	—						
33-1	GrAL-252		—	—	—	—						
34-1	GrAL-99		—	—	—	—						
34-2	GrAL-103	—	—	—	—	—						
34-3	GrAL-255	—	—	—	—	—	—	—				
34-4	GrAL-358					—						
34-5	GrAL-5			—	—	—						
34-21	GrAL-30					—						
34-34	GrAL-95	—	—	—	—							
34-35	GrAL-96	—	—									
34-36	GrAL-106	—	—	—	—	—						
34-37	GrAL-260	—	—	—	—	—						
35-1	GrAL-148		—	—	—	—						
35-2	GrAL-254		—	—								
35-3	GrAL-256		—	—	—	—						
35-5	GrAL-360					—	—	—	—	—	—	—
11N 3W 2-1	GrAL-54		—	—	—	—	—	—				
2-2	GrAL-249		—	—	—	—						
2-3	GrAL-230	—	—	—	—	—						
2-4	GrAL-240		—	—	—	—	—	—	—	—	—	
2-5	GrAL-42		—	—	—							
2-6	GrAL-45								—	—	—	
2-26	GrAL-359					—						
2-29	GrAL-218		—									
3-1	GrAL-23	—	—	—	—	—						
3-4	GrAL-98	—	—	—	—	—						
3-5	GrAL-135		—	—	—	—	—	—	—	—	—	
3-6	GrAL-258	—	—	—	—	—	—	—	—	—	—	—
3-9	GrAL-6	—	—									
3-19	GrAL-253		—	—								
3-26	GrAL-174		—	—	—	—						
3-27	GrAL-215		—									

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HISTORICAL SKETCH OF WATER-SUPPLY DEVELOPMENTS AT ALMA

The first municipal water-supply system for Alma was placed in operation in 1882 and utilized water from the Pine River. River water which was used for fire protection, sprinkling, flushing wastes, and industrial use, was pumped directly into the distribution system without treatment. Potable water was supplied by privately owned wells and by two public fountains. Shallow dug or bored wells were the principal source of water for most residents. Some of the residents in the low areas along the river, however, obtained their water from deeper flowing wells. Some of these wells had sufficient artesian head to flow 17 feet above the level of the Pine River. An inventory by Davis (1907) in the summer of 1904 of 110 wells in Gratiot County included 92 flowing wells.

In 1917, the city of Alma developed a ground-water-supply system at Water Works Park in which a group of 14 wells were connected to a single suction pipe. The total capacity of these wells was about 0.8 mgd (million gallons per day). The need for additional water prompted further exploration, and in 1921 a well was drilled through the Saginaw formation into underlying strata at Water Works Park to appraise the deeper bedrock formations as a source of supply. As the depth of the well increased, however, the mineral content of the water increased. Drilling was stopped at a depth of 775 feet and the well was plugged back to 550 feet to exclude the more highly mineralized waters. The yield of this well was not adequate and a second well tapping bedrock was drilled about 300 feet from the first. The well was completed at a depth of 548 feet. Both wells flowed. The bedrock wells were connected to the suction pipe, which drew water from the wells tapping glacial drift and thus augmented the yield of the drift wells. The combined yield of the 2 wells in bedrock, however, was only about 50 percent more than the yield of either well. In 1925 a large-diameter well was completed which tapped an aquifer in glacial drift at Water Works Park.

To meet the continuing increase in demand for water, another large-capacity well (station 1, pl. 1) was drilled at Lincoln Avenue and Mill Street in 1927. This well, which also tapped the glacial drift, was equipped with a deep-well turbine pump.

In 1931, a third large-capacity well (station 2) was drilled at Pine Avenue and Center Street. When station 2 was put into operation, water levels were lowered, and the wells tapping the drift at Water Works Park could no longer be pumped by suction lift and were abandoned. During the 1930's, stations 1 and 2 supplied water adequate for the city's needs except for periods of peak demand, when the wells tapping bedrock, which could still be pumped by suction lift, were used as a supplemental-supply source. Subsequently, one of the bedrock wells was abandoned. The other was equipped with a deep-well turbine pump and was designated station 3.

The rapid increase in water demand during World War II prompted further search for additional water, and in 1943 another well tapping gravel (station 4) was drilled on the east bank of the Pine River, about a city block north of Water Works Park. The following year another well (station 5) was drilled in drift at River Avenue and Chatterton Street.

In the fall of 1945, residents in the north-central part of the city complained of objectionable tastes and odors in the water. Investigation by the Michigan Geological Survey revealed that the station 5 well was the source of the offensive water (Deutsch, 1963, p. 43). Efforts to treat the water and return the well to service were unsuccessful. The well was removed from service, and exploration for an additional source was started. In 1947 a gravel-walled well with turbine pump (station 6) was constructed at Elizabeth Street and Lincoln Avenue in the southwestern part of the city. In the fall of 1949, station 4 also began to yield water with an objectionable taste and odor, and use of the well was curtailed. An investigation was made to determine the source of the contaminant. It was found that an oil-refinery-waste pit adjacent to the Pine River and nearly half a mile from station 4 was leaking waste containing phenol. Use of the waste pit was discontinued. In 1955 increased water needs, coupled with the decreasing yields from some wells under prolonged use, made it necessary to resume exploration for additional supplies. In late 1955 another well (station 7) was completed in drift at the west edge of Alma just north of Mill Pond.

WELL-NUMBERING SYSTEM

The well-numbering system used in this report indicates the location of the wells within the rectangular subdivisions of the public lands, with reference to the Michigan meridian and base line. The first two segments of a well number designate the township and range; the third segment designates both the section in the township and the serial number of the well, the serial number being assigned arbitrarily. Thus, well 12N 3W 25–1 is well 1 in sec. 25, T. 12 N., R. 3 W. It is therefore necessary to give only the serial numbers of wells on maps that show sections, as the complete number of the well is evident from its location. Street locations or distances in feet from street intersections are given on table 3 for wells within the city of Alma. Wells outside the city limits are located to the nearest 10-acre tract within the section.

METHODS OF INVESTIGATION

The investigation included an intensive bibliographic review of the geology and hydrology of the area. Records of Federal, State, and local agencies were abstracted for well logs, foundation borings, chemical analyses of water, water-use data, and other pertinent information. The files of industries, well drillers, and water-supply consultants were reviewed for similar data. A field check of the geologic and hydrologic data transcribed from these sources was conducted, and observations of trends in water, level, pumpage, and water quality were made. Aquifer tests were made at selected sites, and records of tests made by others were obtained.

Chemical analyses of water from the area were made by the Michigan Department of Health and by the Quality of Water Laboratory of the U.S. Geological Survey at Columbus, Ohio. The altitude above sea level of measuring points at each observation well was determined by the Engineering and Architecture Section of the Michigan Department of Conservation.

ACKNOWLEDGMENTS

Many of the data used in the report were furnished from files of the city of Alma by J. D. McNaughton, City Manager, and Martin Leyer, City Engineer. Additional data were obtained also from the files of the Michigan Geological Survey and the Michigan Department of Health. Layne Northern, Inc., of Lansing, and R. M. Brewer & Son of Parma, well-drilling firms, were especially helpful in providing well data. Information related to studies for development of an additional water supply was obtained from unpublished reports of the following consultants: Ayres, Lewis, Norris, and May of Ann Arbor; W. G. Keck of East Lansing; and James H. Zumberge of Ann Arbor.

GEOGRAPHY

LOCATION AND EXTENT OF AREA

The Alma area consists of a rectangular area of 30 square miles in Gratiot County, Mich.; it includes the southern third of Pine River Township, the northern half of Arcada Township, and the city of Alma (fig. 1). Part of the city of St. Louis is included in the northeast corner of the area.

The Alma area is served by U.S. Highway 27, State Highway M–46 (fig. 2), many county roads, and the Chesapeake & Ohio and Ann Arbor Railroads. The city of Alma (pl. 2), which is near the center of the area, includes about 5 square miles.

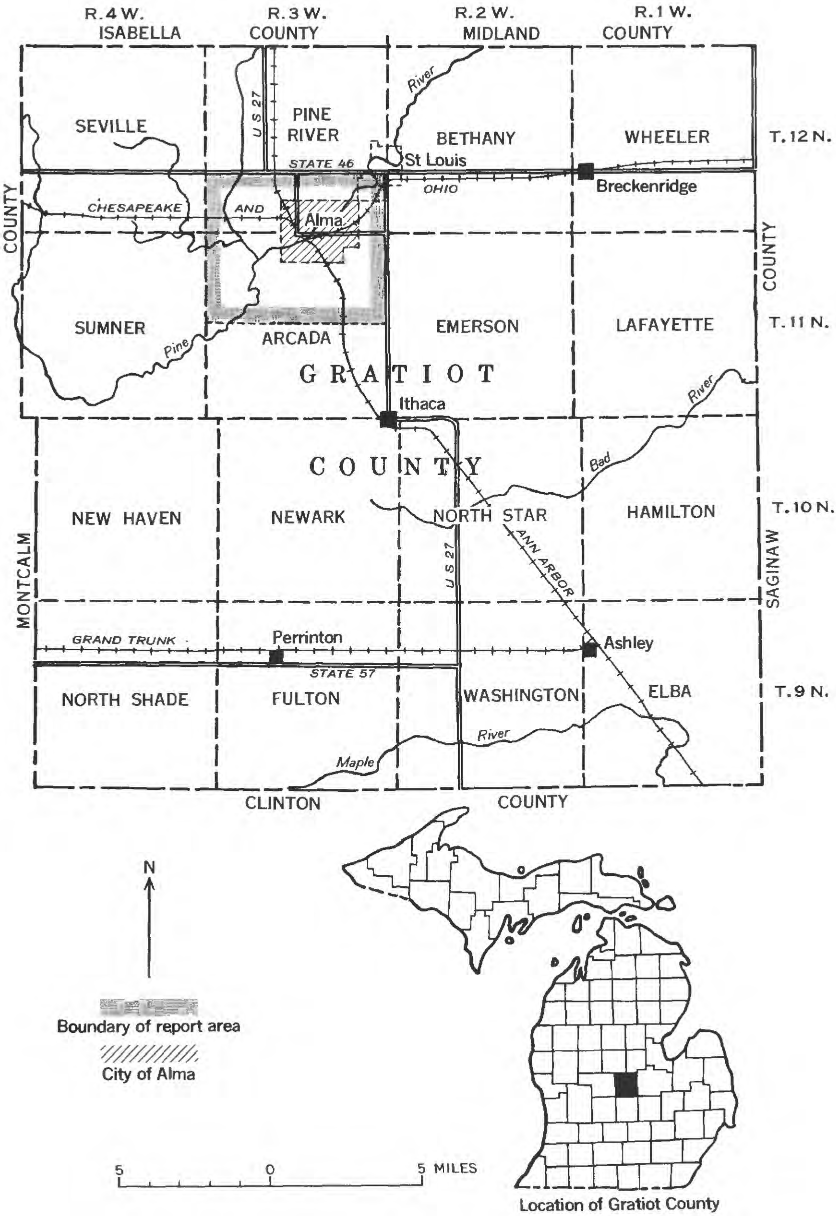


FIGURE 1.—Index map showing location of the Alma area, Gratiot County, Mich.

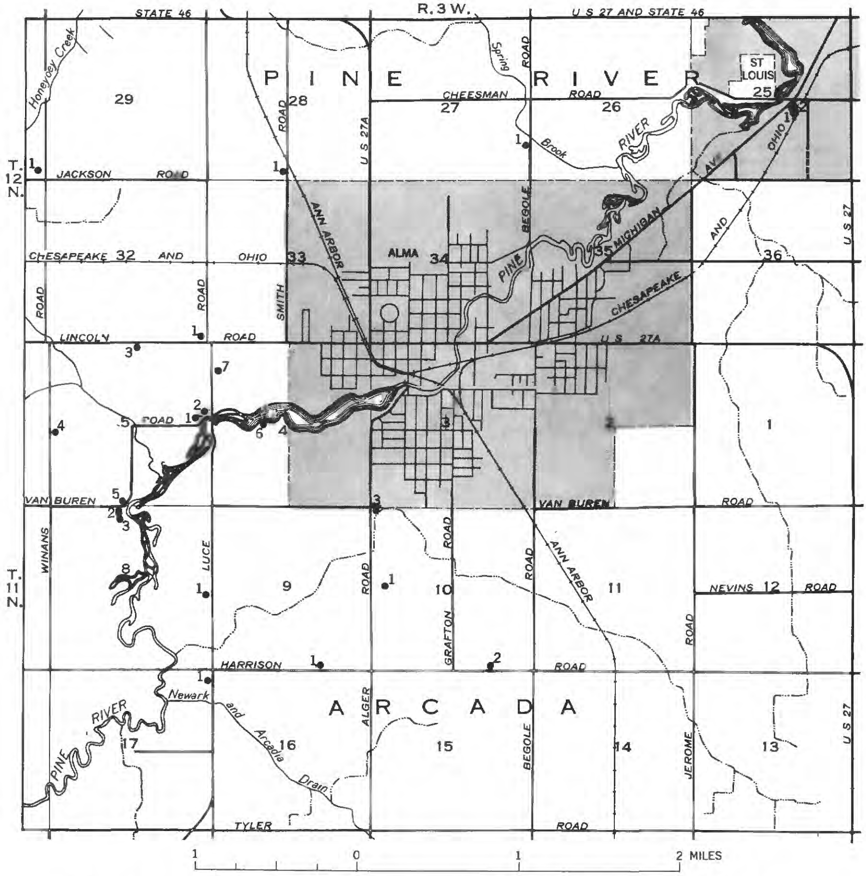


FIGURE 2.—Map of the Alma area showing location of wells outside the city (see plate 2).

POPULATION AND ECONOMIC DEVELOPMENT

Although the area of study represents only about 5 percent of the area of Gratiot County, it contains about 30 percent of the total population reported for this county in the 1950 census. Population data for the report area as a unit are not available, but the population of the cities and townships that relate to the report area and the percent gain for the decade ended in 1950 are as follows:

Civil division	Population		
	1950	1940	Percent gain
City of Alma	8, 341	7, 202	15. 8
City of St. Louis	3, 347	3, 309	1. 1
Arcada Township	1, 047	978	7. 1
Pine River Township	1, 459	1, 181	23. 5
Gratiot County	33, 429	32, 205	3. 8

The principal products manufactured in Alma include house trailers, petroleum products, petrochemicals, machine products, automotive parts, garden tractors, and furniture. Alma is the principal shopping center for residents of Gratiot County. According to the U.S. Department of Agriculture, Gratiot County ranks first in total agricultural production within the eight counties in the central Michigan crop-reporting district.

In the production of minerals, other than water, Gratiot County ranks 17th in the State (Sorenson and Carlson, 1959); brines, petroleum, sand, and gravel are the mineral products of principal value. In statewide production of bromine from mineral brines, Gratiot County ranks third. Magnesium compounds and calcium and magnesium chloride also are produced from mineral brines.

PHYSIOGRAPHY AND RELIEF

The hills, lowlands, and drainage of the Alma area are the result of geologic processes associated with the retreat of the Wisconsin ice sheet, which at one time covered all Michigan. Three generally south-trending belts of low morainal hills of glacial origin are present in or near the area: one is along the western boundary, another crosses the central part, and a third is just west of the area. Flat or gently rolling areas, which overlie lake plains, outwash plains, and till plains, separate the three belts of morainal hills.

The Alma area is one of relatively slight relief. The highest points are on the belts of morainal hills which cross the central and western parts of the area. One hill in the northwestern part and several hills in the north-central part reach altitudes of slightly more than 800 feet. The lowest altitudes, just under 720 feet, are along the Pine River in the northeast. Thus, the total relief in the area is about 80 feet.

DRAINAGE AND STREAMFLOW

The Alma area is in the Pine River drainage basin. The Pine River flows northeastward to the Tittabawasee River, a tributary of the Saginaw River, which empties into Saginaw Bay of Lake Huron. Dams have been constructed across the Pine River at Alma and St. Louis. The Pine River and its tributaries in the Alma area flow along courses established by older glacial melt-water streams. The glacial streams were much larger than the present streams, and some of them flowed in opposite directions to those of the present streams. Streams tributary to the Pine in the Alma area include the West Branch of the Pine River (Honeyoey Creek), Coles Creek, Spring Brook, and Ely Creek. The channels of these small streams have been improved to facilitate drainage.

The average discharge of the Pine River at Alma for the 27-year period through September 1957 was 196 cfs (cubic feet per second). Maximum discharge for the period of record was 4,400 cfs on March 19, 1948. The minimum daily discharge recorded was 2 cfs on July 23, 1938. The low flows recorded indicate the effect of regulation of the stream by the dam at Alma.

CLIMATE

The Great Lakes have a moderating effect on the climate at Alma. Prevailing westerly winds are cooled in the summer and warmed in the winter as they cross Lake Michigan, producing a modified maritime climate.

The highest temperature ever recorded at Alma was 108° F on July 14, 1936. The lowest on record was −22° F on February 9, 1934. Winters have an average of 7 days in which temperatures are zero or lower. Summers have an average of 17 days in which temperatures are 90° F or higher. The average dates of the last freezing temperature in the spring and the first frost in the fall are May 11 and October 4, respectively.

Precipitation averages 28.4 inches per year. It is heaviest during the 6-month growing season, April through September, averaging 61 percent of the annual total. Snowfall totals 36.3 inches during an average winter, only about half as much as normally falls in the snow belt along the west side of the Southern Peninsula of Michigan

SUMMARY OF GEOLOGIC HISTORY

The bedrock formations underlying the Alma area were deposited in the extensive inland seas that covered Michigan during the Paleozoic era, an interval of geologic time which began about 500 million years ago and lasted for more than 300 million years. The soft sediments were lithified by various geologic processes. The lithified sediments consist of limestone, dolomite, shale, and sandstone, which are commonly interbedded with evaporite deposits such as rock salt and gypsum. Although the rocks were deposited in nearly horizontal layers, gradual deformation, subsidence, and compaction of beds, which were contemporaneous with deposition and were greatest in the central part of the State, produced a bowl-shaped structure known as the Michigan basin. The youngest consolidated rocks in the Michigan basin are the so-called red beds of Pennsylvanian or Permian(?) age, which are underlain by the Saginaw formation of Pennsylvanian age. These rocks form the bedrock surface in the Alma area (fig. 3).

The interval after the Paleozoic era was principally one of erosion in the Michigan basin. During this 180-million-year interval the

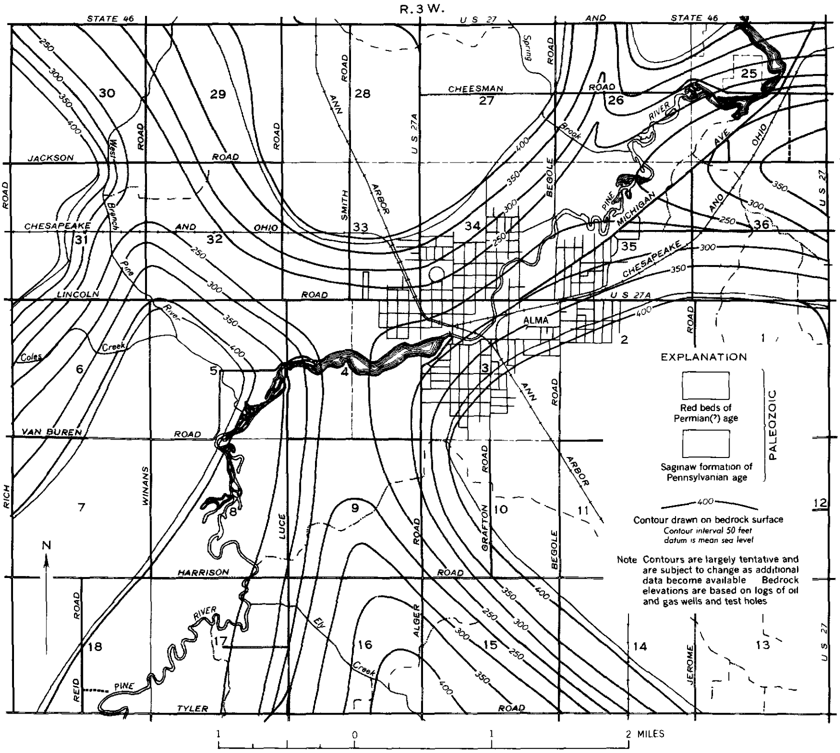


FIGURE 3.—Bedrock geology and contours on the bedrock surface of the Alma area.

Paleozoic rocks were eroded by wind and running water. The softer bedrock was eroded to form valleys; the more resistant strata remained as hills and ridges. Extensive drainage systems evolved and large valleys were cut by the streams. The geologic record of the drainage system is incomplete, but some reconstruction of the pre-Pleistocene topography can be made from drilling records. These records show that deep valleys in the bedrock surface underlie the Alma area (fig. 3).

During the ice age (Pleistocene glacial epoch) a thick mantle of clay, silt, sand, gravel, and boulders was deposited on the eroded bedrock surface. This material was deposited during four major invasions of continental ice sheets (glaciers). The last of the continental glaciers (the Wisconsin Glacier) has obliterated most of the record of the previous three stages of glaciation. The Saginaw Lobe of the Wisconsin Glacier advanced westward across Gratiot County from the vicinity of Saginaw Bay. The Wisconsin glacial deposits are more than 200 feet thick over most of the Alma area and are the source of most of the ground water presently used in the area.

Large supplies of ground water are obtained from outwash deposits of well-sorted sand and gravel that were deposited by glacial melt-water streams which flowed from the melting ice. Thus, a study of the glacial drainage systems which evolved in the area is of considerable aid in locating additional water. Figure 4 shows the inferred drainage system at the time that the front of the glacier was stabilized at the position of the middle Gladwin moraine, which crosses the central part of the Alma area. Figure 5 shows the drainage system at the time that the glacier had melted back to the position of the inner Gladwin moraine in the eastern part of the area. After the glacier had receded to the east, Lake Saginaw was formed. Drainage from Lake Saginaw was to the west through the Grand River drainage system. Large areas in the vicinity of Alma were inundated by glacial lakes associated with Lake Saginaw, and lake sediments mantled much of the previously deposited outwash (fig. 6). The lake sediments in the area west of Alma are predominantly sandy, whereas those to the east are thinner and generally contain higher percentages of clay. Outwash sediments mapped along the West Branch of the Pine River probably represent deltaic materials deposited by a melt-water stream draining from the north.

Additional, more detailed study of the geologic history of the drainage system of the area is beyond the scope of this investigation.

GROUND WATER

A rock formation, part of a formation, or group of formations that yields water in usable quantities is termed an "aquifer." In areas where ground water is difficult to obtain, a formation yielding less than 1 gpm (gallon per minute) to wells may be classified as an aquifer. In areas where wells may yield hundreds or even thousands of gallons per minute, a formation that yields only a few gallons per minute may not be classified as an aquifer.

The capacity of a water-bearing material to transmit water under pressure is termed "permeability." The coefficient of permeability (P) as used herein is defined as the rate of flow of water in gallons per day through a cross-sectional area of 1 square foot under a hydraulic gradient of 100 percent at a temperature of 60° F. The field coefficient of permeability is the same except that it is measured at the prevailing temperature of the water. The coefficient of permeability varies greatly, depending in general upon the degree of sorting and the arrangement and size of the particles which make up the aquifer. Coefficients of permeability of most important water-bearing formations are greater than 10 gpd per sq ft (gallons per day per square foot). The permeability of the deposits of sand and gravel tapped by the large-capacity wells in the Alma area probably ranges from 50 to 1,000 gpd per sq ft.

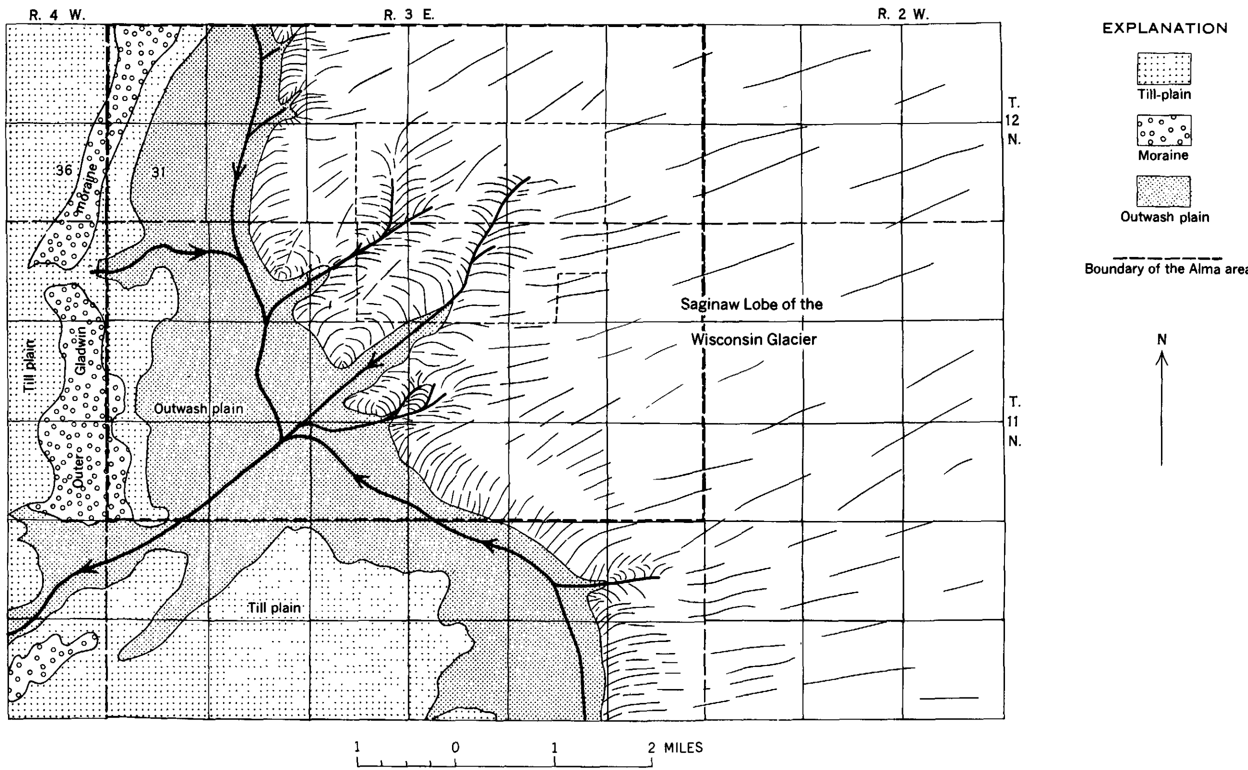


FIGURE 4.—Inferred drainage system at the time that the front of the Wisconsin Glacier was stabilized at the position of the middle Gladwin moraine.

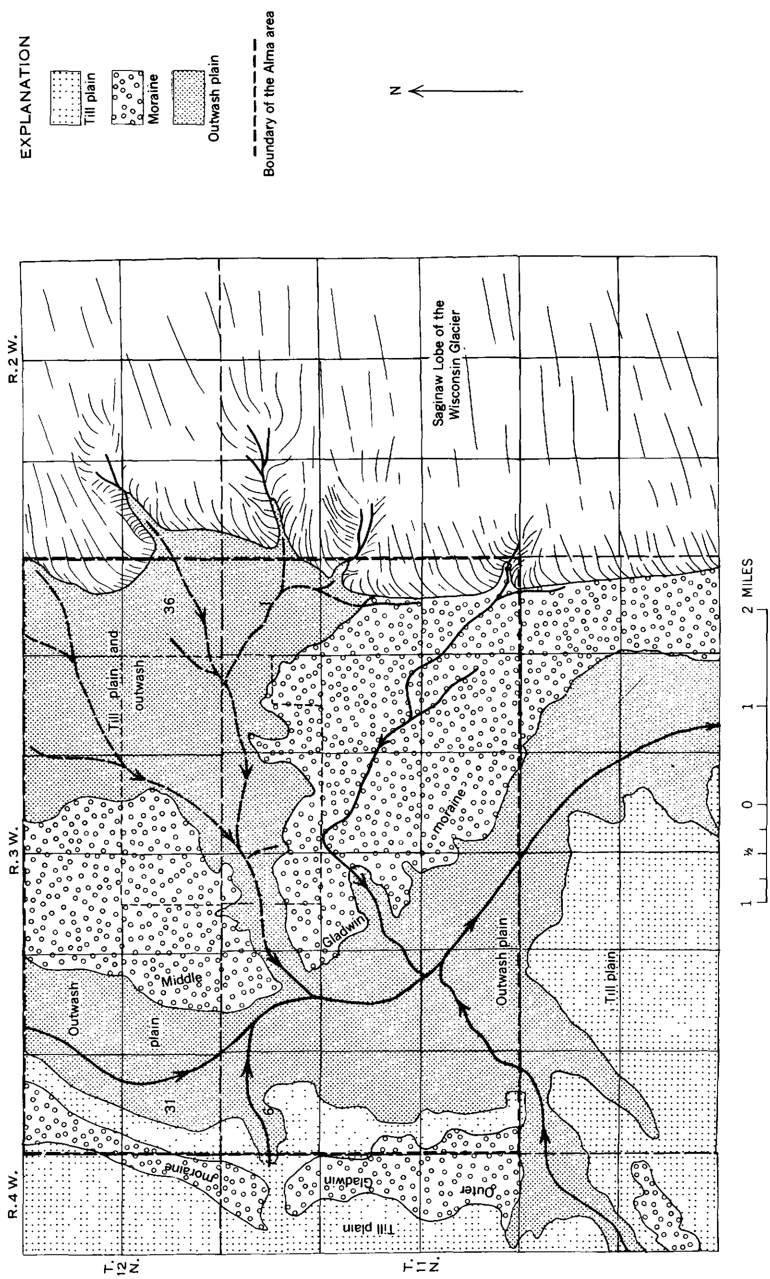


FIGURE 5.—Inferred drainage system at the time that the front of the Wisconsin Glacier was stabilized at the position of the inner Gladwin moraine.

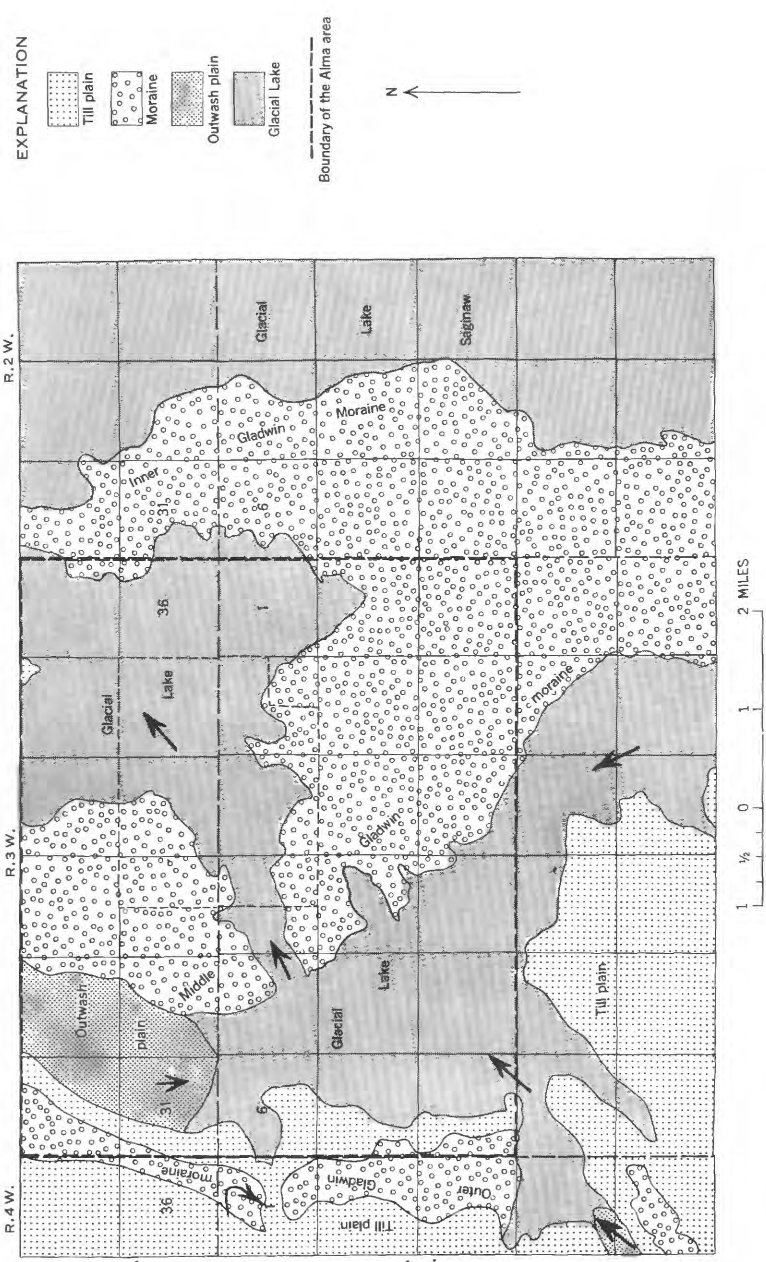


FIGURE 6.—Areas inundated by glacial lakes after recession of the Wisconsin Glacier from the inner Gladwin moraine.

The hydraulic characteristics of an aquifer are commonly expressed in terms of the coefficients of transmissibility and storage. The coefficient of transmissibility (*T*) is defined as the number of gallons of water per day, at the prevailing temperature, that will move through a vertical strip of the aquifer 1-foot wide and of a height equal to the saturated thickness of the aquifer, under a hydraulic gradient of 100 percent. The transmissibility of an aquifer equals the average field coefficient of permeability times the thickness of the aquifer in feet. The coefficient of storage (*S*) of an aquifer is defined as the volume of water the aquifer releases from or takes into storage per unit surface area per unit change in the component of head normal to that surface.

The specific capacity of a well is defined as the yield of water in gallons per minute per foot of drawdown in water level caused by pumping of the well. It is a function of the permeability and thickness of the aquifer and also of the efficiency of the well. The specific capacities of wells in the Alma area are listed in table 3. The amount of water available to a well is governed also by regional hydrologic and lithologic characteristics of the aquifer and by the climatic conditions and the hydraulic properties of the soils and subsurface rocks in the recharge areas.

Ground water is the water in the zone of saturation, in which all voids are filled with water under atmospheric or greater pressure. On the basis of water occurrence, aquifers may be classified as water table or artesian. In a water-table aquifer, ground water is unconfined and its surface within the aquifer is termed the "water table." In an artesian aquifer, ground water is confined under pressure between relatively impermeable strata (strata through which water does not move readily). Under natural conditions, the water in a well finished in an artesian aquifer and tightly cased through the overlying confining bed (aquiclude) will rise above the bottom of that bed. An artesian aquifer is full of water at all times, even while water is being removed from it. In time, however, enough water may be pumped to lower the water level below the bottom of the overlying confining bed, thus locally creating water-table conditions. The imaginary surface connecting all points to which water will rise in wells tapping an artesian aquifer is called the piezometric surface. In topographically low areas the piezometric surface may be higher than the land surface, and wells tapping artesian aquifers in these areas will flow.

GROUND WATER IN CONSOLIDATED ROCKS

The Alma area is underlain by about 10,000 feet of consolidated sedimentary rocks. Where these rocks are near the surface in Michigan they generally yield fresh water to wells. At depth they generally yield highly mineralized water. In the Alma area, the sandstone beds of the Saginaw formation are the only consolidated rocks that yield fresh water (table 2). Permeable formations below the Saginaw yield highly mineralized water. Some of the deeper formations are tapped as a source of brine for the chemical industry in and near the Alma area.

SAGINAW FORMATION OF PENNSYLVANIAN AGE

The Saginaw formation is composed of sandstone, shale, limestone, and coal. The Saginaw is overlain by red beds in part of the Alma area. Along the trace of the major pre-Pleistocene valleys (fig. 3) it is mantled directly by glacial drift. The formation is 200 to 350 feet thick in the area.

The city of Alma derives some of its water supply from the Saginaw formation during periods of peak demand. At one time the city obtained water from 2 wells (12N 3W 34–7 and 12N 3W 34–29) tapping the Saginaw. The combined yield of the 2 wells, however, was only 50 percent greater than the yield of 1 of these wells when pumped alone. For that reason, one well (12N 3W 34–29) was removed from service. Well 12N 3W 34–7 (now called station 3) yields about 250 gpm with about 100 feet of drawdown. The well flows when it is not pumped for prolonged periods.

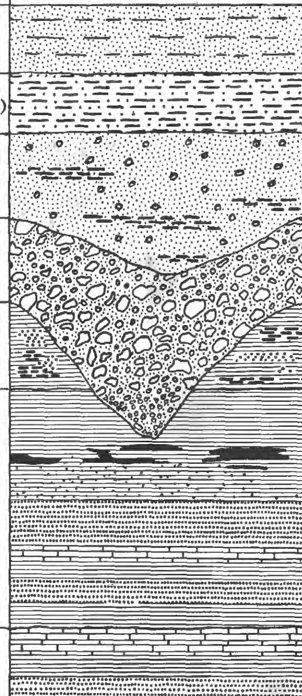
An aquifer test was made during June 1946 of the two municipal wells which tapped the Saginaw formation. The coefficient of transmissibility of the Saginaw, as computed on the basis of the test data, was 2,400 gpd per ft. The aggregate thickness of the main water-bearing beds of the Saginaw formation at this locality is about 75 feet. Thus, the field coefficient of permeability is about 32 gpd per sq ft. The coefficient of storage computed from the test was 0.00012.

The Saginaw is not important as a source of large supplies of water because of its low transmissibility. Increased withdrawal from the Saginaw would result in a significant lowering of the artesian pressure because of the low permeability of the formation. Such a decline in artesian pressure would cause encroachment of saline water.

RED BEDS OF PERMIAN(?) AGE

A series of red sandy gypsiferous shales and shaly sandstones locally underlie the glacial drift over the central part of the Michigan basin, including the Alma area (fig. 3). The descriptive term "Red Beds" has been used to describe these rocks (Cohee, Macha, and Holk, 1951; Michigan Geological Society, 1954, p. 29). The red beds are not known to crop out at the surface in Michigan. The upper surface of these rocks was eroded by wind, running water, and glacial scour and thus

TABLE 2.—*Partial columnar section describing the lithology and hydrology of rocks underlying the Alma area*



AGE			SUBDIVISON		THICKNESS (FEET)	LITHOLOGY (GENERALIZED COLUMN)	WATER-BEARING CHARACTER
CENOZOIC	QUATERNARY	Pleistocene	Glacial lake deposits	Glacial drift	0–30	Sand and silt	Source of small supplies of water
					0–100(?)	Sandy and silty clay	Not a source of water (leaky aquiclude)
			Outwash		0–200	Sand and gravel containing silt and clay lenses	Source of moderate to large supplies of water
			Till		200 to 400	Blue, gray, buff, and red clayey till. Some gravel at base	Not a source of water
PALEOZOIC	PERMIAN(?)		Red beds		0–50	Red sandy gypsiferous shales and shaly sandstones	Not a source of water
	— ? —— ? —						
	PENNSYLVANIAN		Saginaw formation		200 to 350	Black and gray shale Coal Sandy shale Sandstone Limestone Shale Sandstone Shale	Yields moderate supplies of water containing objectionable amounts of chloride
	PRE-PENNSYLVANIAN		Pre-Saginaw rocks		-	Limestone Shale Sandstone	Yields mineralized water

is very irregular. Along the trace of major pre-Pleistocene valleys in the Alma area the red beds have been completely removed by erosion (fig. 3).

The rocks are generally only a few tens of feet thick and have little or no potential as a source of water.

GROUND WATER IN GLACIAL DRIFT

A thick mantle of glacial drift overlies the bedrock of the area. The drift mantle is composed of till, lake deposits, and outwash. Till is a heterogeneous mixture of rock debris ranging in size from clay to boulders deposited directly from the ice, with water playing a minimum part in deposition. Lake deposits consist of well-sorted clay, silt, and sand laid down in former glacial lakes. Outwash is composed of well-sorted sand or sand and gravel deposited by the streams which flowed from the melting glaciers.

Although the glacial drift in the Alma area is as much as 550 feet thick where it fills the deep valleys in the bedrock surface (pl. 2), most wells tapping the drift are less than 150 feet deep. Most of the beds of permeable sand and gravel logged in wells occur in the upper 200 feet of the drift mantle. At depths below 200 feet, the drift is generally composed of varicolored till, although some beds of sand and gravel have been reported below 200 feet and even at the base of the drift mantle (table 4, well 12N 3W 34–32).

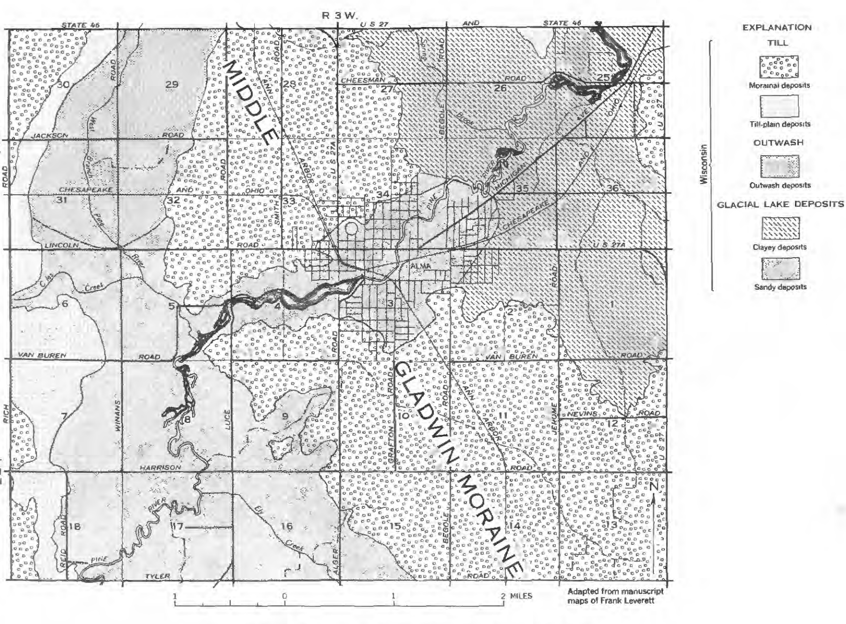


FIGURE 7.—Surface geology of the Alma area.

Figure 7 is a map of the surficial glacial deposits in the Alma area. Although this map does not show the types of drift which are present at depth, it can be used to reconstruct the glacial history of the area, which in turn can be used as an aid in the location of deposits of permeable drift that would yield moderate to large supplies of water.

TILL

Large surface and subsurface deposits of clayey till are present in the Alma area. Locally, farmers refer to the till, the parent material of much of the soil in the area, as boulder clay. The largest surficial deposits of till underlie the middle Gladwin Moraine, which trends roughly south through the center of the Alma area but is breached at Alma by the shallow valley of the Pine River (fig. 7). The narrow till plain along the west margin of the area is also underlain by clayey-till deposits. Neither morainal till nor till-plain deposits are sources of water to wells. In nearly all the area where morainal till deposits are present at the surface, however, saturated sand and gravel layers or lenses interbedded with the till are thick enough to provide water to wells for domestic needs. Locally, morainal deposits include or cover relatively thick beds of sand and gravel outwash which can yield moderate supplies of water.

At depth, thick deposits of dense clayey till lie on the bedrock surface throughout the Alma area, except where some gravel deposits are present along the bottoms of the pre-Pleistocene valleys. When drilling through these deposits, drillers usually log them as hard pan. The top of the extensive subsurface till deposits marks the lower limit of glacial deposits from which significant quanitities of ground water can be obtained.

GLACIAL-LAKE DEPOSITS

Almost half of the Alma area is covered by sandy and clayey sediments deposited in former glacial lakes (figs. 6, 7). The surficial lake deposits in northeastern part of the report area consist of sandy and silty clay of low permeability. In the western part of the area, including most of the city of Alma, these lake deposits are composed predominantly of sand. This sand is a source of small supplies of water to shallow wells.

SHALLOW SAND

Within the city of Alma surficial lake deposits of sand form a thin shallow aquifer which was an important source of water to small-diameter domestic wells prior to the development of the municipal water-supply system. Most of these deposits are less than 25 feet thick. Only a few wells tapping these shallow sand deposits are now used, and extensive future development is not likely, as these deposits are potentially subject to contamination from surface sources. West of Alma, the sand deposits are a source of small supplies of water to shallow wells.

WATER LEVELS

Water levels in the shallow sand aquifer fluctuate primarily in response to climatic conditions. Water levels rise when melting ice and snow and rain recharge the aquifer each spring. During the summer they generally decline, as precipitation is normally lost by evapotranspiration before it can infiltrate into the ground-water reservoir. Water levels rise slightly in the fall when evapotranspiration is low. During the winter they ordinarily decline as precipitation accumulates on the surface in the form of ice and snow.

The hydrographs and climatic graphs of figure 8 show that water levels in the shallow sand aquifer are influenced largely by precipitation. In the 13-year period, 1947–59, they were highest during 1951 and

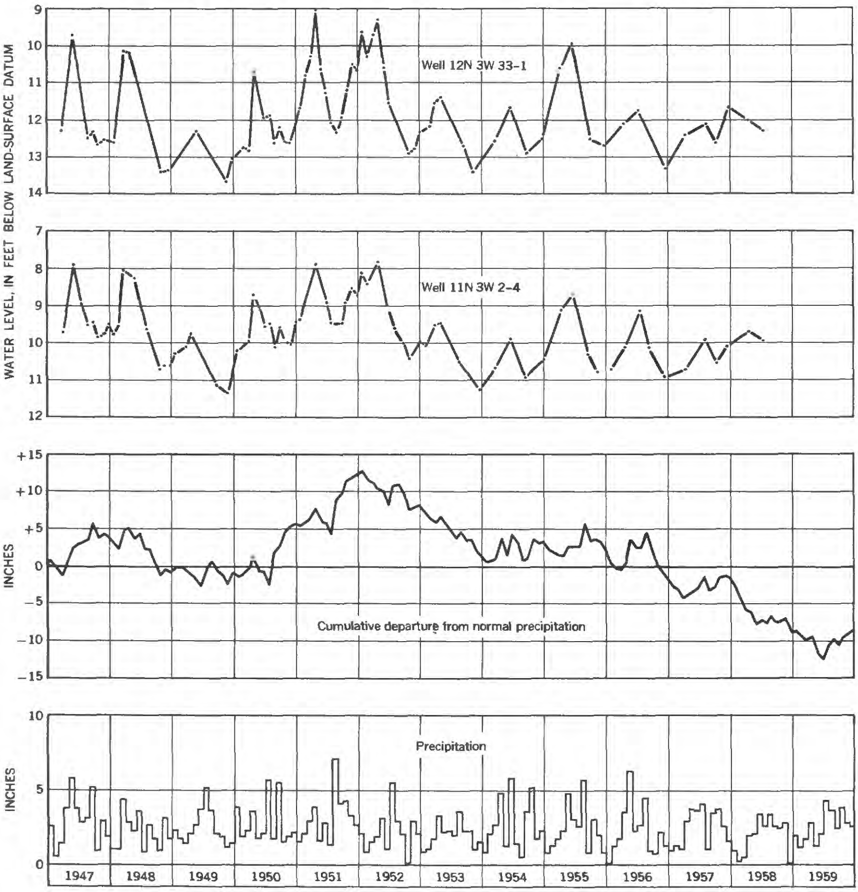


FIGURE 8.—Hydrographs of observation wells tapping the shallow drift aquifer, cumulative departure from normal precipitation, and monthly precipitation, 1947–59.

1952, when precipitation was above normal. The shallow sand is hydraulically connected with the Pine River and, thus, water levels also respond to changes in the stage of the river. Water also moves downward from the shallow sand aquifer to the underlying outwash by vertical leakage. The rate of leakage is controlled by the head difference between the water table in the shallow sand and the piezometric surface of the underlying outwash. Pumping lowers the piezometric surface and causes more water to leak to the underlying outwash; thus, the pumping lowers the water table in the shallow sand.

RECHARGE AND DISCHARGE

The shallow sand aquifer is recharged primarily by precipitation. Water is presently discharged from the aquifer by seepage into the Pine River; by evaporation and transpiration from plants; and where the gradient has been reversed by pumping, by vertical leakage to the underlying outwash aquifer. The configuration of the water table in the shallow sand aquifer during the spring of 1947 is shown in figure 9. When water levels in the shallow sand fall below the stage of Mill Pond, the aquifer is recharged by infiltration from the pond.

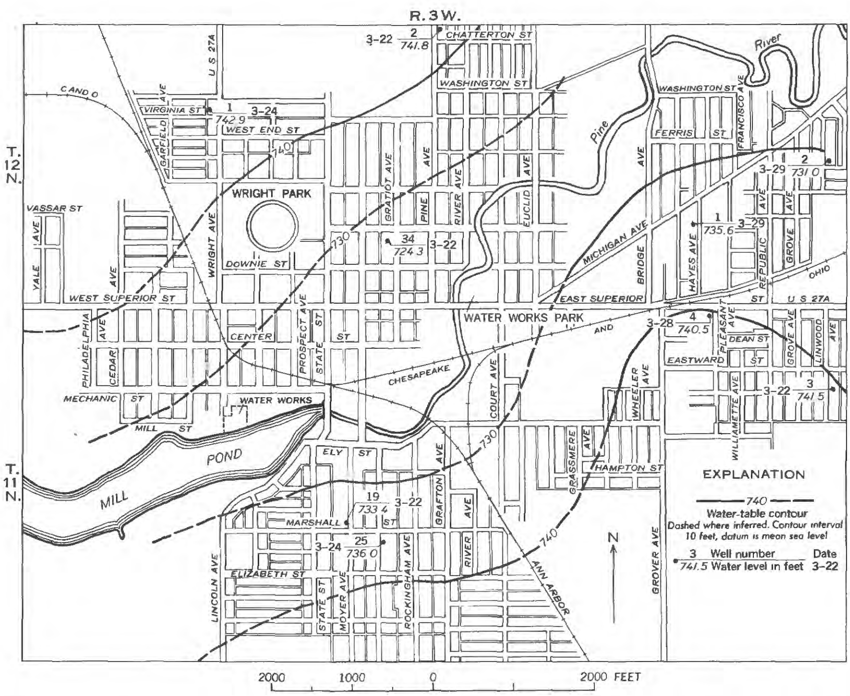


FIGURE 9.—Generalized contours on the water table in the shallow sand aquifer at Alma, March 1947.

CLAYEY LAKE DEPOSITS

The surficial lake deposits in the northeastern part of the area (fig. 7) are composed predominantly of sandy and silty clays and are not a source of water supply. Some shallow wells, however, obtain small supplies from thin sand and gravel lenses interbedded with, or lying beneath, the lake clays (table 4 Well 11N 3W 2–8).

In the rest of the area, including most of the city of Alma, layers of clayey lake sediments underlie the lake-deposited sand. These beds are of low permeability and are not a source of water. They are important, however, in that they form the upper confining layer of the underlying artesian aquifer (see section on "Buried outwash"). Although they are of low permeability, some water may move vertically in either direction through them. The direction of movement is controlled by differences in head between the overlying and underlying aquifers, as illustrated by figure 19.

OUTWASH

Permeable sand and gravel deposited by melt-water streams flowing from the glaciers are the most productive sources of fresh ground-water in the Alma area. The outwash deposits are exposed at the surface only along the West Branch of the Pine River northwest of Alma. Elsewhere in the report area, they are buried beneath the glacial lake deposits. The best-known deposit of buried outwash underlies the western half of the city of Alma (figs. 10, 11, 12). In the southwestern part of the report area, the presence of buried outwash has been inferred by a study of the glacial history of the area (see "Summary of geologic history, p. E12). In addition, records of a few oil wells indicate that thick deposits of sand and gravel are present in the western part of the area. Test drilling and aquifer testing, especially along the reach of the Pine River within the area upstream from Alma, are needed to confirm the presence of outwash deposits, which would provide large sources of supply.

BURIED OUTWASH

A relatively thick deposit of outwash consisting primarily of sand, but including some gravel, underlies most of the western part of Alma and forms an aquifer that is the principal source of water supply for the city. Its permeable sediments are interbedded with numerous layers and lenses of silty or clayey sand of relatively low permeability. The outwash aquifer is separated from the shallow sand aquifer by 10 to 30 feet of clayey lake sediments, which form a leaky aquiclude.

Figure 10 shows the thickness and extent of the outwash aquifer. The configuration of the base of this aquifer is shown in figure 11. The geometry of the aquifer, as shown by figures 10 and 11, indicates that the sand and gravel was deposited at the confluence of several

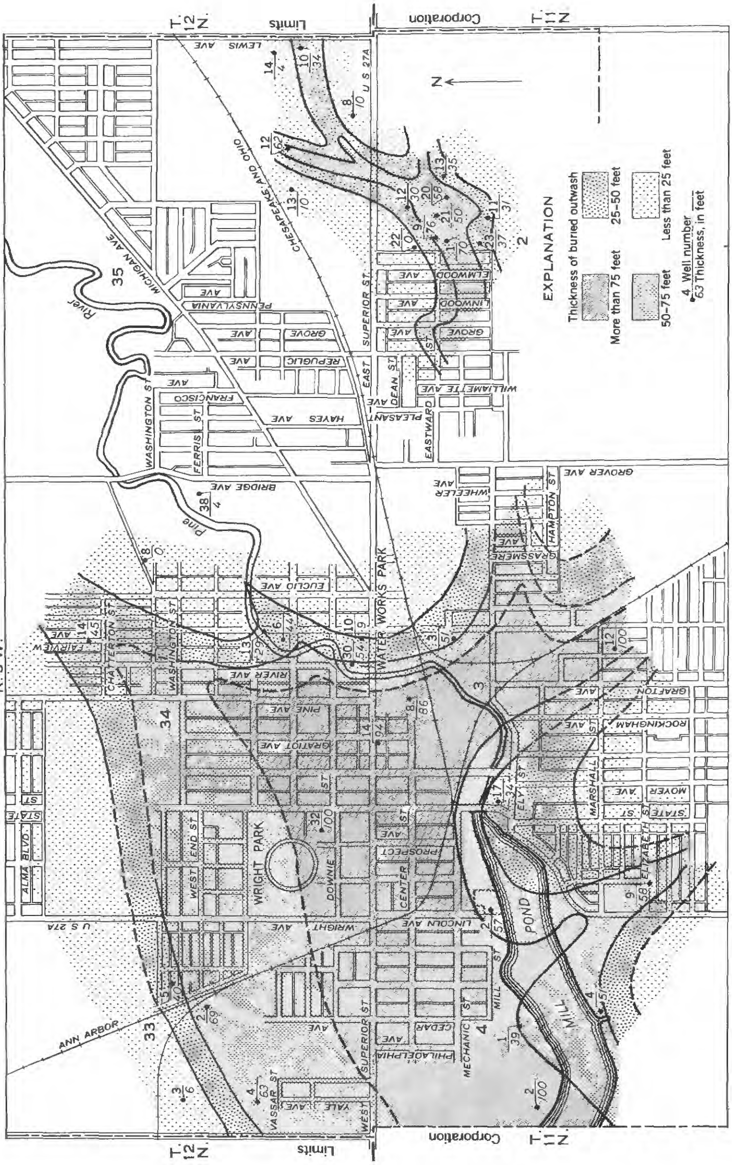


FIGURE 10.—Generalized map showing thickness of the buried outwash at Alma.

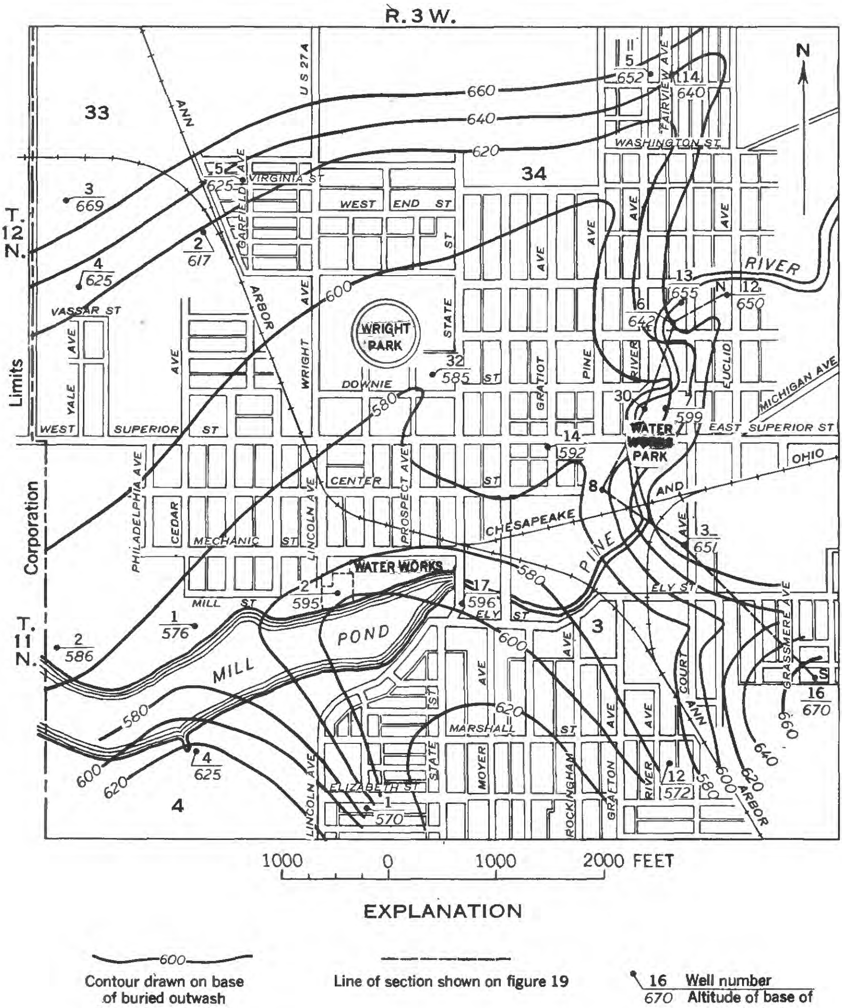


FIGURE 11.—Contours approximating the base of the buried outwash at Alma.

melt-water streams; much of the sand and gravel may be deltaic outwash deposited in a glacial lake. Deltaic outwash tends to be somewhat less permeable than outwash deposited in the channels or flood plains of melt-water streams from which larger percentages of fine sediments have been removed by fast-flowing water.

Significant amounts of coarse sand and gravel of relatively high permeability occur within the buried outwash along a narrow strip trending roughly southwest across the city (fig. 12). The thickness of these highly permeable sediments generally represents less than a

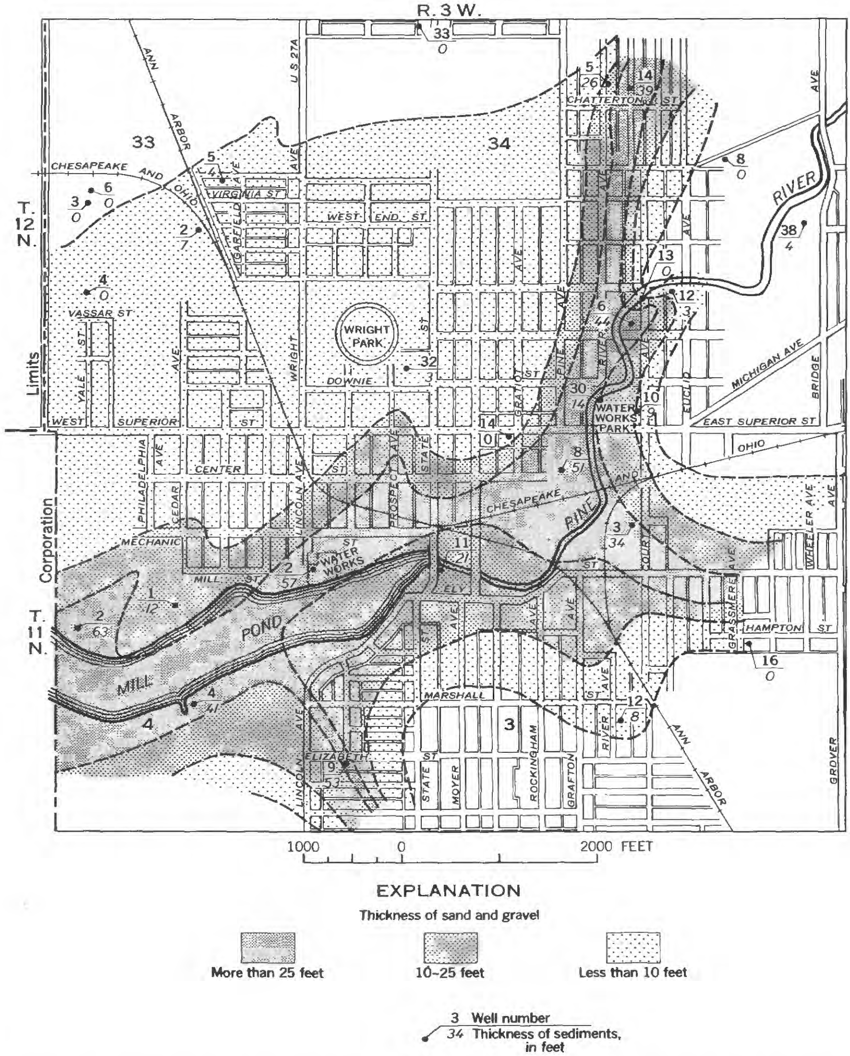


FIGURE 12.—Generalized map showing thickness of highly permeable sediments within the buried outwash at Alma.

third of the total thickness of the outwash deposits, as is indicated by comparison of figures 10 and 12. Nearly all the municipal wells are located along this strip of highly permeable sediments.

In the eastern part of Alma, several industrial wells tap buried sand and gravel outwash deposited in a narrow channel (fig. 10). This outwash probably was deposited by a tributary to the main melt-water stream that deposited the outwash in the western part of Alma.

The highly permeable beds of sand and gravel generally are at depths of less than 100 feet in wells at stations 2, 4, and 5 in the central part of the city (see table 4, wells 12N 3W 34–5, 12N 3W 34–6, and 11N 3W 3–8) and at depths greater than 100 feet at stations 1, 6, and 7 in the western part of the city (see wells 11N 3W 3–2, 11N 3W 3–9, and 11N 3W 4–2). Well 11N 3W 4–5 (station 7) drilled near the western city limits is screened in sand and gravel from 125 to 155 feet and is the deepest of the municipal-supply wells tapping the glacial drift (table 3). Well 11N 3W 4–6 (test-well 15) drilled west of Alma (fig. 2) reached sand and gravel below 188 feet. The outwash above 188 feet consists of layers of fine to medium sand (table 4). From this evidence it can be concluded that municipal-supply wells drilled west of the city will tap permeable sediments at depths considerably greater than those tapped by wells within the city.

WATER LEVELS

Water levels in wells tapping the buried outwash fluctuate principally in response to changes in the rate of withdrawal from the aquifer. In the early 1900's the piezometric surface of the aquifer was above the land surface in the central part of Alma (fig. 13). The artesian pressure was reported to be great enough in some wells to raise the water about 17 feet above the level of the Pine River (Davis, 1907, p. 209).

A large cone-shaped depression in the piezometric surface has formed as a result of the pumping of municipal and industrial wells. The depression extends well beyond the city limits of Alma. During periods of peak demand, water levels in the immediate vicinity of the municipal wells are lowered below the base of the clay, which is the upper confining bed for the artesian aquifer of buried outwash.

The gradual increase in pumpage from the buried outwash has resulted in a gradual lowering of water levels and a steady increase in the size of the composite cone of depression. Figure 14 shows contours on the piezometric surface in the spring of 1947 and the decline of the piezometric surface from 1904 to 1947. Figure 15 shows approximate contours on the piezometric surface in the spring of 1956 and the decline from 1947 to 1956. Figure 16 shows approximate contours on the piezometric surface in the spring of 1960 and the change in the piezometric surface since 1956. Figure 16 also shows that water levels have declined in the western part of the city in response to pumping at station 7, which was put into operation in September 1956. Insufficient data are available on which to base construction of lines of equal decline of the piezometric surface in that area. Water levels rose slightly in a number of wells after a decrease in pumping at stations 2, 4, and 6.

Hydrographs of five wells tapping the buried outwash are shown in figure 17. These hydrographs show that during the period 1948–59

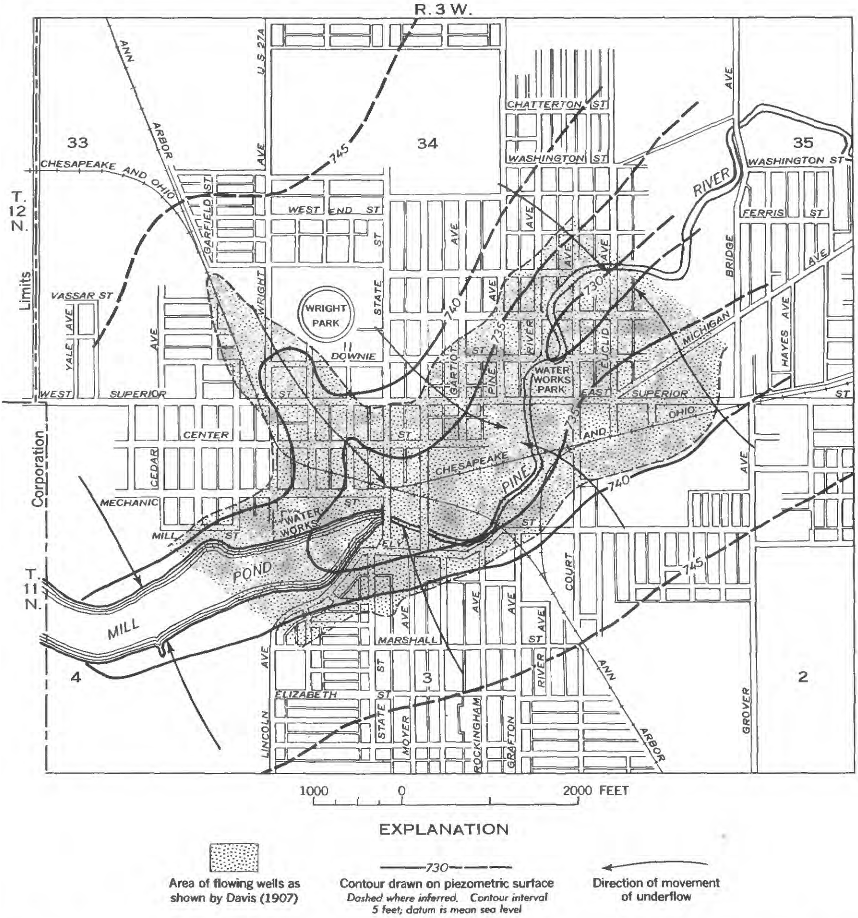


FIGURE 13.—Area of flowing wells and generalized configuration of the piezometric surface of the buried outwash at Alma in 1904. (Adapted from Davis, 1907, fig. 42.)

no serious dewatering of the outwash had occurred in the center of Alma, and they indicate that the aquifer in this area is capable of long-term yield at a rate about equal to that pumped during the period 1948–59.

AQUIFER TESTS

The hydraulic characteristics of an aquifer that are important in determining the optimum production from a well or well field are the coefficient of transmissibility (*T*) and the coefficient of storage (*S*). Several aquifer (pumping) tests have been made since 1946 to determine the hydraulic characteristics of the buried outwash at Alma. The tests consist of pumping one well at a constant rate and measuring in adjacent wells the change in water level caused by the pumping.

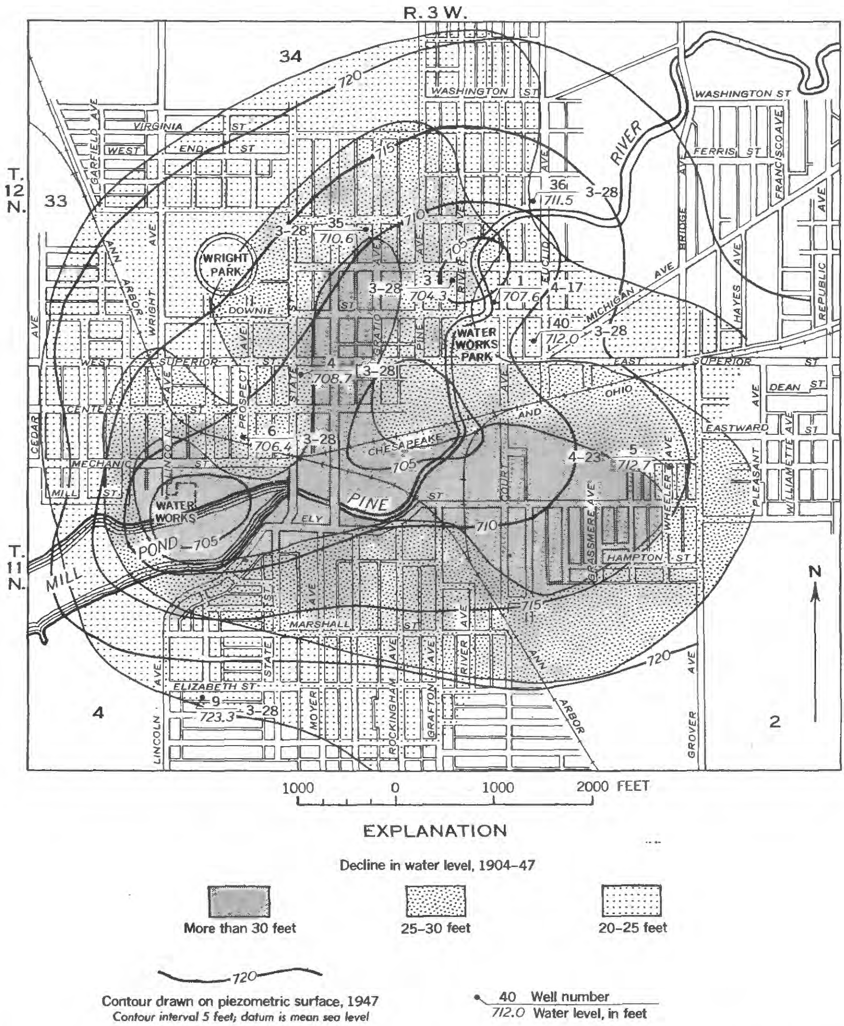


FIGURE 14.—Generalized configuration of the piezometric surface of the buried outwash at Alma in 1947 and approximate decline in water level from 1904–47.

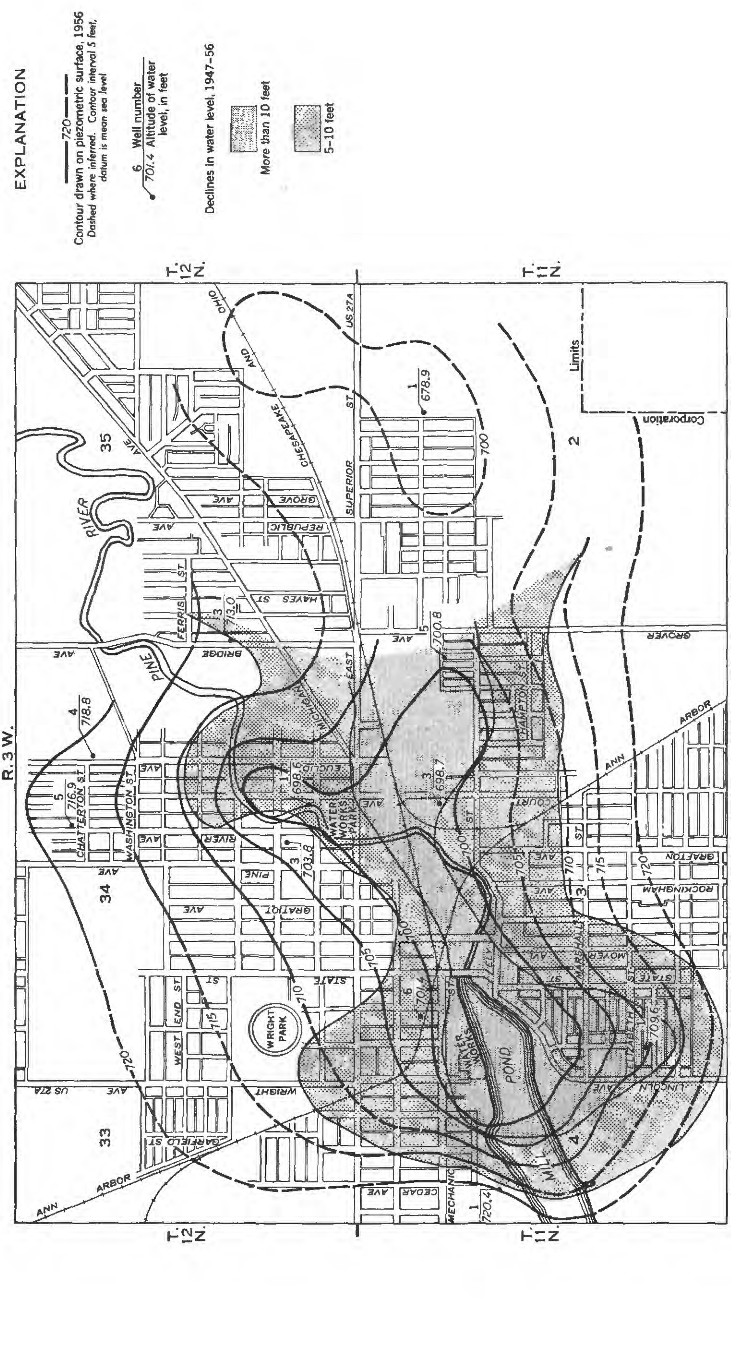


FIGURE 15.—Generalized configuration of the piezometric surface of the buried outwash at Alma in 1956 and the approximate decline in water level from 1947–56.

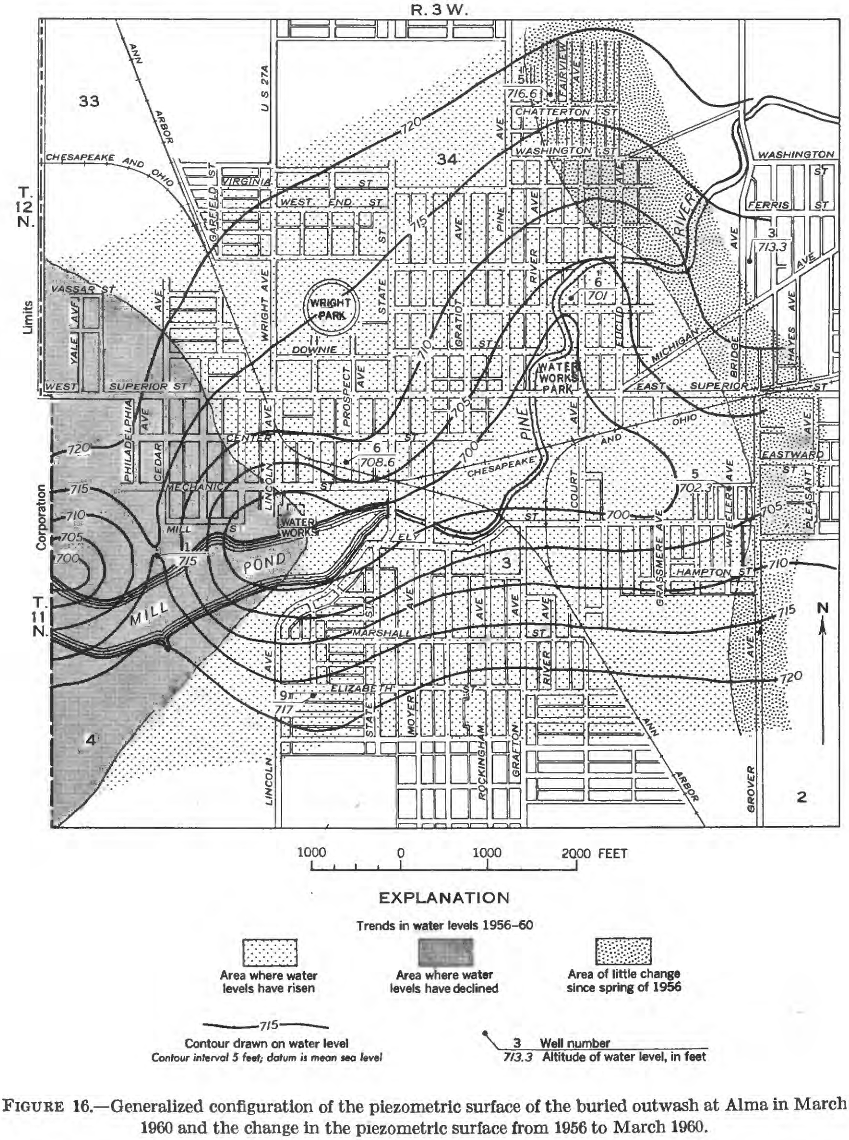


FIGURE 16.—Generalized configuration of the piezometric surface of the buried outwash at Alma in March 1960 and the change in the piezometric surface from 1956 to March 1960.

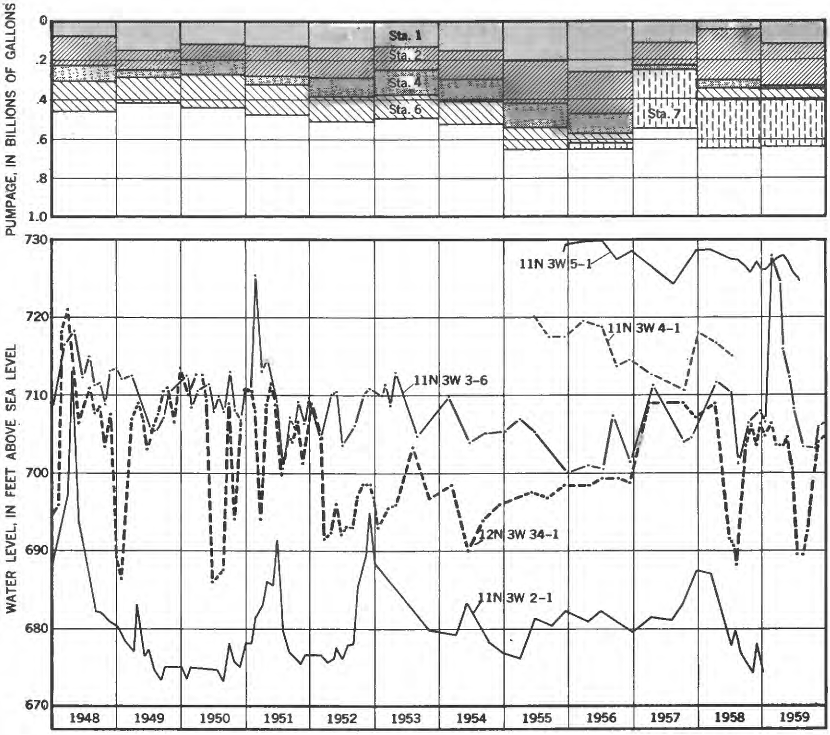


FIGURE 17.—Hydrographs of wells tapping the buried outwash, and graphs of annual pumpage by the city of Alma, 1948–59.

By use of methods devised by Theis (1935) and others, the hydraulic characteristics of an aquifer commonly can be computed.

The Theis equation is as follows:

$$T=\frac{114.6QW(u)}{s},$$

where

T=coefficient of transmissibility, in gallons per day per foot;
Q=rate of pumping, in gallons per minute;
s=drawdown or recovery of water level, in feet;
$W(u)$=well function of u.

$$W(u)=\int_u^\infty \frac{e^{-u}du}{u}$$

and

$$u=\frac{1.87r^2S}{Tt},$$

where

r=distance from pumping well, in feet;

t=time since pumping started or stopped, in days;

S=coefficient of storage.

The outwash aquifer differs considerably from the ideal aquifer of the Theis equation. It is limited in areal extent, varies in permeability both vertically and horizontally, and the confining layer permits leakage of water into the aquifer. Thus, coefficients of transmissibility, storage, and permeability can only be approximated from the test data. The following table summarizes results obtained from five tests in the Alma area.

Pumped well[1]	Date of test	Length of screen in pumped well (feet)	Coefficient of transmissibility (gpd per ft)	Coefficient of storage	Thickness of aquifer (feet)	Field coefficient of permeability (gpd per sq ft)
11N 3W 3-9 (6)	11-21-46	40	29, 000	----------	58	500
12N 3W 34-6 (4)	5-22-50	40	24, 000	0. 00017	44	545
11N 3W 3-2 (1)	7-15-54	30	12, 000	. 064	75	160
11N 3W 4-2 (7)	12-13-54	20	16, 000	. 00078	100	160
11N 3W 5-1	11- 9-55	------	33, 000	. 0015	100	330

[1] City of Alma station given in parentheses.

FLOW-NET ANALYSIS

Pumping-test methods generally define the transmissibilities of only small parts of the aquifer. Average coefficients of transmissibility can be obtained also by analyzing the configuration of the piezometric surface and constructing a flow net. Theoretically, analysis can be made by the flow-net method only if the permeability and transmissibility are uniform throughout the aquifer. It has been shown, however, by Bennett and Meyer (1952, p. 53–58) that reasonably accurate determinations of average transmissibility can be made even if these properties are not uniform, throughout the aquifer.

A flow net of the buried outwash at Alma (fig. 18) was constructed so that, where possible, equipotential lines (connecting points of equal water level or artesian pressure) and flow lines (showing direction of flow parallel to the hydraulic gradient) formed squares; that is, the distance between the equipotential lines is equal to the distance between flow lines. This method is known as the Forcheimer graphical solution (Casagrande, 1937, p. 135–157). The control for the equipotential lines was obtained from the altitudes of water levels on or about July 22, 1947. The net was drawn so that equipotential lines fitted most of the water-level measurements and, at the same

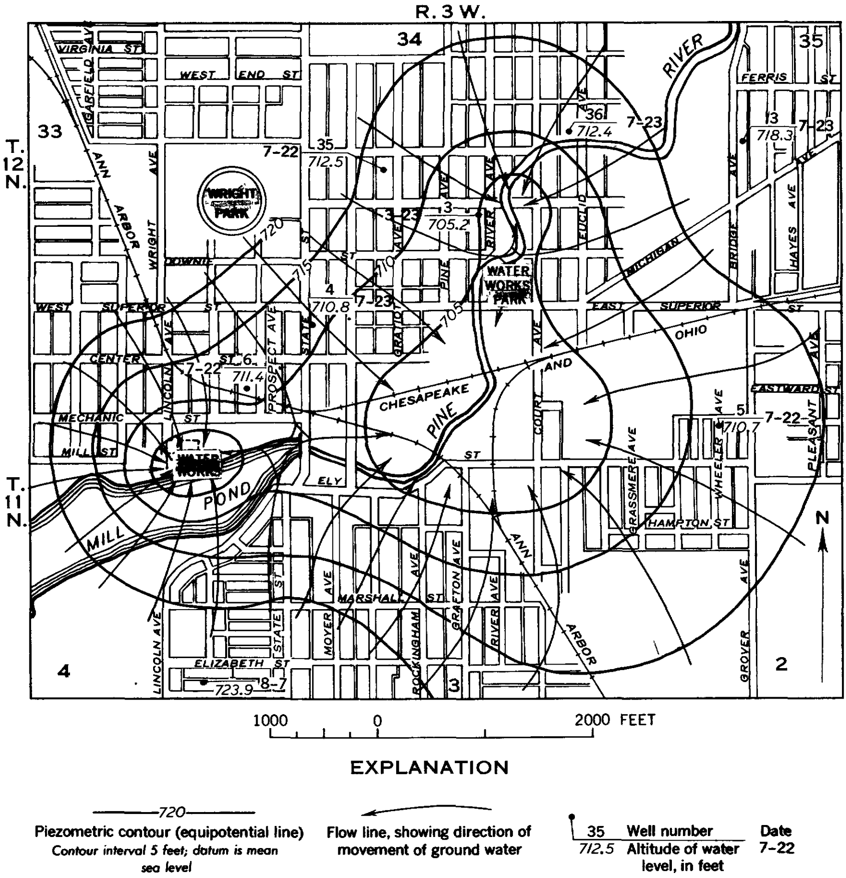


FIGURE 18.—Approximate flow net of the buried outwash during July 1947.

time, formed a system of squares wherever possible with the intersecting flow lines.

The density of flow patterns is controlled by the transmissibility and the rate of discharge. If the rate of discharge and the density of the flow paths are known, the transmissibility can be determined from the equation:

$$T=\frac{Q}{nfs},$$

where

T=the coefficient of transmissibility, in gallons per day per foot;
Q=discharge, in gallons per day, at the pumping station;
nf=the number of flow paths to each pumping station;
s=head loss, in feet, between equipotential lines.

The coefficients of transmissibility determined by the flow-net method are given in the following table:

Pumped well [1]	Average pumpage (Q) (gpd)	Number of flow paths (nf)	Head loss between equipotential lines (s) (feet)	Average coefficient of transmissibility (gpd per ft)
11N 3W 3-7 (1)	520, 000	10	5	10, 000
11N 3W 3-8 (2)	1, 300, 000	13	5	20, 000
12N 3W 34-6 (4)	290, 000	5	5	11, 500

[1] City of Alma station given in parentheses.

The thickness and permeability of the buried outwash vary considerably throughout the Alma area. Locally, the outwash is recharged by interaquifer leakage. Thus, the aquifer is not ideally suited to analysis by either pumping-test or flow-net methods, and the transmissibility values obtained by use of the two methods do not closely agree. The values determined from the flow net, however, are more conservative and probably are more accurate for the large segments of the aquifer than those determined by the pumping tests.

RECHARGE

The buried outwash is recharged indirectly by infiltration of precipitation which moves down to it from the overlying shallow sand and by underflow from the drift deposits adjacent to the aquifer. Although the aquifer is overlain and bounded by materials of relatively low permeability, the cone of depression extends over a considerable area and thus creates a large recharge area. A significant percentage of the precipitation on the area therefore recharges the principal drift aquifer.

Any increase in the rate of withdrawal of water from the part of the aquifer within the city limits of Alma would probably not significantly increase the rate of recharge, as the buried outwash is bound by materials of low permeability to the north, south, and east.

DISCHARGE

Water is discharged from the buried outwash by the pumping of municipal and industrial wells at Alma. The piezometric surface has been lowered by pumping so that it is below the water level in the shallow sand aquifer throughout the city, thus little or no water is discharged naturally from the buried outwash within the city of Alma.

Under natural conditions (prior to development by wells) the buried-outwash aquifer discharged principally by upward leakage to the shallow sand aquifer, although some water moved out of the area by underflow. Upward leakage occurred along the strip of lowland adjacent to the Pine River, where the piezometric surface of the outwash aquifer was above the water table in the shallow sand aquifer. The maximum head difference between the water table and the piezometric surface along this strip was about 20 feet.

In 1904 water was discharged from the outwash aquifer by both upward leakage and flow from artesian wells. Nearly all the discharge occurred in the lowlands along the Pine River. The amount of water moving into this discharge area can be determined from data provided by Davis (1907) and from the flow-net analysis (p. E35) by use of the formula

$$Q=2TI,$$

where

Q=the amount of water moving to a mile-long strip of discharge area;
T=the coefficient of transmissibility, in gallons per day per foot;
I=the average hydraulic gradient toward the river, in feet per mile.

Allowance is made for movement into the discharge area from both sides.

The average transmissibility obtained from the flow-net analysis is about 14,000 gpd per ft, and the average hydraulic grandient toward the area of discharge in 1904 (fig. 13) was about 25 feet per mile. Thus, $Q=2\times14{,}000\times25=700{,}000$ gpd. Therefore, in 1904, an estimated 700,000 gpd moved into a mile strip of discharge area along the river at Alma.

The amount of water that moved into a mile-long strip of discharge area, less the amount of water that moved out of the strip by underflow, is equal to the amount that was discharged in the strip. Analysis of the configuration of the piezometric surface indicates that the amount of water that moved out by underflow was probably relatively small. Thus, the amount of water discharged by artesian flow and upward leakage was about 700,000 gpd. Davis (1907, p. 210, 211) reported that about 230,000 gpd was discharged by flowing wells in 1904. Probably an additional 50,000 gpd was discharged by other wells or moved out of the strip of discharge area by underflow. Thus, an estimated 420,000 gpd was discharged naturally by upward leakage.

The average daily pumpage from municipal wells tapping the buried outwash in 1959 was about 1.9 million gpd. The cone of depression surrounding these wells would have to extend along the river for about 4½ miles in order to intercept the 1.9 million gpd that would be discharged from the aquifer by upward leakage under natural conditions, if the rate of natural discharge was about 420,000 gpd per mile of river reach. The true extent of the cone has not been accurately determined, but, it probably is less than 4 miles long. Not all the water obtained from the municipal wells is intercepted natural discharge, as some water is recharged to the buried outwash through downward leakage from the shallow sand aquifer and the Pine River.

CHEMICAL QUALITY

Water percolating through soil and rocks dissolves some of the material with which it comes in contact. The amount and character of the dissolved mineral matter in ground water depends on (1) the chemical and physical composition of the rocks through which the water moves, (2) the duration of the contact, and (3) other factors such as temperature, pressure, and amount of mixing—if any—with highly mineralized connate sea water (water entrapped at the time the marine sediment was deposited).

The major constituents of ground water are the positively charged ions (cations)—calcium, magnesium, sodium, and potassium—and the negatively charged ions (anions)—bicarbonate, chloride, and sulfate. Additional cations and anions may be present in lesser amounts. Some of these constituents include the cations iron, manganese, and lithium and the anions carbonate, fluoride, nitrate, and phosphate (see table 5).

The concentrations of these constituents affect the quality of the water. For example, the hardness property of water, which is generally expressed in terms of an equivalent quanity of calcium carbonate, is largely dependent on the concentrations of calcium and magnesium. The Michigan Department of Health (1948) has classified the varying degrees of hardness as follows:

Class	*Hardness (ppm)*
Very soft	<50
Soft	50–100
Moderately hard	100–200
Hard	200–300
Very hard	>300

Although it is very difficult to establish safe limits for any of the mineral constituents generally found in water, the standards for drinking water published by the U.S. Public Health Service (1946) are generally accepted. According to these standards, the following elements should not exceed the indicated concentrations, which are mandatory limits.

	Ppm
Fluoride	1.5
Lead	.1
Arsenic	.05
Selenium	.05
Hexavalent chromium	.05

Less restrictive upper limits for other constituents are as follows:

	Ppm		*Ppm*
Copper	3.0	Phenolic compound (as phenol)	005
Iron and manganese (together)	.3	Total dissolved solids:	
Magnesium	125	Water of good quality	500
Zinc	15	Water containing maximum permissible concentration	1,000
Chloride	250		
Sulfate	250		

The foregoing standards, although widely cited for drinking water, are not directly applicable to every situation. The quality of water available in some areas of the United States may not meet the standards in one or more respects. For example, many people have used water containing excessive amounts of dissolved solids for long periods but have not suffered any ill effects.

The shallow sand aquifer at Alma yields water primarily of the calcium magnesium bicarbonate type. The hardness of water sampled from shallow wells in the area ranged from 255 ppm in well 12N 3W 35–5 to 512 ppm in well 12N 3W 36–1. The sulfate content of water samples from the shallow wells in Alma ranged from 45 to 200 ppm. The source of sulfate in the water from both drift aquifers is not definitely known. Presumably the drift contains gypsum (calcium sulfate) which was derived from gypsiferous shale in the underlying red beds.

The iron content of water from the shallow sand also is high. A sample of water taken from well 12N 3W 35–2 in November 1951 contained 11 ppm of iron. This high concentration of iron would make the untreated water unfit for most uses.

Locally, water in the shallow sand aquifer contains nitrate. Nitrate commonly indicates that the ground water is being polluted by sewage or other organic wastes.

The buried outwash generally yields very hard water containing objectionable amounts of iron. Hardness of the water sampled ranged fron 230 to 515 ppm. Iron ranged from 0.3 to 5.6 ppm. The average iron content of the 27 samples collected from public-supply wells tapping the buried outwash was 1.6 ppm.

Some wells tapping the buried outwash yield water containing more than 250 ppm of sulfate, the amount varying considerably, both with the location of the wells and with the time of sampling. Wells at stations 1, 6, and 7 yield water containing nearly twice as much sulfate as do the wells at stations 2, 4, and 5. Furthermore, the well at station 2 yielded water containing more than 275 ppm of sulfate when it was drilled in 1931, but samples collected since 1944 show only about half that amount. The reason for the variation in sulfate content of the water from the various wells and for the decline in sulfate content of water from the well at station 2 has not been conclusively determined. It is likely, however, that water having a low sulfate content moves down under favorable hydraulic head by leakage from the shallow sand aquifer and the Pine River to the outwash aquifer in the area of stations 2, 4, and 5. In 1931, at the time well 11N 3W 3–8 (station 2) was drilled, the piezometric surface at the station and in a large area adjacent to the Pine River was above the water table. Movement of water then was upward from the buried outwash to the shallow sand deposits and thence to the Pine River. Under this hydraulic regimen, water moved a greater distance from areas of recharge to areas of discharge and was in contact with soluble rock material for a greater period of time. When the piezometric surface of the buried outwash was lowered by pumping to a level below

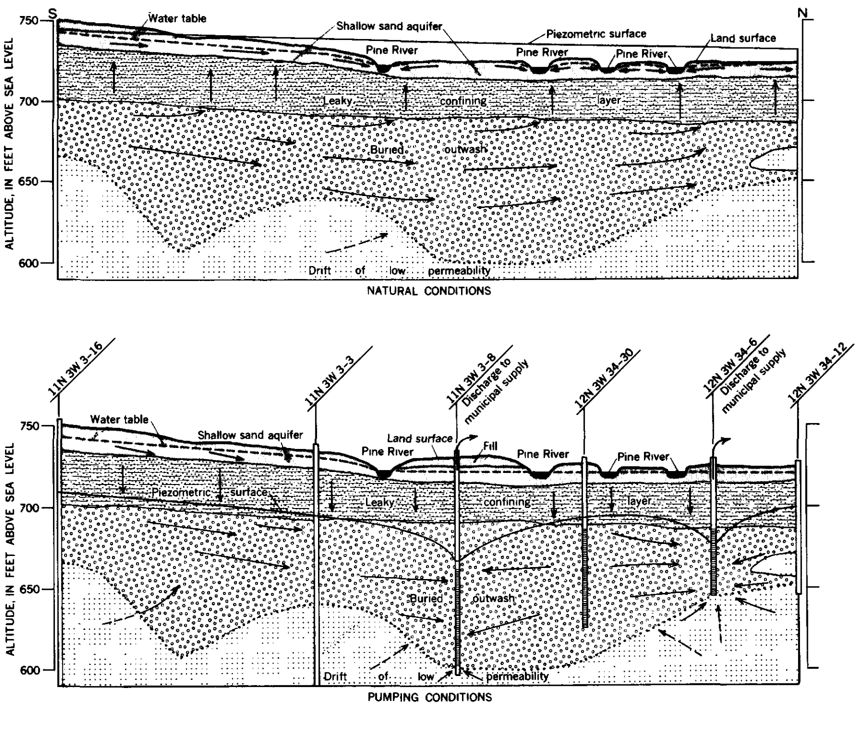


FIGURE 19.—Schematic diagrams showing hydrologic regimen under natural and under pumping conditions along line shown on figure 11.

the water table in the shallow sand, the water moved downward from the shallow sand aquifer to recharge the buried outwash. Under favorable hydraulic head the shallow sand aquifer will receive recharge from the Pine River. The principles outlined here are diagrammed on figure 19.

The temperature of water in the buried outwash ranges from about 50° to 52° F. Generally, water in the shallow sand is warmer, the average temperature at the time of sampling being 54° F. In wells at stations 2 and 4 the average temperature was 51.1° F, and at stations 1, 6, and 7 it was 50.7° F. This evidence also indicates that water from the shallow sand aquifer is being recharged to the buried outwash in the vicinity of stations 2 and 4.

PHENOL CONTAMINATION

In the fall of 1945, the well at station 5 began to yield water with an objectionable taste and odor. It was eventually determined that the water contained phenol (carbolic acid), a byproduct of petroleum refining. Phenol is objectionable in water in very small quantities; and if water containing phenol is chlorinated, the resulting chlorophenolic substance is detectable to taste in concentrations of 0.001 ppm, or 1 part per billion of water. Although there is some disagreement, as to what the maximum permissible concentration of phenol in drinking water should be, it is apparent that even a small concentration is sufficient to impart a detectable taste.

In November 1949 the well at station 4 also began to yield water contaminated with phenol. Personnel of the Michigan Water Resources Commission, Michigan Department of Health, and Michigan Geological Survey cooperated in an investigation to determine the source of the phenol. The investigation revealed that oil-refinery wastes were being discharged to a pit adjacent to the Pine River near Bridge Street, and phenol was leaking from the pit into the ground. The pit was sealed to curtail further contamination.

The well at station 4 was temporarily retired from service and is now (1960) being pumped only during the summer months when demands are high. In 1959 the well still produced water which was contaminated with phenol (table 6), but the concentrations were considerably less than when the well had been tested in 1949. A significant part of the buried outwash north and east of station 4 contained phenol-contaminated water in August of 1959 (fig. 20).

Restriction of pumping at stations 2 and 4 has allowed the piezometric surface to rise in the vicinity of these wells and has decreased the hydraulic gradient from the area of the greatest concentration of phenol. This has tended to retard the rate of migration of phenol-contaminated water toward these two stations.

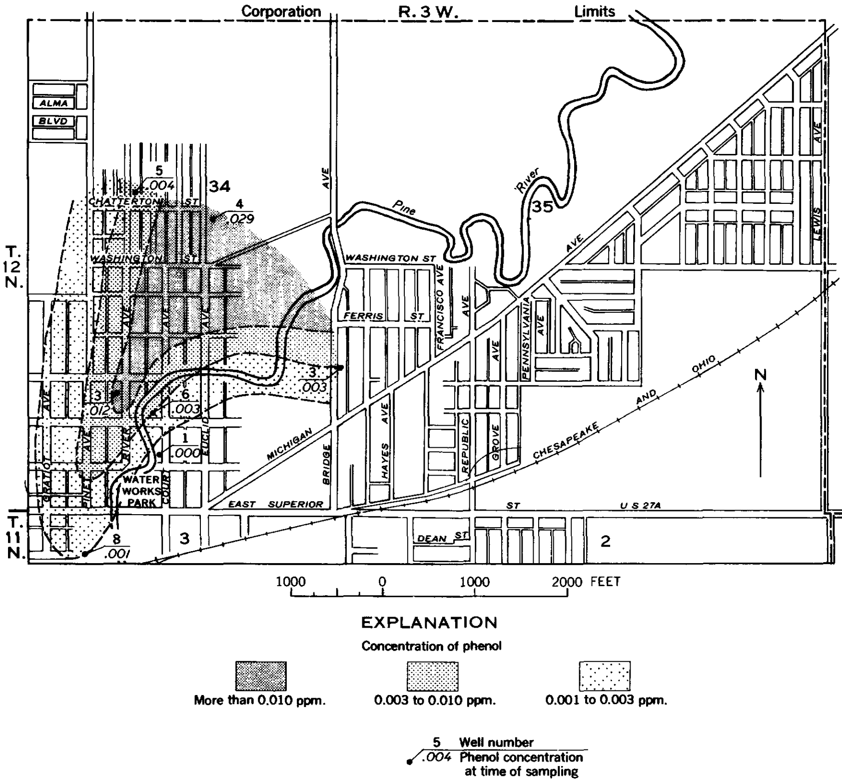


FIGURE 20.—Phenol content of water in the buried outwash at Alma, August 1959.

SUMMARY AND CONCLUSIONS

The city of Alma and one major industrial concern use nearly all the water pumped in the Alma area. Alma obtains most of its water supply from wells tapping the buried outwash that underlies the western half of the city. A small amount of water is obtained from one well that taps the Saginaw formation. The large industrial supply is obtained from wells tapping the buried outwash deposited in a narrow channel in the eastern part of Alma. The glacial aquifers within the city of Alma produced an average of about 2.5 million gallons per day during 1959.

A net decline in water levels in response to the increase in the rate of withdrawal of water at Alma has been recorded during the period 1950–60. The decline has not been excessive, however, as the large-capacity wells drilled since 1950 are located at considerable distances from the older production wells. Thus, the area of the composite cone of depression caused by pumping has enlarged considerably without a corresponding increase in the depth of the cone. Since

1947 the cone has expanded rapidly in the eastern part of the city in response to the pumping of water for industrial use, and since 1956 in the western part of the city in response to the pumping at station 7. Lowered water levels have increased the rate of recharge to the aquifers and reduced the rate of natural discharge.

Although the aquifers within the city of Alma are capable of yielding some additional water to wells, the presence of phenol in the part of the outwash aquifer north and east of station 4 limits the amount of water which can be withdrawn by existing wells within the city without causing further encroachment of phenol through the aquifer. Additional withdrawals would lower the piezometric surface and thus increase the rate of migration of phenol-contaminated water to the discharging wells. The present practice by the city of Alma of discontinuing pumping at station 4 during the periods of low demand should be continued, as this allows water levels to rise in the area of contamination and may permit some natural discharge of phenol-contaminated water to the river. The advantages of withdrawing water from the aquifer at station 5 or from another "scavenger well" which would intercept the contaminated water before it migrated to the presently used municipal supply wells should be considered, especially if the contaminated water can be used. This practice would also tend to speed up removal of phenol from the aquifer. Although the phenol makes it objectionable for public supply, the water can be used for cooling and many other industrial uses.

If the present rate of increase in water use continues, the demand for water will soon exceed the safe yield of the aquifers within the city of Alma. Safe yield in this instance is defined as the maximum yield that could be obtained without inducing additional contaminated water to migrate to the municipal wells.

The geology and water-bearing potential of the glacial-drift and bedrock aquifers within the city have been adequately defined by the drilling of almost 100 test wells, municipal and industrial supply wells, and by pumping tests, in addition to the long-term records of pumping and the drawdown of water levels in response to pumping. All these data indicate that development of an additional supply of water to provide for normal development and growth during the next decade cannot be made within the present (1960) city limits of Alma.

Although there are few data available concerning the types of material present at depth beyond the city, the surficial geology indicates that the areas west and southwest of Alma are the most favorable for the development of additional supplies of water. Test drilling and aquifer testing are necessary before the water-supply potential of the drift west and southwest of Alma can be determined adequately. Despite the lack of conclusive hydrogeologic data for the Alma area, the writer believes that the ground-water resources of the area are adequate for present and anticipated future needs of the city of Alma.

The long-term effects of pumping on the ground-water resources of the area should be determined by a continuous program of water-level observations and interpretations. In addition, a program of periodic sampling for phenol content should be started to determine when the contaminated part of the buried outwash may again be tapped for public water supplies.

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BASIC DATA

TABLE 3.—*Records of selected wells and test holes in the Alma area, Michigan*

Well number: See page E5 for description of well-numbering system.
Location: Wells beyond the city of Alma are located to the 10-acre tracts within the sections. Wells within the city are located by street address or distance from designated street intersections. The notation "70N, 685W, Wright-Virginia" indicates that the well is 70 ft north and 685 ft west of the intersection of Wright Avenue and Virginia Street.
Use: D, domestic; I, industrial; Ir, irrigation; O, observation; P, public supply; T, test.

Interval screened: Depth, in feet below land surface, of top and bottom of screen.
Specific capacity: Maximum reported, in gallons per minute per foot of drawdown.
Altitude: Land-surface datum. Estimated in feet above mean sea level from U.S. Geological Survey topographic map (Alma quadrangle) or city of Alma topographic maps. Altitudes reported to 0.1 foot where established by instrumental leveling by the Michigan Department of Conservation.

Well	Location	Owner	Owner's designation	Driller	Use	Year drilled	Depth (feet)	Diameter (inches)	Interval screened (feet)	Specific capacity	Altitude (feet above mean sea level)	Remarks
T. 12 N., R. 3 W.												
12N 3W 25-1	NW¼NW¼SE¼ sec. 25	City of St. Louis.	TW 59A	Layne Northern Co.	T	1959	222	8			730	
25-2	NW¼NW¼SE¼ sec. 25	City of St. Louis.	TW 59C	do	T	1959	262	12			730	
27-1	NE¼NE¼SE¼ sec. 27	H. E. Kirby			D	1904	195	2			763	Flowed in 1904.
28-1	SE¼SE¼SW¼ sec. 28	Keith Knudson.			D, O		37	2			777	
30-1	SE¼SE¼SE¼ sec. 30	N. Whitcraft			D	1904	80	2			750	
32-1	SE¼SE¼SE¼ sec. 32	City of Alma	TW 14	Theron Brewer.	T	1956	147				765.6	
33-1	817 Wright Ave	E. E. Peterson		do	O		19	1¼			756.2	
33-2	100S, 420W, West End-Garfield.	City of Alma	TW 2	R. M. Brewer	T	1954	147	8			749.6	
33-3	100S, 1600W, Virginia-Garfield.	do	TW 14	Layne Northern Co.	T	1946	105	6			763	
33-4	250N, 25E, Vassar-Yale	do	TW 15	do	T	1946	136	6			761	
33-5	70N, 685W, Wright-Virginia.	do	TW 5	do	T	1940	120	6			745	
33-6	70N, 1500W, Virginia-Garfield.	do	TW 5	R. M. Brewer	T	1954	152	8			756	
33-7	315S, 70W, Alma-Wright	Consumers Power Co.		Raymond Co	T	1949	50	2½			761	
33-8	315S, 254W, Alma-Wright	do		do	T	1949	35	2½			756	
33-9	50S, 254W, Alma-Wright	do		do	T	1949	35	2½			755	
33-10	50S, 70W, Alma-Wright	do		do	T	1949	35	2½			755	
34-1	511 North Court Ave	S. J. Brown			O	1912	55	2			727.1	Flowed 1912-22+.
34-2	1208 Pine Ave	V. J. Mills			O		12	1¼			748.2	

34-3	525 River Ave	M. G. Patterson.			O	1908	79	2			728.7	Flowed 1908-22+.
34-4	1030 Euclid Ave	Oris Martin		Lewis Gould	O	1937	55	2			744	
34-5	125N, 50E, Chatterton-River.	City of Alma	5	Layne Northern Co.	P	1944	90	18	65-90	10	742	Gravel packed.
34-6	630N, 100W, Downie-Court.	City of Alma	4	Layne Northern Co.	P	1943	82	18	42-82	12	724	Gravel packed.
34-7	244N, 227W, Superior-Court.	do	3	E. J. Meyers	P	1921	550	6		2½	724	Taps Saginaw formation. Original depth 775 ft. Flows.
34-8	50N, 300E, Washington-Euclid.	do	TW 3	Layne Northern Co.	T	1940	230	6			737	
34-9	70N, 30E, Chatterton-River.	do	TW 4	do	T	1940	90	6			742	
34-10	200N, 40W, Court-Superior.	do	TW 7	do	T	1943	108	6			723	
34-11	100W, 500N, Court-Downie.	do	TW 8	do	T	1943	78	6			724	
34-12	900N, 140W, Euclid-Downie.	do	TW 10	do	T	1944	80	6			723	
34-13	750N, 490W, Euclid-Downie.	do	TW 11	do	T	1944	78	6			723	
34-14	150N, 25W, Fairview-Chatterton.	do	TW 13	do	T	1944	105	6			741	
34-15	275N, 14W, Court-Superior.	do	Old 1	A. R. Purcell	P	1917	90	10	70-90		724	Flowed. Now destroyed.
34-16	165N, 10W, Court-Superior.	do	2	do	P	1917	100	10	90-100		726	Do.
34-17	85N, 13W, Court-Superior.	do	3	do	P	1917	65	10	45-65		732	Do.
34-18	169N, 226W, Court-Superior.	do	4	do	P	1917	105	10	75-105		726	Do.
34-19	62N, 135W, Court-Superior.	do	5	do	P	1917	105	10	75-105		732	Do.
34-20	335N, 98W, Court-Superior.	do	6	do	P	1917	120	10	90-120		724	Do.
34-21	73N, 254W, Court-Superior.	do	7	do	P	1917	105	8	75-105		727.6	Do.
34-22	282N, 276W, Court-Superior.	do	8	do	P	1917	140	10	110-140		724	Do.
34-23	55N, 323W, Court-Superior.	do	9	do	P	1917	110	10	80-110		726	Do.
34-24	276N, 385W, Court-Superior.	do	10	do	P	1917	105	10	75-105		726	Do.
34-25	162N, 341W, Court-Superior.	do	11	do	P	1917	105	10	75-105		726	Do.
34-26	158N, 57W, Court-Superior.	do	12	do	P	1917	110	8	80-110		726	Do.
34-27	231N, 476W, Court-Superior.	do	13	do	P	1917	105	10	75-105		728	Do.
34-28	80N, 419W, Court-Superior.	do	14	do	P	1917	105	10	75-105		726	Do.

TABLE 3.—*Records of selected wells and test holes in the Alma area, Michigan*—Continued

Well	Location	Owner	Owner's designation	Driller	Use	Year drilled	Depth (feet)	Diameter (inches)	Interval screened (feet)	Specific capacity	Altitude (feet above mean sea level)	Remarks
T. 12 N., R. 3 W.—Continued												
12N 3W 34-29	109N, 514W, Court-Superior.	City of Alma	16	E. J. Meyers	P	1922	548	10			725	Tapped Saginaw formation. Flowed. Abandoned.
34-30	176N, 484W, Court-Superior.	do	17	Kelly Well Co.	P	1925	99	24	40–98		726	Sealed in 1946.
34-31	650N, 90W, Court-Downie.	do	TW 3	Theron Brewer.	T	1954	160	8			724	
34-32	200N, 250W, State-Downie.	Masonic Home.			I	1889	2,861	6			745	Mineral well. Sealed and abandoned.
34-33	245S, 75W, State-Alma	City of Alma	TW 7	Theron Brewer.	T	1954	151	8			756	
34-34	513 Gratiot Ave	Robert McKee.			O		23	2			739.2	Destroyed.
34-35	613 Gratiot Ave	C. A. Mapes			O		37	2			741.4	
34-36	713 Euclid Ave	H. J. Farwell			O		40	2			728.5	
34-37	513 River Ave	Gordon Brown.			O	1908	62	3			727.6	Flowed.
34-38	150N, 235W, Ferris-Bridge.	City of Alma	TW 13	Theron Brewer.	T	1955	135	8			734.8	
34-39	1302 Wright Ave	VFW Post 1454.		Switzer	P	1946	153	3			756	
34-40	413 Euclid Ave	W. E. Wilber			O	1914	42	2			736.1	
35-1	535 Hayes Ave	A. F. Tennant.			O	1918	24	1¼			747.9	
35-2	726 Pennsylvania Ave	C. H. Gould			O		15	1¼			739.7	
35-3	712 Bridge Ave	L. A. Halker			O	1918	26	2			732.8	Flowed 1918–22+.
35-4	712 Grove Ave	Calvin Sherwood.		Worthington	O	1925	28	1½			733.5	
35-5	1060 Bridge Ave	Reed Excavating Co.			O		19	36			738.8	
35-6	40N, 175E, Michigan-Republic.	City of Alma	TW 1	LayneNorthern Co.	T	1937	124	6			740	
35-7	490N, 275W, Lewis-Superior.	Layne Water Co.	TW 2	do	T	1947	78	6			745	
35-8	250N, 910W, Lewis-Superior.	do	TW 3	do	T	1947	119	6			742	

	35-9	817 Francisco Ave	City of Alma		City of Alma	O	1950	22	1¼			731	Abandoned.
	35-10	850N, 125W, Lewis-Superior.	Layne Water Co.	TW 16	Layne Northern Co.	T	1951	126	8			744	
	35-11	1660N, 125W, Lewis-Superior.	do	TW 17	do	T	1951	154	8			742	
	35-12	1050N, 1350W, Lewis-Superior.	do	TW 18	do	T		142	6			740	
	35-13	950N, 1875W, Lewis-Superior.	do	TW 19	do	T	1951	132	4			742	
	35-14	1175N, 180W, Lewis-Superior.	do	TW 20	do	T	1951	114				743	
	35-15	700N, 105W, Lewis-Superior.	do	1N	do	D	1948	104	4			745	
	35-16	900N, 125W, Lewis-Superior.	do	21N	do	I	1951	102	34	80-100	9	744	
	35-17	950N, 1370W, Lewis-Superior.	do	22N	do	I	1951	131	34	95-118	11	740	
	35-18	600E, 750N, Bridge-Washington.	City of Alma	TW 16	Theron Brewer.	T	1956	130	8			736.7	
	36-1	SW¼SW¼SE¼ sec. 36	F. E. Hill		F. E. Hill	D	1952	20	1¼			740	Taps gravel 16 to 20 ft.

T. 11 N., R. 3 W.

11N 3W	2-1	95S, 305E, Elmwood-Eastward.	Layne Water Co.	TW 2	Layne Northern Co.	O	1947	132	8			745	
	2-2	1408 Eastward St	M. J. Patterson.			O	1922	21	1¼			749.9	
	2-3	128 Linwood Ave	B. F. Engbloom.			O		22	1¼			749	
	2-4	335 Pleasant Ave	C. O. Peet			O	1917	20	1¼			750.2	
	2-5	505S, 560E, Elmwood-Eastward.	Layne Water Co.		Layne Northern Co.	O	1947	94	6			744	Converted to 1¼-inch observation well.
	2-6	311S, 754E, Elmwood-Eastward.	do	TW 4	do	O	1947	90	6			742.6	Converted to 1½-inch observation well.
	2-7	610S, 294E, Elmwood-Eastward.	do	TW 5	do	T	1947	94	8			744	
	2-8	560S, 705E, Elmwood-Eastward.	do	TW 6	do	T	1947	97	8			742	
	2-9	50S, 340E, Elmwood-Eastward.	do	TW 7	do	T	1947	132	6			744	
	2-10	105S, 700E, Elmwood-Eastward.	do	TW 8	do	T	1947	106	6			742	
	2-11	600S, 535E, Elmwood-Eastward.	do	TW 9	do	T	1947	105	8	74-94		744	
	2-12	320N, 690E, Elmwood-Eastward.	do	TW 10	do	T	1947	191	8			742	
	2-13	135S, 1090E, Elmwood-Eastward.	do	TW 11	do	T	1948	260	8			746	
	2-14	495S, 550E, Elmwood-Eastward.	do	1S	do	I	1947	100	8	84-95	2.2	744	

TABLE 3.—*Records of selected wells and test holes in the Alma area, Michigan*—Continued

Well	Location	Owner	Owner's designation	Driller	Use	Year drilled	Depth (feet)	Diameter (inches)	Interval screened (feet)	Specific capacity	Altitude (feet above mean sea level)	Remarks
T. 11 N., R. 3 W.—Continued												
11N 3W 2-15	112S, 702E, Elmwood-Eastward	Layne Water Co.	3S	Layne Northern Co.	I	1947	119	8	110-120	3.2	742	
2-16	330N, 690E, Elmwood-Eastward	do	4S	do	I	1947	143	6		4.3	742	
2-17	112S, 330E, Elmwood-Eastward	do	5S	do	I	1948	130	8	107-117	12	744	
2-18	70N, 470E, Elmwood-Eastward	do	TW 3R	do	T	1948	106	2			745	
2-19	317N, 680E, Elmwood-Eastward	do	6S	do	I	1949	135	12	115-135	6	742	
2-20	105S, 712E, Elmwood-Eastward	do	7S	do	I	1952	120	14	99-119		742	
2-21	90S, 670E, Elmwood-Eastward	do	TW 13	do	T	1950	125	12			742	
2-22	280N, 270E, Elmwood-Eastward	do	TW 14	do	T	1951	152	8			744	
2-23	490S, 275E, Elmwood-Eastward	do	TW 15	do	T	1950	150	8			748	
2-24	50S, 50E, Republic-Dean	City of Alma	TW 2	do	T	1937	80	6			745	
2-25	850S, 50E, Hampton-Grover.	do	TW 17	Theron Brewer.	T	1956	150	8			749.2	
2-26	131 South Grover Ave	Frank Hooper			D	1897	30	2			760	
2-27	117 Williamette Ave	Vernon Parks			D		28	1¼			752	
2-28	185S, 625E, Elmwood-Eastward.	Layne Water Co.	TW 12	Layne Northern Co.	T	1950	165	12			743	
2-29	1039 Rosedale	Glen Urie			O	1921	24	1¼			756.4	
3-1	165S, 390E, Lincoln-Elizabeth.	City of Alma	TW 17	Layne Northern Co.	O	1946	179	4			749.6	Converted to 1¼-inch observation well.
3-2	40S, 35E, Mill-Lincoln	do	TW 1	R. M. Brewer	O	1954	160	8			733.5	
3-3	100S, 100W, Court-Mechanic.	do	TW 9	do	T	1954	145	8			734.7	
3-4	320½ North State Ave	Marshall Sign Shop.			O		44	2			737.5	
3-5	118 Wheeler Ave	Thomas Thompson.			O		56	2			743.3	

3-6	219 Prospect Ave	E. A. Waber		Harry Chivers.	O		48	2			733.3	Flowed.
3-7	35S, 50E, Mill-Lincoln	City of Alma	1	Harmon-Ness Co.	P	1927	83	26	51-71	20	734	Abandoned.
3-8	10N, 70E, Pine-Center	do	2	Layne Northern Co.	P	1931	135	26	70-130	25	732	
3-9	65S, 365E, Elizabeth-Lincoln.	do	6	do	P	1946	154	8	113-153	18	749	
3-10	60S, 380E, Elizabeth-Lincoln.	do	TW 6	do	T	1940	178	6			748	
3-11	250N, 90E, State-Ely	do	TW 12	do	T	1944	105	6			730	
3-12	300N, 125E, Elizabeth-River.	do	TW 16	do	T	1946	175	4			747	
3-13	91N, 96W, Van Buren-Grover.	do	TW 18	do	T	1956	120	8			752	
3-14	35S, 35W, Gratiot-Superior.	do	East	Harry Chivers.	P	1904	143	3			735	Flowed in 1904. Abandoned.
3-15	75S, 365E, Elizabeth-Lincoln.	do	6A	T. R. Brewer	T	1955	150	12			749	
3-16	133S, 133E, Hampton-Grassmere.	do	TW 3	do	T	1954	154	8			748	
3-17	100N, 100E, State-Ely	do	TW 8	do	T	1954	160	8			731	
3-18	40S, 55E, Mill-Lincoln	do	1-A	do	P	1955	140	12	110-140		734	
3-19	174 Moyer Ave	John Hillsinger.		John Hillsinger.	O		10	1¼			739.2	Abandoned.
3-20	314 Moyer Ave	A. B. Gais		A. B. Gais	D	1917	27	1¼			740	
3-21	632 Rockingham Ave	Leonard Randell.		L. Randell	D	1946	11	1¼			751	
3-22	606 Moyer Ave	Milton Miller		Milton Miller	D	1938	25	1¼			760	
3-23	702 Grafton Ave	Frank Lippert.		Frank Lippert.	D	1946	28	1¼			748	
3-24	5S, 70E, Pine-Center	City of Alma	2A	T. R. Brewer	P	1959	120	16			732	
3-25	315 Allen Ave	A. Johnson			O	1917	20	1¼			743	
3-26	111 North Grover Ave	Leo Dalrymple.			D		24	1¼			752.6	
3-27	319 Allen Ave	Ray Shaw			O	1919	20	1¼			743.1	
4-1	370S, 100E, Mill-Cedar	City of Alma	TW 6	T. R. Brewer	T, O	1954	165	8			733.3	
4-2	550S, 680W, Mill-Philadelphia.	do	TW 10	do	T	1954	167	8			733.6	
4-3	490S, 50E, Mill-Cedar	do	TW 9	Layne Northern Co.	T	1944	82	6			731	
4-4	110S, 1120W, Marshall-Lincoln.	do	TW 11	T. R. Brewer	T	1955	141	8			735.3	
4-5	545S, 680W, Mill-Philadelphia.	do	7	do	P	1955	155	12	125-155	12	738	
4-6	SW¼SE¼NW¼ sec. 4	do	TW 15	do	T	1956	204	8	191-203	3.3	733.2	

TABLE 3—*Records of selected wells and test holes in the Alma area, Michigan*—Continued

Well	Location	Owner	Owner's designation	Driller	Use	Year drilled	Depth (feet)	Diameter (inches)	Interval screened (feet)	Specific capacity	Altitude (feet above mean sea level)	Remarks
T. 11 N., R. 3 W.—Continued												
11N 3W 4-7	SW¼NW¼NW¼ sec. 4	Pine River Country Club.			P		52	3			740	
4-8	SE¼SE¼SE¼ sec. 4	George Smith		E. D. Schlarf	D	1950	30	2				
5-1	SE¼SE¼NE¼ sec. 5	City of Alma	TW 12	T. R. Brewer	T, O	1955	162	8			741.0	
5-2	SE¼SE¼NE¼ sec. 5	John Pfarr		Layne Northern Co.	D	1948	68	6	63-67		740	
5-3	NW¼NW¼NE¼ sec. 5	Brick School			P	1951	40	3			760	
5-4	NW¼NW¼SW¼ sec. 5	Gale Bovee			D, S		75	2			752	
5-5	SE¼SE¼SW¼ sec. 5	Robert Layman			D		120	2			740	
6-1	SE¼SW¼SE¼ sec. 6	Morse School			P			2			760	
6-2	SE¼SE¼NE¼ sec. 6	E. J. Munn and Sons.		Chester Gates	I		185	6			745	
8-1	NE¼NE¼SE¼ sec. 8	R. L. Duckworth.		John Brown	D	1939	137	2			743	
8-2	NE¼NE¼NW¼ sec. 8	John Wolf			D	1902	41	2			740	Flowed in 1904.
8-3	NE¼NE¼NW¼ sec. 8	Garth Sensabaugh.			D	1947	105	2			740	
9-1	SE¼SW¼NE¼ sec. 9	Homer Humphrey.			D		22	2			749	
10-1	SE¼SW¼NW¼ sec. 10	Elmer Harpst		Elmer Harpst	Ir	1945	35	2			750	
10-2	SW¼SW¼NW¼ sec. 10	do		do	D	1945	35	2			755	
10-3	NW¼NW¼NW¼ sec. 10	Fred La Banville.			D	1956	146	2			750	
17-1	NE¼NE¼NE¼ sec. 17	Ely School			P	1935	70	2			740	Flowed in 1935.
17-2	SE¼NE¼NE¼ sec. 17	R. L. Duckworth.		Lester Waldron.	D	1956	57	2				

TABLE 4.—*Selected logs of wells in the Alma area, Michigan*

[Altitude of land surface given in feet above sea level]

12N 3W 32-1

[Alt 765.6 ft]

	Thickness (feet)	Depth (feet)
Glacial drift:		
Gravel and clay	25	25
Sand, water-bearing	3	28
Gravel and clay	17	45
Clay and gravel	10	55
Sand, fine, and clay	5	60
Clay and medium gravel	5	65
Glacial drift—Continued		
Gravel and clay	10	75
Clay, gray	25	100
Sand, fine, and clay	4	104
Gravel, medium, and clay	4	108
Gravel, fine; sand and clay	27	135
Gravel, medium, and clay	4	139
Clay and gravel	8	147

12N 3W 33-2

[Alt 749.6 ft]

	Thickness (feet)	Depth (feet)
Glacial drift:		
Clay, gravelly	10	10
Sand, water-bearing	5	15
Clay, gravelly	5	20
Sand, water-bearing	18	38
Gravel, coarse	6	44
Glacial drift—Continued		
Clay, gravelly	20	64
Sand, medium	48	112
Sand, muddy	15	127
Gravel, muddy	5	132
Gravel, coarse	1	133
Clay, gravelly	14	147

12N 3W 33-3

[Alt 763 ft]

	Thickness (feet)	Depth (feet)
Glacial drift:		
Clay, yellow	17	17
Sand, fine, gray	8	25
Clay, blue	3	28
Clay and coarse gravel	20	48
Glacial drift—Continued		
Sand, dirty	4	52
Clay, gray, and small gravel	30	82
Clay, hard, and gravel	10	92
Sand, fine, gray	2	94
Sand and clay, soft, gray	11	105

12N 3W 33-4

[Alt 761 ft]

	Thickness (feet)	Depth (feet)
Glacial drift:		
Clay, soft, yellow	17	17
Sand, fine, gray	8	25
Clay, soft, gray	22	47
Glacial drift—Continued		
Clay, hard; sand, and gravel	26	73
Sand, yellow, dirty	58	131
Sand, fine, gray	5	136

12N 3W 33-5

[Alt 745 ft]

	Thickness (feet)	Depth (feet)
Glacial drift:		
Soil	1	1
Sand	2	3
Clay, sandy, hard	9	12
Sand, clean	13	25
Clay, sandy, soft	46	71
Sand, coarse	1	72
Glacial drift—Continued		
Clay, sandy, soft	6	78
Sand, coarse, clean, and gravel	4	82
Clay, sandy	1	83
Sand, fine	27	110
Clay and gravel	2	112
Sand	8	120

12N 3W 33-6

[Alt 756 ft]

	Thickness (feet)	Depth (feet)
Glacial drift:		
Clay, sandy	15	15
Clay, hard	20	35
Clay, sandy	10	45
Clay and gravel	12	57
Glacial drift—Continued		
Sand and clay	21	78
Clay, gray, hard	27	105
Clay, sandy, soft	42	147
Clay, gravelly, hard	5	152

TABLE 4.—*Selected logs of wells in the Alma area, Michigan*—Continued

12N 3W 33-10

[Alt 755 ft]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Glacial drift:			Glacial drift—Continued		
Clay, sandy, black	4	4	Clay, sandy and gravelly, hard, blue	4	28
Clay, varicolored; some sand and a little gravel	9	13	Hardpan, sandy, clayey; some gravel	7	35
Sand, fine, gray	4	17			
Sand, medium, gray	7	24			

12N 3W 34-5

[Alt 742 ft]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Glacial drift:			Glacial drift—Continued		
Soil	1	1	Clay, boulders	2	44
Clay, gummy	7	8	Clay, hard, and gravel	11	55
Sand and gravel	1	9	Clay, sandy	6	61
Clay, hard	5	14	Sand, medium	3	64
Clay and gravel	2	16	Sand and gravel	26	90
Clay, sandy	11	27	Clay		
Clay and gravel	15	42			

12N 3W 34-6

[Alt 724 ft]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Glacial drift:			Glacial drift—Continued		
Sand	7	7	Sand	1	29
Gravel	1	8	Clay	9	38
Clay, hard	10	18	Sand and gravel	44	82
Clay	10	28			

12N 3W 34-7

[Alt 724 ft]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Glacial drift:			Saginaw formation—Continued		
Clay, gravel, and hardpan	56	56	Shale, gray	105	672
Gravel, coarse, water-bearing	2	58	Sandstone and shale	8	680
Gravel, fine, water-bearing	10	68	Sandstone, pyritic, slightly calcareous, white	10	690
Clay, gritty, buff	53	121	Bayport limestone:		
Sand, coarse, water-bearing	4	125	Dolomite, buff	13	703
Clay, sticky, brown, and pebbles	225	350	Limestone, gray to buff	17	720
Clay, hard, red, and pebbles	94	444	Limestone, shaly, gray	1	721
Saginaw formation:			Limestone, shaly, buff to gray	24	745
Sandstone, buff, and gray shale	2	446	Michigan formation:		
Shale, dark-gray, laminated	4	450	Sandstone, shaly	16	761
Shale, black, laminated	26	476	Shale, calcareous, green, plastic	12	773
Sandstone, white	57	533	Dolomite, sandy, pyritic	2	775
Coal	1	534			
Shale, bluish-black, laminated	33	567			

12N 3W 34-8

[Alt 737 ft]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Glacial drift:			Glacial drift—Continued		
Soil	3	3	Clay, brown, and gravel	55	110
Sand, fine	21	24	Clay, sandy, brown	20	130
Sand, clean	6	30	Clay and gravel	100	230
Clay, sandy, hard	25	55			

TABLE 4.—*Selected logs of wells in the Alma area, Michigan*—Continued

12N 3W 34-9

[Alt 742 ft]

	Thickness (feet)	Depth (feet)
Glacial drift:		
Muck	2	2
Sand	6	8
Clay, hard, blue, and gravel	11	19
Sand and gravel	1	20
Clay, hard, blue, sandy	7	27
Glacial drift—Continued		
Gravel, clean	3	30
Clay, hard, and sand	32	62
Sandy, muddy, and gravel	5	67
Gravel, coarse, and sand	5	72
Sand and gravel	18	90

12N 3W 34-10

[Alt 723 ft]

	Thickness (feet)	Depth (feet)
Glacial drift:		
Fill	2	2
Sand	6	8
Clay	25	33
Glacial drift—Continued		
Clay and gravel	7	40
Gravel and sand	9	49
Clay	59	108

12N 3W 34-11

[Alt 724 ft]

	Thickness (feet)	Depth (feet)
Glacial drift:		
Sand	7	7
Gravel	1	8
Clay, hard	10	18
Clay	10	28
Glacial drift—Continued		
Sand	1	29
Clay	9	38
Gravel and sand	40	78

11N 3W 34-12

[Alt 723 ft]

	Thickness (feet)	Depth (feet)
Glacial drift:		
Loam, sandy	7	7
Gravel, coarse; some sand	1	8
Clay, gravelly, gray	26	34
Sand, fine, muddy	2	36
Sand, coarse to medium	4	40
Sand, medium to fine	10	50
Sand, coarse to fine; some gravel	3	53
Glacial drift—Continued		
Clay, hard, and gravel	5	58
Clay, gummy, gray	8	66
Sand, coarse to medium	2	68
Sand, medium to fine	5	73
Clay, hard	7	80

12N 3W 34-13

[Alt 723 ft]

	Thickness (feet)	Depth (feet)
Glacial drift:		
Loam, sandy	8	8
Gravel, coarse	2	10
Clay, sandy	20	30
Sand, fine, muddy	4	34
Sand, fine	10	44
Clay, sandy, brown	3	47
Sand, fine	2	49
Clay, brown	3	52
Glacial drift—Continued		
Sand, fine	1	53
Clay	2	55
Sand, medium to fine	3	58
Clay, brown	1	59
Sand, fine	2	61
Sand, medium to coarse	7	68
Clay, gummy	10	78

12N 3W 34-14

[Alt 741 ft]

	Thickness (feet)	Depth (feet)
Glacial drift:		
Fill, dirt	1	1
Muck	1	2
Sand	4	6
Clay, gravelly, tough	40	46
Clay, sandy, tough, brown	4	50
Clay, soft, brown	7	57
Sand, medium to fine	5	62
Glacial drift—Continued		
Sand, coarse, and gravel	23	85
Gravel, medium to coarse	7	92
Sand, medium, and fine gravel	9	101
Clay, sandy, gray	3	104
Sand, fine to medium	1	105

TABLE 4.—*Selected logs of wells in the Alma area, Michigan*—Continued

12N 3W 34-30

[Alt 726 ft]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Glacial drift:			Glacial drift—Continued		
Soil, sandy	7	7	Sand, hard, and gravel	7	49
Sand and clay, hard	8	15	Sand and stones	7	56
Sand, clay, and boulders	13	28	Sand	6	62
Clay	4	32	Sand, fine	9	71
Clay and quicksand	4	36	Sand	1	72
Clay, sand, and boulders	2	38	Sand, fine	20	92
Sand, fine	2	40	Gravel and clay	6	98
Sand, hard	2	42	Sand and clay	1	99

12N 3W 34-31

[Alt 724 ft]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Glacial drift:			Glacial drift—Continued		
Sand	15	15	Clay and boulders	5	86
Gravel	1	16	Clay, gravelly	19	105
Clay, hard	12	28	Clay, sandy	3	108
Gravel, coarse	5	33	Clay, stony, hard	7	115
Clay, soft	5	38	Clay, sandy, soft	25	140
Sand, fine, and gravel	8	46	Gravel, medium, and sand	5	145
Gravel, medium, and sand	34	80	Clay, gravelly	15	160
Boulders	1	81			

12N 3W 34-32

[Alt 745 ft]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Glacial drift:			Saginaw formation—Continued		
Clay	60	60	Sandstone, pyritiferous, and brine	80	790
Quicksand, water-bearing	97	157	Michigan formation:		
Gravel	3	160	Shale, sandy, blue and black	70	860
Clay and gravel	315	475	Gypsum, blue and white	35	895
Sand and gravel	25	500	Limestone, dolomitic or argillaceous, red and blue	120	1,015
Saginaw formation:			Marshall formation:		
Sandstone, feldspathic	50	550	Sandstone, white, clean, and brine	85	1,100
Shale, black, pyritiferous, and coal	25	575	Shale, sandy, red	200	1,300
Shale, blue	40	615	Coldwater shale:		
Shale, white	22	637	Shale, blue	20	1,320
Sandstone, pebbly	38	675			
Shale and coal	35	710	Total depth of well	--------	2,861

12N 3W 34-33

[Alt 756 ft]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Glacial drift:			Glacial drift—Continued		
Clay, hard, sticky	10	10	Clay, sandy	51	96
Sand	11	21	Clay, hard, and boulders	18	114
Clay and boulders	5	26	Clay, sandy, soft	12	126
Clay, hard, and boulders	19	45	Clay and boulders	11	137
			Clay, hard, gray	14	151

12N 3W 34-38

[Alt 734.8 ft]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Glacial drift:			Glacial drift—Continued		
Fill	7	7	Clay, brown, gravelly	3	48
Clay, gray-brown	8	15	Sand and gravel, water-bearing	4	52
Clay, sandy, hard	30	45	Clay, red, gravelly	83	135

TABLE 4.—*Selected logs of wells in the Alma area, Michigan*—Continued

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
12N 3W 34-39 [Alt 756 ft]					
Glacial drift:			Glacial drift—Continued		
No record	135	135	Clay	11	148
Sand	2	137	Gravel and clay	2	150
			Sand, very coarse	3	153
12N 3W 35-6 [Alt 740 ft]					
Glacial drift:			Glacial drift—Continued		
Clay, sandy	18	18	Gravel	2	20
			Clay, hard, yellow	104	124
12N 3W 35-7 [Alt 745 ft]					
Glacial drift:			Glacial drift—Continued		
Clay	11	11	Sand, fine, and clay	13	48
Sand, gray	24	35	Clay and gravel	30	78
12N 3W 35-8 [Alt 742 ft]					
Glacial drift:			Glacial drift—Continued		
No record	26	26	Sand, fine	5	55
Clay	24	50	Gravel	5	60
			Clay	59	119
12N 3W 35-10 [Alt 744 ft]					
Glacial drift:			Glacial drift—Continued		
Clay, yellow	25	25	Sand, muddy, water-bearing	7	75
Sand and clay, muddy	43	68	Sand, clean	27	102
			Clay, sandy	24	126
12N 3W 35-12 [Alt 740 ft]					
Glacial drift:			Glacial drift—Continued		
Soil	2	2	Gravel and clay	8	85
Clay	26	28	Sand and gravel	7	92
Sand, gravel, and clay	6	34	Sand and gravel; some clay	13	105
Sand and gravel	8	42	Sand and gravel	7	112
Silt, fine	10	52	Sand and gravel, muddy	13	125
Sand	5	57	Clay, soft	10	135
Sand and gravel	20	77	Clay, hard, gravelly	7	142
12N 3W 35-13 [Alt 742 ft]					
Glacial drift:			Glacial drift—Continued		
Soil	2	2	Sand, medium	4	18
Clay, sandy	6	8	Clay, medium to hard	17	35
Sand, fine	6	14	Clay, very hard	97	132

TABLE 4.—*Selected logs of wells in the Alma area, Michigan*—Continued

12N 3W 35–14

[Alt 743 ft]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Glacial drift:			Glacial drift—Continued		
Soil	1	1	Sand and silt	4	60
Clay, red	6	7	Clay, sandy, gray	4	64
Clay, sandy	10	17	Clay, hard, gray	8	72
Clay, medium to hard	13	30	Sand	2	74
Clay, very hard	26	56	Clay, hard	16	90
			Clay, very hard, gray	24	114

12N 3W 35–18

[Alt 736.7 ft]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Glacial drift:			Glacial drift—Continued		
Clay, gray, gravelly	20	20	Gravel, gray, muddy	52	110
Clay, red, sticky	27	47	Clay, red, gravelly	20	130
Gravel, coarse, and sand	11	58			

11N 3W 2–1

[Alt 745 ft]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Glacial drift:			Glacial drift—Continued		
Clay	20	20	Gravel, medium	5	123
Sand	20	40	Sand, brown	2	125
Clay	20	60	Gravel	5	130
Gravel, fine	40	100	Clay	2	132
Sand, fine	18	118			

11N 3W 2–6

[Alt 742.6 ft]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Glacial drift:			Glacial drift—Continued		
Soil	1	1	Sand, white	38	73
Sand	24	25	Gravel, coarse	16	89
Clay, blue	10	35	Clay	1	90

11N 3W 2–9

[Alt 744 ft]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Glacial drift:			Glacial drift—Continued		
Soil	1	1	Clay, blue, sandy	6	50
Clay, red	5	6	Gravel, some clay	3	53
Clay, red, sandy	2	8	Sand, some clay	3	56
Clay, blue	9	17	Sand, some clay	4	60
Gravel, medium; some sand and clay	3	20	Sand, gravel, medium	30	90
Clay, blue	3	23	Gravel, coarse, and sand	10	100
Sand, medium	2	25	Sand and gravel, medium	14	114
Clay, blue-gray, gravelly	12	37	Sand and gravel	18	132
Clay, blue, gravelly	7	44	Clay, blue, at bottom of well		

11N 3W 2–11

[Alt 744 ft]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Glacial drift:			Glacial drift—Continued		
Soil, black	2	2	Sand, gravel, and gray clay	5	70
Clay, yellow	4	6	Sand, fine	4	74
Sand, fine	1	7	Gravel, coarse	3	77
Clay, gray	13	20	Gravel and sand	3	80
Clay and sand	5	25	Sand, coarse	4	84
Sand and gravel	2	27	Gravel and sand, coarse, gray	5	89
Clay, gray	10	37	Sand, brown, and coarse gravel	12	101
Gravel and clay	3	40	Clay, dark-blue; some gravel	4	105
Clay, gray	15	55			
Gravel, sand, and clay	10	65			

TABLE 4.—*Selected logs of wells in the Alma area, Michigan*—Continued

	Thickness (feet)	Depth (feet)
11N 3W 2-12 [Alt 742 ft]		
Glacial drift:		
Soil	1	1
Clay	12	13
Gravel	5	18
Clay	7	25
Sand, fine	6	31
Clay, hard, blue	32	63
Sand	4	67
Glacial drift—Continued		
Clay, hard	24	91
Sand	15	106
Clay	4	110
Sand	2	112
Clay	3	115
Gravel, coarse	13	128
Clay and gravel, hard	63	191
11N 3W 2-13 [Alt 746 ft]		
Glacial drift:		
Clay	14	14
Gravel, dirty	19	33
Clay	40	73
Sand, brown	29	102
Glacial drift—Continued		
Gravel, coarse	6	108
Clay, sandy	32	140
Clay, hard, blue	120	260
11N 3W 2-18 [Alt 745 ft]		
Glacial drift:		
Soil	2	2
Clay, red	10	12
Clay, blue	8	20
Clay, gravelly, hard, blue	40	60
Glacial drift—Continued		
Sand, gravel, and clay	20	80
Sand, fine to medium	6	86
Sand and gravel, clayey	20	106
11N 3W 2-20 [Alt 742 ft]		
Glacial drift:		
Soil	1	1
Clay	10	11
Sand and gravel	5	16
Clay, hard, stony	42	58
Sand, brown	5	63
Sand and gravel	23	86
Sand, brown	4	90
Glacial drift—Continued		
Sand, gravel, and boulders	9	99
Sand, gravel, and boulders, clayey	3	102
Clay	3	105
Sand and gravel, water-bearing	14	119
Clay	1	120
11N 3W 2-21 [Alt 742 ft]		
Glacial drift:		
Soil	1	1
Sand and clay, gray	12	13
Gravel	2	15
Sand, gravel, and clay	7	22
Gravel, fine	6	28
Gravel and clay, gray	30	58
Glacial drift—Continued		
Gravel, fine	12	70
Sand, fine, brown	30	100
Gravel	8	108
Clay	2	110
Clay, gravelly	15	125
11N 3W 2-22 [Alt 744 ft]		
Glacial drift:		
Clay, sand, and gravel	30	30
Sand and clay	115	145
Glacial drift—Continued		
Clay, soft to hard	7	152

TABLE 4.—*Selected logs of wells in the Alma area, Michigan*—Continued

11N 3W 2-23

[Alt 748 ft]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Glacial drift:			Glacial drift—Continued		
Soil and clay	7	7	Sand and gravel, coarse	20	95
Sand and gravel, gray	23	30	Sand and gravel, rusty	11	106
Clay, gray	39	69	Clay, gray, gravelly	44	150
Sand, medium, brown	6	75			

11N 3W 2-24

[Alt 745 ft]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Glacial drift:			Glacial drift—Continued		
Clay	10	10	Clay, hard	47	80
Sand, fine	16	26	Boulders at 80 ft.		
Sand, coarse, and gravel	7	33			

11N 3W 2-25

[Alt 749.2 ft]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Glacial drift:			Glacial drift—Continued		
Sand and clay	5	5	Clay, gray, gravelly, sandy, hard	56	109
Gravel, coarse	28	33	Clay, gray, sticky, and stones	41	150
Clay, gravelly	7	40			
Clay, gravelly, hard	13	53			

11N 3W 3-1

[Alt 749.6 ft]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Glacial drift:			Glacial drift—Continued		
Soil	1	1	Sand and gravel, clean	6	102
Sand and gravel	20	21	Sand, gravel, and streaks of clay	7	109
Gravel and clay	52	73	Sand, fine; some gravel	14	123
Clay, sandy	4	77	Sand, fine	5	128
Gravel	1	78	Sand, fine; some gravel	26	154
Sand, gravel, and clay	13	91	Sand, fine	25	179
Gravel	1	92	Clay at 179 ft.		
Gravel and streaks of clay	4	96			

11N 3W 3-2

[Alt 733.5 ft]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Glacial drift:			Glacial drift—Continued		
Sand, muddy	10	10	Clay, sandy	10	61
Gravel and clay	5	15	Sand and gravel, coarse	17	78
Clay, hard	17	32	Clay, sandy	18	96
Clay, sticky, soft	3	35	Gravel, coarse	40	136
Clay, hard	10	45	Gravel, muddy	3	139
Clay, sandy, soft	5	50	Clay	21	160
Clay, brown	1	51			

11N 3W 3-3

[Alt 734.7 ft]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Glacial drift:			Glacial drift—Continued		
Sand	10	10	Gravel, coarse, uniform	34	94
Clay, gray, hard	33	43	Clay, gray	20	114
Sand, muddy	7	50	Clay, gray to dark-red	31	145
Sand and gravel, muddy	10	60			

TABLE 4.—*Selected logs of wells in the Alma area, Michigan*—Continued

11N 3W 3-8

[Alt 732 ft]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Glacial drift:			Glacial drift—Continued		
Clay	7	7	Sand, medium, and gravel	11	68
Sand and gravel	2	9	Gravel, coarse, and sand	17	85
Clay, sandy	23	32	Sand, medium	27	112
Sand, dirty	6	38	Gravel, coarse	6	118
Sand, medium	2	40			
Sand and gravel	14	54	Total depth of well		135
Gravel, a little sand, and a trace of clay	3	57			

11N 3W 3-9

[Alt 749 ft]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Glacial drift:			Glacial drift—Continued		
Soil and sand	20	20	Gravel, clay, and boulders	9	89
Clay, sandy	15	35	Boulders	1	90
Clay, sandy, and boulders	24	59	Gravel and clay	5	95
Clay, sandy, and gravel	11	70	Sand	5	100
Gravel and clay	10	80	Sand and gravel	53	153

11N 3W 3-10

[Alt 748 ft]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Glacial drift:			Glacial drift—Continued		
Soil	1	1	Sand, fine, clean	8	113
Sand, fine, yellow	17	18	Sand, coarse, yellow	4	117
Sand, coarse	2	20	Sand, fine, clean	10	127
Clay and gravel	40	60	Sand, coarse, clean	4	131
Clay, sandy	13	73	Sand, fine, clean	9	140
Sand, muddy, and gravel	7	80	Sand, coarse; some gravel	5	145
Clay	1	81	Sand, fine, clean	5	150
Sand, muddy, and gravel	17	98	Sand, clean, and gravel	3	153
Clay, sandy	7	105	Sand, fine, clean	25	178

11N 3W 3-11

[Alt 730 ft]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Glacial drift:			Glacial drift—Continued		
Fill	8	8	Clay, brown	2	75
Clay, gritty	27	35	Sand, gravel, and clay	5	80
Hardpan and gravel	8	43	Sand and gravel	4	84
Clay, gritty	9	52	Sand, fine to medium, and gravel, fine	6	90
Sand, medium	8	60	Sand, fine	8	98
Sand, medium, and gravel, fine	3	63	Clay, brown	2	100
Clay, sandy, brown	1	64	Sand, fine	2	102
Sand, fine to medium	6	70	Clay, gray	3	105
Sand, coarse, and gravel, fine	3	73			

11N 3W 3-12

[Alt 747 ft]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Glacial drift:			Glacial drift—Continued		
Clay, yellow	10	10	Sand, fine, gray, clean	10	142
Clay, hard, gray, and gravel	30	40	Sand, medium, gray, clean	9	151
Clay, gray, sand, and gravel	35	75	Sand, fine, gray, clean	11	162
Sand, yellow, muddy	5	80	Sand, fine, gray, muddy	5	167
Sand, yellow, clean	10	90	Sand, fine, muddy, some gravel	8	175
Sand, fine, gray, clean	26	116	Clay at 175 ft.		
Sand, fine, gray, muddy	16	132			

TABLE 4.—*Selected logs of wells in the Alma area, Michigan*—Continued

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
11N 3W 3-13 [Alt 752 ft]					
Glacial drift:			Glacial drift—Continued		
Clay, gray, gravelly	20	20	Clay, gray, gravelly, hard	87	120
Sand and gravel, muddy	13	33			
11N 3W 3-14 [Alt 735 ft]					
Glacial drift:			Glacial drift—Continued		
Clay, till, compact	50	50	Sand	93	143
11N 3W 3-16 [Alt 748 ft]					
Glacial drift:			Glacial drift—Continued		
Clay, sandy	15	15	Sand and clay	21	78
Clay, hard	20	35	Clay, gray, hard	27	105
Clay, sandy	10	45	Clay, sandy, soft	42	147
Gravel and clay	12	57	Clay, gravelly, hard	5	152
11N 3W 3-17 [Alt 731 ft]					
Glacial drift:			Glacial drift—Continued		
Fill	20	20	Clay, sandy	27	121
Clay, hard	18	38	Sand, muddy	14	135
Clay, sandy	6	44	Clay, sandy	22	157
Clay	30	74	Clay	3	160
Sand, muddy	20	94			
11N 3W 3-21 [Alt 751 ft]					
Glacial drift:			Glacial drift—Continued		
Clay, sandy, yellow	5	5	Sand and gravel	3	11
Clay, blue	3	8			
11N 3W 3-23 [Alt 748 ft]					
Glacial drift:			Glacial drift—Continued		
Clay	4	4	Gravel	23	28
Gravel, sandy	1	5			
11N 3W 4-1 [Alt 733.3 ft]					
Glacial drift:			Glacial drift—Continued		
Sand	10	10	Clay, sandy, soft	5	119
Clay, hard	18	28	Clay, hard, and boulders	6	125
Clay, sandy	15	43	Clay, sandy, soft	17	142
Clay, gravelly	27	70	Gravel, muddy	3	145
Gravel, coarse	1	71	Gravel, medium	11	156
Gravel and sand, muddy	24	95	Clay, hard, sticky	9	165
Clay, hard	19	114			

TABLE 4.—*Selected logs of wells in the Alma area, Michigan*—Continued

11N 3W 4-2

[Alt 733.6 ft]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Glacial drift:			Glacial drift—Continued		
Clay, sandy	35	35	Sand and gravel, gray	25	130
Clay, gray, gravelly	5	40	Sand and gravel	5	135
Clay, sandy	10	50	Sand, coarse, and gravel	15	150
Sand, brown	30	80	Clay, sticky	17	167
Sand, gray, and gravel	18	98			
Gravel, brown to gray, muddy	7	105			

11N 3W 4-3

[Alt 731 ft]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Glacial drift:			Glacial drift—Continued		
Clay; some gravel	36	36	Sand, fine, muddy; and soft clay	7	69
Sand, fine; gravel, and clay	4	40	Sand, coarse; some gravel	4	73
Sand, fine, muddy, brown	18	58	Sand, fine, muddy	9	82
Clay, soft, yellow	4	62			

11N 3W 4-4

[Alt 735.3 ft]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Glacial drift:			Glacial drift—Continued		
Clay, brown, sandy	10	10	Gravel, sandy, water-bearing	6	100
Clay, gray	5	15	Gravel, sandy, clayey	10	110
Sand and gravel	3	18	Sand, clayey	24	134
Clay, gravelly	41	59	Clay, sandy	4	138
Gravel	11	70	Clay, sticky	3	141
Gravel, sandy, clayey	24	94			

11N 3W 4-6

[Alt 733.2 ft]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Glacial drift:			Glacial drift—Continued		
Clay, gray	10	10	Sand, red, fine	55	105
Clay, gray, and fine sand	5	15	Sand, red and white, fine	45	150
Clay, gray; sand and gravel	15	30	Sand, red, fine	29	179
Clay, gravel, and sand	15	45	Sand, white, fine	9	188
Sand, fine	5	50	Sand and medium gravel	16	204

11N 3W 5-1

[Alt 741.0 ft]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Glacial drift:			Glacial drift—Continued		
Clay, brown to red, sandy	20	20	Sand, medium to fine, gravelly	20	105
Clay, sandy, gravelly	27	47	Sand, fine	40	145
Sand and gravel, brown clayey	8	55	Gravel, medium, sandy	13	158
Sand and boulders, water-bearing	5	60	Sand, gray, clayey	1	159
Sand, fine, brown, clayey	25	85	Clay	3	162

11N 3W 10-1

[Alt 750 ft]

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Glacial drift:			Glacial drift—Continued		
Clay, red	6	6	Sand, gray	28	40
Sand, yellow	6	12			

TABLE 5.—*Chemical analyses of ground-water samples from the Alma area, Michigan*

[Chemical constituents given in parts per million, except as indicated. Analyst: M, Michigan Department of Health; L, Layne Water Co.; U, U.S. Geological Survey]

Well	Analyst	Date sampled	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue on evaporation at 180° C)	Hardness as $CaCO_3$	pH	Specific conductance (micromhos at 25° C)	Temperature (° F)
12N 3W 34-2	M	11-28-51	7.7	6.1	88	28	8.8	1.0	318	70	2	0.0	4.4	434	335	7.8	540	58.8
34-2	M	9-26-52							283	45	4				320		670	57.2
34-5	M	1- 5-46	7.2	.5	73	28	46		333	96	16	.6		438	296			
34-5	M	8-11-48		.4							14				350			
34-5	M	11- -50		.6					255						245	8.0		
34-6	M	1- 5-46	8.8	.8	82	29	30		351	89	8	.5		432	325			
34-6	M	11- -50		1.2					295						355	7.9		
34-6	M	11-28-51	9.8	2.3	104	29	35	2	339	161	2	.3		566	380	7.8	555	48.9
34-6	M	9-26-52							366	80	8				340		750	51.0
34-6	M	3-17-54							393	93	9				315		800	51.4
34-6	M	10-25-56							380	90					365		770	52.1
34-7	M	3- 6-22	13		82	25	608		293	194	840			2,038				
34-7	M	4- 3-24	8.8		60	21	314		296	145	372			1,051				
34-7	M	11-28-51	6.8	1.1	66	25	242	10	273	148	300	.2	0	950	270	7.7	1,240	54.2
34-7	M	9-26-52							261	145	300				270		1,600	54.6
34-7	M	3-17-54							268	145	290				215		1,600	54.5
34-7	M	6-26-59	11	1.1	68	19	253	5.5	278	150	285	.1	0.0	872	250	7.6	1,600	
35-2	M	11-28-51	12	11	124	50	11	1.2	454	123	27	.1	0	662	515	7.7	645	54.7
35-2	M	9-26-52							430	108	24				500		850	56.5
35-5	U	4-17-59	8.5	.1	74	17	11	7.3	269	51	7	.1	4.0	311	255	7.5	538	45.6
36-1	M	10-12-54	5.0		142	38	52		346	200	57	.0	63	840	512	7.5	1,000	56.5
11N 3W 2-16	M	11-28-51	12	.4	60	29	33	2.0	334	55	6	.3	0	362	270	7.8	525	50.1
2-17	M	9-26-52							334	53	6				260		650	50.5
2-19	M	3-17-54							322	58	5				230		680	50.5
2-26	M	11-28-51	9.0	1.6	128	34	6	1.0	417	117	7	.1	0	546	460	7.3		49.8
2-26	M	9-26-52							434	75	5				440		800	50.6
3-1	M	5-11-46		1.8							11				480			
3-2	M	7-15-54		.3							12				490			
3-7	M	12-15-27	16	1.2	126	32	25		274	257	5			678	445			
3-7	M	5- 7-30	11	1.1	121	32	37		270	255	17			632	432			
3-7	M	1- 5-46	7.2	.5	115	30	34		312	205	11			580	410			
3-7	M	10-10-49		.9							12				410			
3-7	M	11-28-51	9.8	1.3	114	33	32	1.7	303	212	11	.1	.0	600	420	7.8	770	50.7
3-7	M	9-26-52							312	223	11				420		830	50.8
3-8	M	2-25-31	15	1.6	135	35	30		287	278	16				478			
3-8	M	2-25-31	39	5.6	147	37	19		288	288	16				515			
3-8	M	1- 5-46	9.6	1.3	106	30	32		325	170	11	.4		552	390			
3-8	M	6-15-49								125	11				380			
3-8	M	12- 9-49		1.2							10				320			

3-8	M	11-28-51	10.2	1.3	92	28	30	2.1	327	125	10	.3	.0	460	345	7.8	617	51.3
3-8	M	9-26-52							329	117	10				340		760	51.4
3-8	M	3-17-54							322	130	10				305		750	51.4
3-8	M	10-25-56							320	115					340		750	51.7
3-8	M	6-26-59	15	1.4	96	28	28	1.4	330	120	9	.1	1.0	446	350	7.3	700	
3-9	M	11-21-46	9.6	1.2	122	31	20		275	230	8	.3		579	443			
3-9	M	12- 9-49		1.9							17				480			
3-9	M	11-28-51	10	2.0	132	33	34	2	287	265	14	.3	0	690	465	7.8	645	50.4
3-9	M	9-26-52							292	285	14				464		900	50.6
3-9	M	3-17-54							290	280	12				440		950	50.8
3-9	M	10-25-56							295	250					450		940	50.8
3-9	M	6-26-59	16	1.5	127	32	29	1.6	295	250	32	.2	0	704	451	7.4	940	
3-12	M	4- 8-46		1.8							2				300			
3-18	L	10-17-56		1.5							15				444	7.2		
3-18	M	10-25-56							290	220					425		865	50.8
3-18	M	6-26-59	16	1.5	122	26	30	1.3	275	225	10	.1	1.0	590	410	7.4	830	
3-20	M	11-28-51	8.1	2.5	108	35	7	1.2	372	83	27	0	1.5	590	412	7.6	665	54.8
3-20	M	9-26-52							383	52	27	0			400		800	57.4
4-3	M	12-15-54		2.2							15				495			
4-5	L	10-17-56		2.5							15				470	7.3		
4-5	M	10-25-56							280	260					455		950	50.9
4-5	M	6-26-59	15	1.7	122	29	33	1.6	292	240	11	.2	0	636	430	7.5	890	
5-3	M	10-13-54	13	.4	50	27	27		322	19	5	.3	0	330	236	8.2	560	
17-1	M	10-13-54	13	2.8	66	34	4		344	17	4	0	0	330	304	7.9	560	57

TABLE 6.—*Concentrations of phenol in ground water sampled at Alma, Mich.*

[Analyst: M, Michigan Department of Health; U, U.S. Geological Survey]

Source of Sample	Date sampled	Analyst	Concentration (ppm)
Well, 12N 3W 34-6 (station 4)	12-11-49	M	0.05
Boring, 7 ft deep, 30 ft south of oil-refinery-waste pit.	12-21-49	M	200
Boring, 7 ft deep, 30 ft west of oil-refinery-waste pit.	12-21-49	M	300
Boring, 7 ft deep, 30 ft north of oil-refinery-waste pit.	12-21-49	M	10
Boring, 7 ft deep, 30 ft east of oil-refinery-waste pit.	12-21-49	M	10
Well 11N 3W 3-7 (station 1)	12-28-49	M	.00
Well 11N 3W 3-8 (station 2)	12-28-49	M	.00
Well 11N 3W 3-9 (station 6)	12-28-49	M	.00
Well 11N 3W 3-8 (station 2)	8-18-59	U	.001
Well 12N 3W 34-6 (station 4)	8-18-59	U	.003
Well 12N 3W 34-1	8-26 59	U	.000
Well 12N 3W 34-3	8-26-59	U	.012
Well 12N 3W 34-4	8-26-59	U	.029
Well 12N 3W 34-5	8-26-59	U	.004