HYDROLOGICAL STUDIES OF THE SAGINAW FORMATION IN THE LANSING, MICHIGAN AREA - 1962

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ABSTRACT

HYDROLOGICAL STUDIES OF THE SAGINAW FORMATION IN THE LANSING, MICHIGAN AREA - 1962

by Assadolah Firouzian

The purpose of this investigation was to study the hydrological characteristics of the Saginaw formation in the Lansing, Michigan area. The water-bearing beds of sandstone in the Saginaw formation are the principal source of water for the greater Lansing area including the cities of Lansing and East Lansing, Michigan State University, industrial plants and also surrounding townships. The Saginaw formation is the bedrock formation in the area and is overlain by Pleistocene glacial deposits.

By comparing the 1945 and 1962 piezometric maps, it was found that the piezometric surface has declined as much as 90 feet since 1945. The main reason for the decline is the increase in the rate of pumpage in the area. This is further indicated by the fact that the deepest portions of the cones of depression are located in the areas where the ground water pumpage is maximum. The average daily pumpage in 1945 was 17 million gallons per day, while the daily average pumpage in July 1962 was 30 million gallons per day in the problem area.

The average transmissibility of the Saginaw formation as determined by flow net analysis on the basis of 1962 piezometric map is 23,000 gallons per day per foot.

The study showed that the aquifer is recharged from the Grand River at the rate of 3 million gallons per day. The average recharge from precipitation into the aquifer is estimated at 4.8 inches per year which is equivalent to 28 million gallons per day based on the recharge area of an estimated 120 square miles.

The amount of water discharged by pumpage is presently balanced by the amount of water recharged into the area. Thus, the cone of depression should remain static if the pumpage is continued at its present rate.

HYDROLOGICAL STUDIES OF THE SAGINAW FORMATION IN THE LANSING, MICHIGAN AREA - 1962

By

Assadolah Firouzian

A THESIS

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TABLE OF CONTENTS

LIST OF FIGURES

* Figures found in back pocket.

LIST OF TABLES

Table

INTRODUCTION

Purpose and Scope of Study

The purpose of this research study was to define the hydrologic characteristics of the Saginaw formation in the Lansing, Michigan area. Special emphasis was given to determining the transmissibility throughout the area by flow net analysis. The study included the following objectives:

1. Construction of a new piezometric map of the problem area.

2. Determination of coefficients of transmissibility by flow net analysis.

3. Determination of changes in the piezometric surface since 1945.

4. Determination of recharge to the aquifer by flow net analysis.

Previous Investigation

In order to study the general ground water conditions and determine the quantity of water available in the Lansing area, W. T. Stuart (1945) of the U. S. Geological Survey prepared the first piezometric map of the area in 1945. The study was made because the heavy draft of ground water for domestic and industrial uses had caused a drop of water level at that time. His piezometric map of the area showed that ground water flow was toward Lansing from all directions, the greatest slope being from the south with less slope from the east and north indicating that much more water was flowing toward Lansing from the south than from the east or north.

According to Stuart's calculations the average rate of inflow to the area at the time of his study was from 5 to 9 million gallons per day. He found that the average daily withdrawal of less than 8.5 million gallons a day prior to 1930 did not cause a noticeable decline of the water level in the aquifer since the withdrawal was about equal to the inflow to the area. However, he showed that due to increased pumpage (18 million gallons a day in 1945), the water level, by 1945, had dropped from 12 to 40 feet below the 1930 level. According to Stuart, the total daily pumpage was almost twice the inflow to the area. This indicated that water had to be taken out from storage in order to provide for increased pumpage.

Studies of the general ground water conditions in this area have not been made since 1945.

DESCRIPTION OF THE PROBLEM AREA

Location and Extent of Problem Area

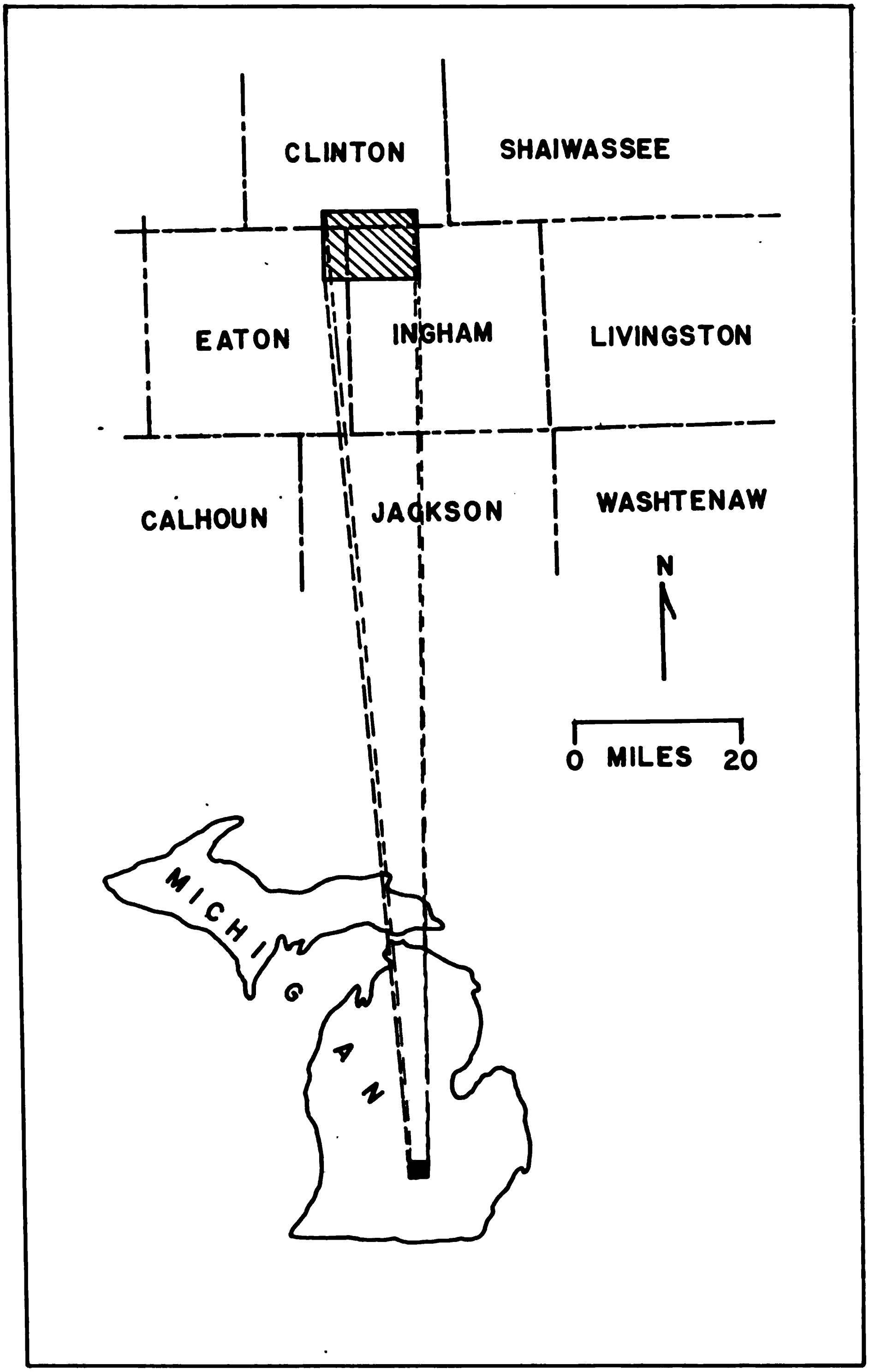
The Lansing area is located in the south-central part of the Southern Peninsula of Michigan (Figure 1). It includes the Cities of Lansing and East Lansing, Lansing and Meridian Townships in Ingham County, Watertown and DeWitt Townships in Clinton County, and Delta Township in Eaton County.

The piezometric surface in the Saginaw formation was defined for all of Ingham County and portions of Ionia, Clinton, Shiawassee, Livingston, Eaton, Calhoun, and Jackson Counties (Figure 2).

Geology of the Area

Surface Geology

The glacial drift which covers the rock surface of the Southern Peninsula is the surface formation in the Lansing area. It consists chiefly of a heterogeneous mass of boulders, cobbles, and pebbles in a sandy or clayey matrix. It was deposited by the Saginaw lobe of the Wisconsin glaciation which moved southwestward from Canada into the Southern Peninsula of Michigan.



LOCATION OF AREA OF INVESTIGATION

FIGURE I

Recessional moraines are the most characteristic surface feature of the area. They are belts of undulating topography which were formed at places where the edge of the melting ice held a nearly constant position for a long period of time. Two moraines that are a part of the West Branch morainic system cross the Lansing area (Leverett and Taylor, 1915). One is the Grand Ledge moraine; the other is the Lansing moraine. The Grand Ledge moraine is more strongly developed. It extends southwestward from Lake Lansing to the campus of Michigan State University and then northwestward across the northern part of the problem area. The Lansing moraine passes about two miles south of Grand Ledge to the southern part of the Lansing area where it is breached by the Grand River and Sycamore Creek. The area between the two moraines consists of ground moraine; the southern part of the Lansing area is also composed of ground moraine.

Belts of outwash deposits occur along the Grand and Cedar Rivers.

Subsurface Geology

The glacial deposits of the Lansing area rest directly upon rocks of Pennsylvanian age. Winchell (1861) divided the Pennsylvanian system into the Parma sandstone, the "Coal Measures", and the Woodville sandstone. Lane (1901) introduced the term Saginaw series to replace the term "Coal Measures" used by Winchell. The classification of Parma, Saginaw, and Woodville has continued to be used to the present time with some modification of the units included in the

Saginaw and Woodville formations.

Kelly (1940) included the Woodville sandstone with the Eaton and Ionia sandstones in the Grand River group overlying the Saginaw formation. The main water-bearing beds of the problem area are beds of sandstone in the Saginaw formation. The lowermost beds of the water-bearing sandstone may be the Parma sandstone. Stuart (1945) used the term "Pennsylvanian sandstone" for the Saginaw formation in his report.

The Paleozoic sediments below the Pennsylvanian rocks consist of about 8000 feet of sandstone, limestone, dolomite, shale, and evaporites ranging from Cambrian to Upper Mississippian age (Dott, Murray, Grove, 1954). The formations below the Saginaw generally are of low permeability or impermeable. In the problem area they contain water which is highly mineralized (Stuart, 1945).

Parma Sandstone

The name Parma sandstone was proposed by A. Winchell (1861) for a "White, or slightly yellowish, quartzose glistening sandstone, containing occasional traces of terrestrial vegetation". The Parma sandstone lies below the micaceous sandstones, shales, and coal beds of the Saginaw group. It directly overlies the Bayport limestone and is usually the basal member of the Pennsylvanian system in Michigan.

The Parma is a white quartzose sandstone, coarse to conglomeratic. It is cleaner and better cemented than the overlying Saginaw formation.

The thickness of the Parma varies from 0 to 220 feet in the area (Kelly, 1940).

Saginaw Formation

According to Kelly (1940): "The Saginaw group directly overlies the Parma sandstone wherever that formation is present. It is composed of material of fresh water, brackish water, and marine origin and consists of sandstones, shales, coal, and limestones".

The sandstones of the Saginaw group are frequently lenticular, nonpersistent, and have irregular bedding. Most of the beds exposed at the surface are less than 10 feet thick. In some places sandstone beds are thicker and make up a larger part of the Saginaw section. Examples of such places are to be noted in the vicinity of Lansing where beds of sandstone over 100 feet thick are reported from several wells.

The texture of the Saginaw sandstones is usually fine. Quartz is the principal constituent, but is associated locally with decomposed feldspar and usually with abundant white mica.

The sandstones contain less than one percent of heavy minerals. Tourmaline and zircon are the most common heavy minerals. Fossils in the sandstone are limited to plant fragments. These characteristics indicate a terrestrial origin for the sand in which shifting currents with rapidly alternating periods of erosion and deposition played a major part.

Kelly (1940) divides the shales of the Saginaw group into three subdivisions: (a) shales with considerable sandy material; (b) shales with little or no sandy material; and

(c) underclays. The sandy shales possess many characteristics in common with sandstones. Plant fossils are often found in these shales and probably had a terrestrial origin.

The shales of the second group are ordinarily dark in color. They may or may not be limy. The limy shales are regularly bedded. The non-limy shales vary in structure from very fissile to almost structureless layers up to 3 feet or more in thickness.

According to Kelly (1940) shales of the third group, the underclays, are structureless white to light gray beds of claylike or sandy texture. They often occur below coal seams and commonly contain irregular nodules of iron carbonate a few feet from the top.

The average thickness of the Saginaw group is 400 feet and the maximum reported is 535 feet (Kelly, 1940).

Hydrology of the Area

Drainage

The Grand River comprises the major drainage system of the area. It enters the area from the southwest and flows north through Lansing and then west to Grand Ledge. Its drainage area above Lansing is 1230 square miles which represents 22 percent of its total drainage area. Cedar River and Sycamore Creek are tributaries of the Grand River in the area. The Cedar River flows west through the center of the area and enters the Grand at Lansing. Its drainage area above East Lansing is 355 square miles. Sycamore Creek flows northwest from Mason and joins the Cedar River at Lansing.

The Grand River drainage basin has gently undulating topography and predominantly sandy loam soil. Deposits of sand and gravel occur along the major streams. The beds and banks of the streams consist of the same permeable material.

The portion of the surface flow which is derived from ground water is called base flow. The base flow for the Grand and Cedar Rivers has been estimated from flow duration curves of the Surface Water Section of the U. S. Geological Survey. According to this estimation, the amount of base flow for the Grand River at Lansing is 0.26 cfs per square mile which is equivalent to 3.52 inches of precipitation per year.

The amount of base flow for the Cedar River at East Lansing is estimated to be 0.16 cfs per square mile which is equivalent to 2.17 inches per year.

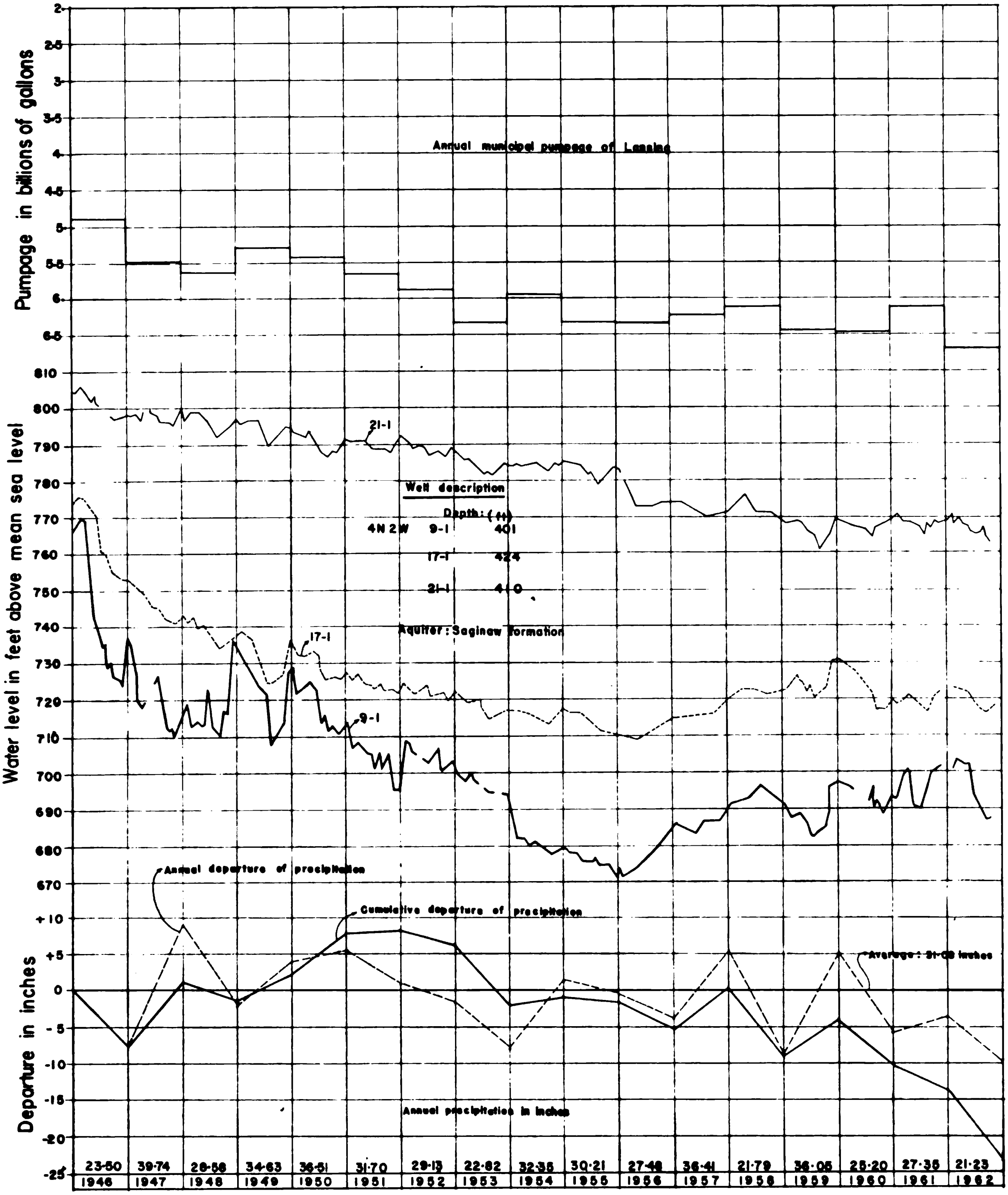
Precipitation

Precipitation is one of the major factors that controls the general ground water condition in any area. It controls directly or indirectly the amount of recharge to the Saginaw formation. Ground water levels are affected by the quantity, time of occurrence, intensity, and nature of the precipitation.

According to the U. S. Weather Bureau, precipitation in the area of investigation is fairly well distributed throughout the year. The wettest months of the year are May and June. Snowfall for Lansing is generally fairly light.

The annual precipitation for the area in 1962 was 21.23 inches which was 9.85 inches below the average of 31.08 inches.

The variation of precipitation from year to year is shown in Figure 3. Annual precipitation, annual and cumulative departure of precipitation from 1946 to 1962 are also shown in Figure 3 and in Table 1. The cumulative departure of precipitation is determined by taking the difference between annual precipitation and the average annual precipitation and then adding these differences algebraically. The average annual precipitation as determined by the U. S. Weather Bureau is the average of 10 years annual precipitation. This value for the last 10 years in the Lansing area is 31.08 inches.



Hydrographs of 3 selected wells tapping Saginaw formation
showing water level fluctuation, municipal pumpage, and departure of precipitation at Lansing, 1946-62

FIGURE 3

Table 1.--Annual Precipitation, Cumulative and Annual Departure of Precipitation

Years	Annual Precipitation in Inches	Annual Departure of Precipitation in Inches	Cumulative Departure of Precipitation in Inches
1946	23.50	-7.58	- 7.58
1947	39.74	+8.66	+ 1.08
1948	28.58	-2.50	- 1.42
1949	34.63	+3.55	+ 2.13
1950	36.51	+5.43	+ 7.56
1951	31.70	+0.62	+ 8.18
1952	29.13	-1.95	+ 6.23
1953	22.82	-8.26	- 2.03
1954	32.35	+1.27	- 0.76
1955	30.21	-0.87	- 1.63
1956	27.48	-3.60	- 5.23
1957	36.41	+5.33	+ 0.1
1958	21.79	-9.29	- 9.19
1959	36.05	+4.97	- 4.22
1960	25.20	-5.88	-10.10
1961	27.35	-3.73	-13.83
1962	21.23	-9.85	-23.68

METHODS OF INVESTIGATION

Collection of Data

In order to make the general piezometric surface of the greater Lansing area, it was necessary to locate as many wells as possible for which water-level data were available. Most of the data on wells and their static water levels were obtained from well drillers who kindly let us use their files. Records of Federal, State, and private agencies also were reviewed.

Approximately 250 wells in 53 townships in Ingham, Eaton, Clinton, Ionia, Shiawassee, Jackson, Livingston, and Calhoun Counties were checked. Wherever it was possible, the static water levels of the wells were measured; otherwise static levels obtained from well drillers were used. The elevation of the static water level above mean sea level was determined from Federal and State bench marks. For wells where there were no nearby bench marks, the elevation was determined from topographic maps. The accuracy for this type of elevation determination is estimated to be ± 5 feet. The tools used for determining the water level elevation were plane table with tripod, alidade, and rod.

The Flow Net: Its Development and Application

In analyzing ground water problems, a graphical representation of the flow pattern is of considerable assistance and sometimes provides the only means of solving those problems for which mathematical solution is not practicable.

The first significant development in graphical analysis of flow patterns was made by Forchheimer (Ferris, 1955).

A "flow net", which is a graphical representation of the flow pattern, is composed of two families of curves. One family represents the flow lines or paths followed by a particle of water as it moves through the aquifer in the direction of decreasing head. Intersecting the flow lines at right angles is a family of curves termed equipotential lines which represent contours of equal head in the aquifer.

The change in potential or drop in head between two equipotential lines in an aquifer divided by the distance traveled by a particle of water moving from a higher to a lower potential, determines the hydraulic gradient.

The movement of a water particle is controlled by the flow path that involves the least work (i.e., the shortest possible path between the two equipotential lines), therefore, the direction of water movement is everywhere normal to equipotential lines.

By considering the above mentioned principles, a flow net is an orthogonal pattern of squares. In ground water problems the flow net is drawn by trial and error so that equipotential lines fit the water level measurements and at the same time form a system of squares with intersecting flow lines. It should be recognized that in flow fields involving curved paths of flow, the elements of the net are curvilinear, so they are not true squares; however, the corners of each "square" are right angles.

Determination of Discharge and Transmissibility From a Flow Net

The discharge through any path of the flow net may be obtained by application of Darcy's Law, in which

(1) $Q = PIA$

Q = Discharge

P = Permeability

A = Area

I = Hydraulic gradient.

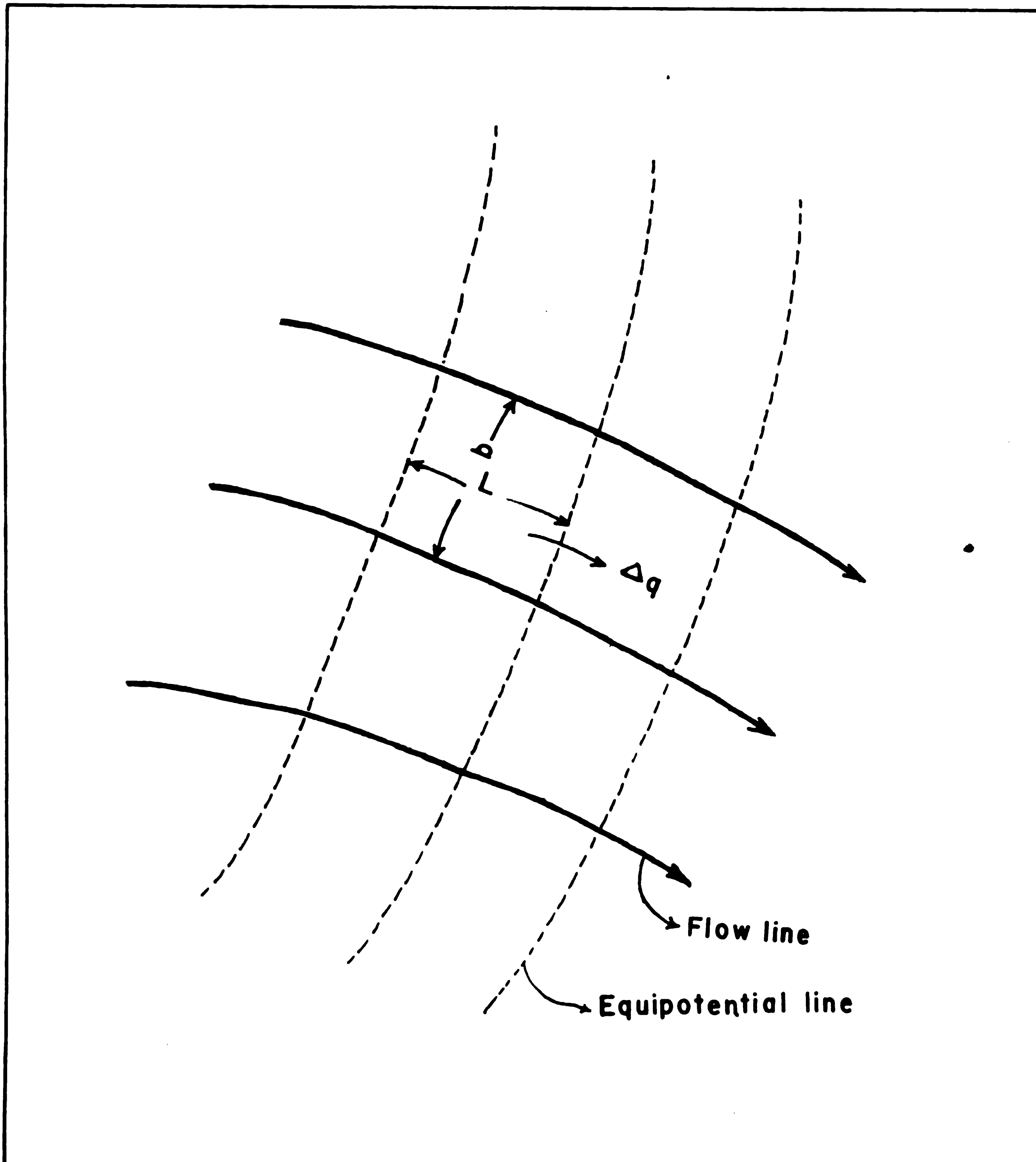
By considering the flow through a unit thickness and applying Darcy's formula, the discharge for one flow channel through the net will be (Figure 4):

(2) $\Delta q = PIb$

where Δq gives the flow occurring between a pair of adjacent flow lines (one flow channel) and b is the spacing of the flow lines.

If L represents the spacing between equipotential lines and h represents the drop in head, then equation (2) becomes

(3) $\Delta q = P\Delta h \frac{b}{L}$.



SCHEMATIC DIAGRAM OF A FLOW NET

FIGURE 4

As a flow net is designed to be a system of "squares", the ratio b/L is equal to unity and the same potential drop occurs across each "square". It follows from equation (3) that the same increment of flow, Δq, occurs between each pair of adjacent flow lines. So if there are n_f flow channels, the total flow, q, through a unit thickness of the aquifer is given by:

(4) $$q = n_f \Delta q.$$

If there are n_d potential drops, the total drop in head, h, is given by:

(5) $$h = n_d \Delta h.$$

Substituting in equation (4) the values of Δq and Δh given by equations (3) and (5), results in:

(6) $$q = \frac{n_f}{n_d} Ph.$$

Considering that q represents the total flow through a unit thickness of the aquifer, the equation for total flow through the full thickness of the aquifer will be:

(7) $$Q = \frac{n_f}{n_d} Phm$$

where Q = flow through the full thickness of the aquifer in gallons per day

n_f = number of flow channels

n_d = number of potential drops

P = coefficient of permeability of the aquifer material, in gallons per day per square foot

m = saturated thickness of aquifer, in feet

h = total potential drop in feet

Pm = transmissibility of the aquifer, in gallons per day per foot.

By substitutinq T for Pm, equation (7) can be written as:

(8) $$Q = n_f T \frac{h}{n_d}$$

and equation (8) in turn can be written as:

(9) $$T = \frac{Q}{n_f \frac{h}{n_d}}.$$

Knowing Q, the transmissibility can be determined from the flow net by using equation (9).

Application of Flow Net in the United States

The flow net has not been used extensively for analyzing ground water flow problems in this country. Apparently very few hydrologists have tried this method to determine its values and limitations.

Robert R. Bennett and R. Mayer (1952) used the flow net technique to analyze ground water problems in the Baltimore, Maryland area. According to their report, the transmissibility values obtained by flow net analysis were in close agreement with the ones determined by pump tests. In addition, they also determined the areal variation in transmissibility by flow net analysis. This is the great advantage of flow net analysis over a pump test.

The transmissibility determined from pump tests represents only a small portion of the aquifer. On the other hand, Bennett and Mayer have shown that the approximate values of transmissibility of a large part of the aquifer can be obtained by the flow net technique.

The values and limitations of flow net analysis will be better understood when more hydrologists use this method to study ground water problems related to transmissibility.

Flow Nets of the Problem Area

A piezometric or ground water contour map of the area under study must be prepared before drawing a flow net.

The piezometric surface is the surface which coincides with the static level of water in the aquifer or with the height to which water will rise in a well or piezometer in an artesian aquifer.

Two flow nets were made for the problem area (Figures 6 and 8). One was made on the basis of a 1945 piezometric map prepared by W. T. Stuart of the U. S. Geological Survey (Figure 5). The other was made on the basis of a map of the piezometric surface during the summer of 1962 which was prepared as a part of this investigation (Figure 7). The piezometric map of 1962 is based on the elevation of static water levels in observation wells and on the static water levels reported by well drillers for other wells in the problem area. For the observation wells equipped with continuous water-level recording gages, the reading on May 31, 1962 was taken as the static level, and for the ones measured quarterly, the closest reading to May 31 was selected as the static level. The May 31 reading is the average of the daily low and daily high of the water level for each observation well. In order to determine the magnitude of the water-level fluctuation for May 31, the daily average water level from May 30 to June 1, 1962 was determined from the hydrographs of five observation wells. The range of fluctuation of water level was found to be from ± 0.03 to ± 0.2 feet per day (Table 2).

For the other wells, the static water level measurement made by well drillers after the completion of the well was used regardless of the date.

On both piezometric maps of the area the solid contours are the ones that were used for flow net analysis. To simplify drawing the flow nets, the dashed contours were not used. This did not affect the general pattern of the flow nets.

The main objective in drawing the flow net was to make a system of "squares" in which the distances between the equipotential lines were equal to distances between the flow lines.

Table 2.--Fluctuation of Water Level in Observation Wells From May 30 to June 1, 1962

Well Number	Water level below LSD* in feet. May 30, 1962	Water level below LSD in feet. May 31, 1962	Water level below LSD in feet. June 1, 1962	Fluctuation in feet per day
16-1	61.8	61.9	62.03	0.06
17-1	143	142.7	143.1	0.03
9-1	143	143	143.6	0.2
21-1	68.1	68.1	68.45	0.1
23-2	5.42	5.42	5.27	0.05

* Land Surface Datum

HYDROLOGY OF THE AQUIFER

Transmissibility

The coefficient of transmissibility can be expressed as the quantity of water in gallons per day that flows through a strip of the aquifer 1 mile wide under a hydraulic gradient of 1 foot per mile. It is the product of the field coefficient of permeability times the thickness of the saturated part of the aquifer. The coefficient of permeability as defined by Meinzer is 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 permeability of a sandstone aquifer is controlled by: the size of the grains, the shape of the grains, the degree of sorting of the grains, and the degree of cementation or lithification and packing. Fracturing and bedding are also controlling factors.

There are several mathematical formulas based on the condition of the water table or piezometric surface around a pumped well that can be used to determine the coefficient of transmissibility. These formulas are of two basic types - equilibrium and non-equilibrium. According to the equilibrium formula which is also known as the Theim formula, the pumping must continue at a uniform rate for a sufficient time to approach a steady state condition, that is, one in which the drawdown changes negligibly with time.

The basic non-equilibrium formula, or Theis formula, is based on the assumption that as water must come from a reduction of storage within the aquifer, the head will continue to decline as long as the aquifer is infinite; therefore, no steady flow exists. The rate of decline, however, decreases continuously as the area of influence expands.

These formulas are based on ideal conditions that are seldom found in nature. It is assumed that the aquifer has infinite areal extent; that it is homogeneous and isotropic (transmits water equally in all directions); that it is bounded at the top and bottom by impermeable material; that it has a uniform thickness; that water is released instantaneously from storage with a decline in head. It is further assumed that the discharging well is of infinitesimal diameter, completely penetrates the aquifer, and the flow of the water toward the well is radial or two dimensional.

Determination of Transmissibility By Flow Net Analysis

One of the main objectives of this research was to determine the coefficients of transmissibility (T) and the variation in T throughout the area. Values of T obtained in the past in this area are based on pump test analysis using equilibrium and non-equilibrium formulas.

Stuart used an average value of 23,000 gpd/ft for T when he calculated the amount of inflow into the area. He indicated this value was the average obtained by pump tests in different parts of the area.

The method used to determine the coefficient of transmissibility and its areal variation in this investigation is a flow net analysis. This method is based on the following formula described in detail above:

$$T = \frac{Q}{n_f \frac{h}{n_d}}$$

The values of n_f and $h/_{n_d}$ can be obtained directly from the flow net; Q is the amount of discharge or pumpage.

In order to determine the areal variation of transmissibility, each flow net was divided into sub-areas on the basis of the general pattern of flow lines to the areas of pumpage. In the computations the average daily pumpage in gallons per day, Q, during the month of July was used for each sub-area.

Determination of Transmissibility From the 1945 Flow Net

A flow net was constructed from the 1945 piezometric surface as defined by Stuart (Figure 5). This flow net was divided into 4 sub-areas marked A, B, C, and D as shown in Figure 6. The pumpage data for each sub-area was taken from the data collected by Stuart in 1945.

Using values of n_f and $h/_{n_d}$ obtained directly from the flow net, the transmissibility was determined for each sub-area. For example, for sub-area A: average daily pumpage, Q, was 5,010,385 gallons a day, the number of flow paths, n_f, was

23, and the head loss between equipotential lines, $h/_{n_d}$, was 10 feet; thus:

$$T = \frac{Q}{n_f \; h/_{n_d}} = \frac{5010385}{230} = 21784 \text{ gpd/ft.}$$

The values of transmissibility of other sub-areas were determined in the same manner and are shown in Table 3.

Determination of T From 1962 Flow Net

The 1962 flow net was divided into five sub-areas marked as A, B, C, D, and E as shown in Figure 8.

The pumpage data for these sub-areas were obtained from the Lansing Board of Water and Light, East Lansing Water Superintendent, and Michigan State University Power Plant Superintendent.

For each sub-area the values of n_f and $h/_{n_d}$ were taken directly from the flow net, and the transmissibility for each sub-area was determined from equation 9. For example, in sub-area A: average daily pumpage, Q, was 15,852,193 gallons per day; the number of flow paths, n_f, was 58; and the head loss, $h/_{n_d}$, was 10 feet; thus: $T = \frac{15,852,193}{580} = 27,331$ gpd/ft.

The transmissibility values for other sub-areas are shown in Table 4. The average transmissibility in the area was determined from the transmissibilities of the five sub-areas shown in Table 4.

This value is 23,628 gpd/ft which is approximately the value Stuart determined from pumping tests.

Table 3.--Coefficients of Transmissibility Determined From the 1945 Flow Net

Subareas	Pumpage in gallons per day (Q)	Number of flow paths (n_f)	Head loss in feet $^h/_{n_d}$	Coefficient of transmissibility in gallons per day per foot (T)
A. Northwest field, Maple St. field, Olds Drop Forge	5,010,385	23	10	21,784
B. Cedar St. field, Air Conditioning - Lansing Ice and Fuel, Atlas Drop Forge	4,052,729	33	10	12,281
C. Pennsylvania Riverside PM fields	6,026,639	40	10	15,066
D. MSU-East Lansing	952,000	10	10	9,520
Average				14,662

Table 4.--Coefficients of Transmissibility

Determined From the 1962 Flow Net

Subareas	Pumpage in gallons per day (Q)	Number of flow paths (n_f)	Head loss in feet $^h/_{n_d}$	Coefficient of transmissibility in gallons per day per foot (T)
A. Northwest well fields	15,852,193	58	10	27,331
B. Southeast well fields	5,785,967	30	10	19,286
C. East-Landale wells	524,645	3	10	17,488
D. East Lansing	1,688,000	10	10	16,880
E. MSU	2,972,551	8	10	37,156
Average				23,628

Discharge From the Aquifer

The discharge from the aquifer takes place in two ways: artificial discharge of ground water by pumpage and natural discharge of ground water either to rivers or evapotranspiration. The amount of discharge of ground water by pumpage can be measured much more accurately than the discharge to evapotranspiration and to the rivers.

Most of the ground water pumpage in the area was by the following:

1. Lansing Board of Water and Light
2. City of East Lansing
3. Michigan State University
4. Lansing Township
5. Oldsmobile Division of General Motors

To determine the average daily pumpage in the whole area, the total pumpage in each pumpage area was obtained for the month of July 1962. The daily average for each area was determined on that basis. The sum of these average daily pumpage in each area was considered to be the total average daily pumpage in the whole area. Table 5 shows the total, daily, and percent of pumpage with respect to the total for each area. Figure 1 also shows the total annual pumpage from 1946 to 1962.

The amount of ground water discharged to rivers (base flow) is estimated on the basis of a flow duration curve. According to this estimation, the amount of base flow is 0.26 cfs or 117 gallons per minute for Grand River and 0.16 cfs or

72 gallons per minute for Cedar River.

No data was available on the pumpage from private wells both in rural and urban sections of the problem area. However, according to Tri-County Planning Commission, 56,000 people in 9 townships in the Lansing area get water from private wells. Allowing 50 gallons per day per person, the total daily pumpage by private wells is estimated to be over 3 million gallons per day.

As is shown in Table 5, the total average daily pumpage in the area is more than 27 million gallons a day which is a 30 percent increase over the total daily pumpage of 17.6 million gallons per day in 1945. The Lansing Board of Water and Light pumps more than 20 million gallons daily or 74 percent of the total daily pumpage in the area.

A very noticeable increase was observed in the rate of pumpage for Michigan State University between 1945 and 1962. According to Stuart, the daily average pumpage for the University was 392,000 gallons per day in 1945. The daily average during July, 1962 was about 3 million gallons per day. This is an increase of 86 percent over 1945. The University pumpage has exceeded pumpage by the City of East Lansing.

Changes of Piezometric Surface Since 1945

A map of the piezometric surface on May 31, 1962 in the Lansing area is shown in Figure 7. This map was made on the basis of static water levels in observation wells.

Several factors such as variations in the rate of pumpage, changes in barometric pressure, recharge from different

Table 5.--Municipal and Industrial Pumpage

Pumping Areas	Total pumpage in July 1962 (gallons per day)	Daily average pumpage based on July 1962 (gallons per day)	Percent of pumpage with respect to total daily average pumpage
Lansing	623,000,000	20,096,774	74.06
East Lansing	52,321,000	1,688,000	6.21
MSU	93,397,600	2,972,551	10.92
Lansing Township	60,727,000	1,958,935	7.21
Olds Plant	13,479,000	434,806	1.60
Total	842,924,600	27,151,066	100.00

sources, and evapotranspiration cause periodic fluctuations of the piezometric surface.

The main factor in the decline of the piezometric surface has been the increase in the rate of pumpage. This fact becomes apparent when the 1945 piezometric map (Figure 5) and the 1962 piezometric map (Figure 7) are compared. By superimposing the two maps, the differences between contours on the two maps can be plotted. Figure 9 shows the decline of the piezometric surface from 1945 to 1962. The map shows that the piezometric surface has declined as much as 90 feet in the last 17 years.

The contours of decline of the piezometric surface show clearly the cones of depression developed around the pumping areas. The deepest part of these cones are in the areas where the largest amounts of ground water withdrawal are made. For instance, in the northern part of the area, as a result of heavy withdrawal of water from city wells, the piezometric surface has dropped more than 90 feet. In the west, due to heavy pumpage by Lansing Township and also the Oldsmobile plant, the piezometric surface has declined as much as 70 feet. The decline of 10 to 60 feet in the piezometric surface in the East Lansing and Michigan State University areas reflects the increased rate of pumpage in these areas.

The hydrographs of observation wells in the area of influence of pumpage show a similar decline in the piezometric surface shown in Figure 9.

Table 6 shows the decline of the piezometric surface in the observation wells affected by pumpage. The table gives the static water levels of May 1945 and May 1962 of selected observation wells. If no record of the static water level in May 1945 was available, the level in May 1946 or a later year is shown.

Table 6.--Decline in Piezometric Surface in Feet

(Elevations in feet above mean sea level)

Well Number	Location	Date	Elevation of static level	Date	Elevation of static level	Decline in feet	Decline in feet per year
4N 2W *9-1	N. Grand River & Josephine St.	5-1945	749	5-1962	685	65	3.8
4N 2W 17-2	Verlinden Ave.	5-1947	761	5-1962	723	34	2.2
4N 2W 21-1	Townsend St. & Olds Ave.	5-1945	800	5-1962	766	33	1.9
4N 2W 22-1	S. Pennsylvania Ave. & Grand Trunk Railroad	5-1945	790	5-1962	768	22	1.3
4N 2W 24-1	Michigan State University	5-1945	825	5-1962	770	55	3.2
4N 2W 28-1	W. Mt. Hope Ave. & Davis Ave.	5-1948	817	5-1962	796	21	1.5
4N 2W 16-1	S. Cedar & Jay Street	5-1946	781	5-1962	770	11	0.68

* The first number shows section number and the second number the well number in that section.

Recharge

Recharge is the process by which a ground water reservoir is replenished either naturally or artificially. Most aquifers are recharged naturally by precipitation. This primarily occurs in the spring and fall. In the spring, before the growing season commences, rainfall and snowmelt add large quantities of water to the ground water reservoirs. In the fall, after the end of the growing season, evapotranspiration demands are drastically reduced and much of the rainfall is recharged to ground water reservoirs.

One of the principal factors controlling recharge from precipitation is the air temperature. This factor is important since it determines the length of the growing season and therefore, the amount of rainfall lost by evapotranspiration, thus unavailable as a source of recharge. Temperature also directly affects the amount of recharge derived from ice and snow by controlling the evaporation.

The configuration of the land surface has some effect on the amount of ground water recharge. On steep slopes precipitation runs off more rapidly than from a flat surface. The areal extent of the outcrops and subcrops of the water-bearing sandstones also is important as more water may enter a formation if its area of intake is large. In the case of artesian aquifers, the permeability and thickness of the confining beds are also the important controlling factors of recharge. The permeability of the surface materials also controls the amount of recharge.

According to Stuart (1945), recharge to the sandstone aquifers in the Lansing area takes place in three ways: (1) direct recharge from surface water in contact with the sandstones; (2) downward and lateral percolation where the sandstones are in contact with the saturated sands and gravels of the glacial cover; and (3) the vertical percolation through the poorly permeable clays and shales by means of existing joint systems and solution channels within the clays and shales.

The greatest amount of recharge to the aquifers in the greater Lansing area is by means of downward and lateral percolation in areas where the sandstones are in contact with the saturated portions of the glacial material. It is believed that the depressions eroded in the Pennsylvanian bedrock are filled with water-bearing sands and gravels that are recharged by the downward movement of precipitation. Thus, the sandstone aquifers are recharged when the piezometric surface is lowered below the overlying saturated sands and gravels.

Direct recharge of the aquifers in the area takes place where beds of sandstones crop out at land surface. Stuart indicates that the formation is recharged directly near Grand Ledge and in some places along the Grand and Cedar Rivers and Sycamore Creek.

The flow nets of the area (Figures 6 and 8) show that the aquifer is recharged from the Grand River in sub-areas E of Figure 6 and F of Figure 8. The pinching of piezometric contours and closeness of flow lines in sub-areas E and F and also the presence of sandstone outcrops and permeable drift overlying the sandstone along this section of the river indicate the direct recharge into the aquifer.

The amount of recharge from the river can be obtained from these flow nets by using equation (9), $Q = n_f \times T \times h/n_d$. The values of n_f and h/n_d were taken directly from the flow net of each sub-area. Transmissibility for the sub-areas E and F was determined as the average transmissibility of the adjacent sub-areas. The transmissibility of sub-area E of Figure 6 is the average of the transmissibilities of sub-areas B and C of Figure 6. The transmissibility for the sub-area F of Figure 8 was determined from the average for sub-areas A and B of Figure 8. The results of the determination of recharge from the Grand River for both sub-areas are shown in Table 7.

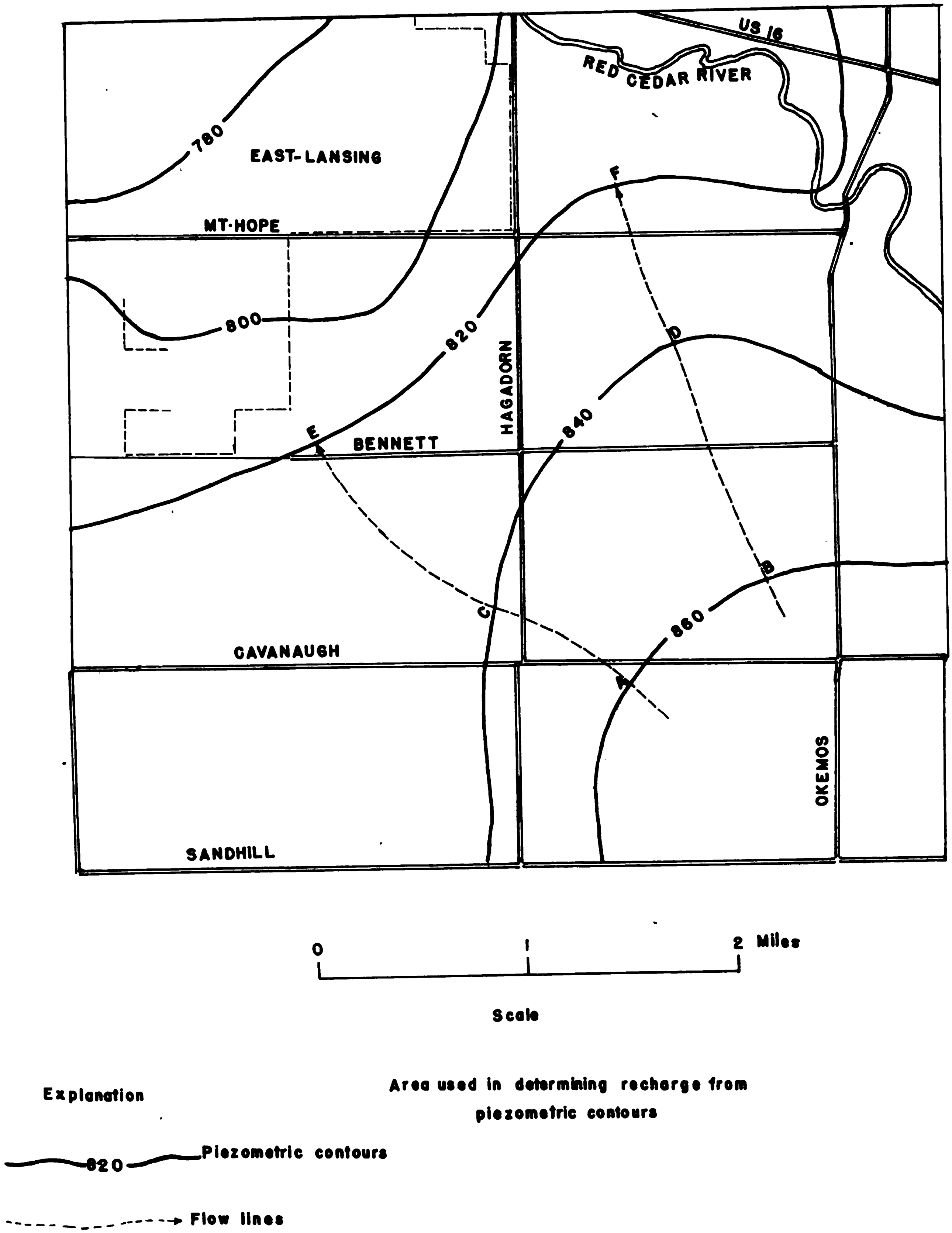
Table 7.--Determination of Recharge From Grand River Into Aquifer

Subareas	Number of flow paths (n_f)	Head Loss in feet $\frac{h}{n_d}$	Transmissibility in gallons per day per foot (T)	Recharge in gallons per day (Q)
E (Figure 6)	22	10	13,673	3,008,060
F (Figure 8)	12	10	23,308	2,796,960

Recharge From Precipitation

It was possible to estimate the quantity of water recharged to the ground water reservoir from precipitation by a study of the flow nets using the formula Q = TIL where

Q = quantity of water in gallons per day crossing each piezometric contour.



Area used in determining recharge from piezometric contours

FIGURE 10

T = transmissibility in gallons per day per foot

I = hydraulic gradient, in feet per mile

L = length of piezometric contour in miles.

This method is based on the principle that the volume of water increases as it passes through successive piezometric contours. To determine the recharge in gallons per day per square mile, the difference in the quantities of water crossing each two contours, $Q_2 - Q_1$, is divided by the area A between the contours. Area ABEF (Figure 10) was used to estimate the recharge. This area is bounded by flow lines AE, BF which cross the piezometric contours at right angles. Using the above formula the amount of ground water moving under contours AB, CD, and EF can be determined. The hydraulic gradients, I, and the lengths of piezometric contours, L, were determined from Figure 10. A coefficient of transmissibility of 23,000 gpd/ft (the average T determined from 1962 flow net) was used in all calculations. This value is also the average transmissibility determined by Stuart from pump tests.

Table 8 shows the results; the average amount of recharge is over 350,000 gpd/square mile which is equivalent to 7.6 inches of rain per year.

Using the same principle, the amount of recharge was estimated in the western part of the recharge area. As shown in Table 9 the average amount of recharge in this section is over 100,000 gpd/square mile which is equivalent to 2 inches of rain per year.

The above mentioned technique of recharge determination is based on the following assumptions: (1) that there

is no significant discharge to streams or wells from the recharge area; (2) that there is no recharge from streams into the recharge area; and (3) that transmissibility is constant throughout the recharge area.

Table 8.--Determination of Recharge

From Precipitation East of Recharge Area

(Meridian Township)

Contours	Length of contour line L (miles)	Hydraulic gradient I (ft/mile)	Quantity of water Q = TIL (gpd)	Section	Section area A (sq. miles)	Recharge $\frac{Q_2 - Q_1}{A}$ $\frac{\text{gpd}}{\text{sq. mile}}$
AB------	0.86	20	395,600	ABCD	1.1	372,181
CD------	1.4	25	805,000	CDEF	1.3	355,615
EF------	1.9	29	1,267,300			
Average						363,898

Table 9.--Determination of Recharge

From Precipitation in Western Part of Recharge Area

(Delta Township)

Contours	Length of contour line L (miles)	Hydraulic gradient I (ft/mile)	Quantity of water Q = TIL (gpd)	Section	Section area A (sq. miles)	Recharge $\frac{Q_2 - Q_1}{A}$ $\frac{\text{gpd}}{\text{sq. mile}}$
AB------	1.2	25	690,000	ABCD	0.39	117,940
CD------	1.3	25	736,000	CDEF	0.51	90,196
EF------	1.2	29	782,000			
Average						104,068

SUMMARY AND CONCLUSIONS

Transmissibility

The coefficients of transmissibility determined by flow net analysis are approximate values, but they show the areal variation in transmissibility. The 1945 flow net shows that the T ranges from 9,520 gpd/ft in the central part of the City of East Lansing to 21,784 gpd/ft in the northwestern part of the City of Lansing. The 1962 flow net indicated a range in T from 16,880 gpd/ft in the northeastern part of the City of East Lansing to 37,156 gpd/ft in the Michigan State University well field in the southeastern part of the area. The differences in transmissibility determined from the 1945 and 1962 flow nets result in part from the fact that different areas are involved in the two flow nets. For example, the well fields used by Michigan State University and the City of East Lansing in 1945 are several thousand feet from the well fields operating in 1962. The flow net of 1962 includes a larger area than the 1945 flow net. It also should be noted that the 1945 flow net is based on data collected about 17 years ago and it is impossible to check the accuracy of all this data. The differences in transmissibility are due in part to the limitations of the flow net technique which provides only approximate answers as do all quantitative field hydrologic methods.

The differences in transmissibility of the Saginaw formation in the problem area are due to differences in the thickness of Saginaw sandstones or a difference in the permeability of the sandstones resulting from variations in the sand-shale ratio. A correlation of geologic and lithologic changes with changes in transmissibility has not been attempted in this study.

Determining transmissibility by flow net analysis includes large parts of the aquifer, and eliminates or minimizes considerably the effect of local irregularities. It also prevents the errors commonly made in pump test interpretation. It is concluded that the coefficients of transmissibility determined by flow net analysis are more representative for the whole area than the ones determined by pump test technique.

Flow net analysis can be made by using existing data such as was available in Stuart's report of the Lansing area.

Decline in Piezometric Surface

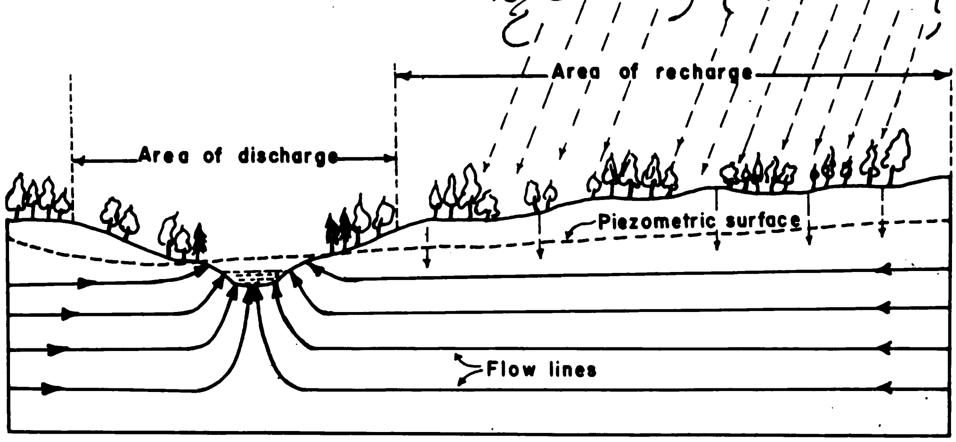
The study showed that the piezometric surface has dropped as much as 90 feet since 1945. Although the increased rate of pumpage has been the main factor in the decline of the piezometric surface, there have been other factors which may account for part of the decline. As is shown in Table 1, the cumulative departure of precipitation has been -23.68 inches since 1945. In other words, precipitation has decreased 1.3 inches annually since 1945. This decrease in precipitation would have a detrimental effect on recharge to the aquifer which would result in decline of the piezometric surface.

The flow net analysis showed that in the section where the aquifer is directly recharged from the Grand River (Sub-area E of Figure 6 and sub-area F of Figure 8), the decline of piezometric surface has not been significant.

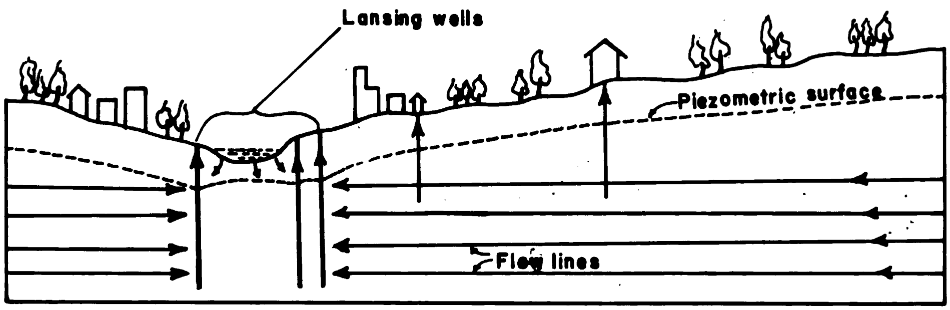
As a result of urban development and industrial expansion since 1945, more ground water has been intercepted by industrial and private wells; thus, less water has been available to city wells. This has contributed to the decline in the piezometric surface as has the pumpage by the City of Lansing. In other words, the decline in the piezometric surface in the Lansing area has not been due only to pumpage by city wells. Figure 11 shows diagrammatically the gradual decline in piezometric surface with respect to interception of ground water by private and industrial wells in the area. The upper part of the aquifer has been dewatered in the central part of the cone of depression which has developed in the Lansing area. The extent of dewatering could be determined from the relative position of the top of the aquifer with respect to the piezometric surface. This study was not made because of the lack of data.

Recharge

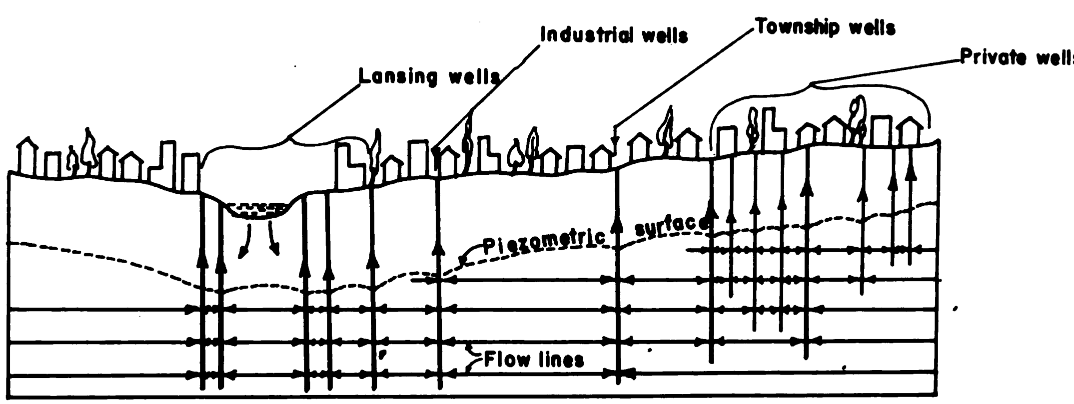
This study shows that the aquifer is recharged directly from the Grand River and indirectly from precipitation. Both the 1945 and the 1962 flow nets indicate that the river recharges the aquifer at the rate of about 3 million gallons per day. The recharge is induced as a result of the lowering of the piezometric surface below the water level in



A· Hydrologic system-Natural conditions



B· Hydrologic system-Moderate withdrawal of ground water



C· Hydrologic system-Extensive ground water development

DIAGRAMMATIC CROSS SECTIONS SHOWING HISTORY OF DECLINE IN THE PIEZOMETRIC SURFACE

FIGURE 11

the river. Increased pumpage in the area has been the main factor in the decline of the piezometric surface. The area of recharge to the cone of depression from precipitation was determined by analyzing the pattern of flow lines.

It is estimated that the area of recharge includes 120 square miles. This area is about 2.5 times the 46 square miles recharge area estimated by Stuart in 1945. The expansion of the recharge area is due to the gradual expansion of the cone of influence resulting from increased pumpage since 1945. According to calculations, the amount of recharge from precipitation is not uniform within the area of recharge. In the southeastern part of the area (Figure 10) the average recharge is estimated to be about 350,000 gpd/square mile (Table 7) which is equivalent to 7 inches of rainfall per year; on the other hand, in the western part of the recharge area, it is estimated that 100,000 gpd/square mile is recharged to the ground-water reservoir from precipitation. This is equivalent to 2 inches of rainfall per year. The difference in the rate of recharge in the two areas is believed to be a result of the difference in the permeability of the drift materials due to variation in the clay content. According to Stuart (1945), there are areas west of Lansing where sandstones are sealed from vertical recharge because of impermeable layers of clay and shale.

Taking the average of the two figures, the effective recharge from precipitation is estimated to be 4.8 inches per year which is equivalent to 28 million gallons per day.

Considering the average daily discharge of 30 million gallons a day, it is concluded that discharge is almost balanced by recharge. Thus, if the present rate of withdrawal of ground water is kept constant, the cone of depression should not expand. If the future rate of ground water withdrawal exceeds its present rate, there will be further decline in piezometric surface in the Lansing area. Thus, increased pumpage will cause excessive dewatering of the aquifer and depletion of the ground water reservoir. For future development of ground water resources in the area, the well fields should be shifted in the areas where piezometric surface is high. Special attention also should be given to development of glacial drift aquifers.

The accuracy of quantitative analysis of ground water mentioned above is based on the accuracy of the data from which the piezometric contours were drawn. The quantitative determination of ground water will become very important in future development of ground water resources in the Lansing area if pumpage exceeds its present rate. The quantitative study of ground water is essential as it gives data on the safe yield of the aquifer with respect to pumpage. The safe yield of a water-bearing formation is the maximum rate at which water may be withdrawn without impairing the quantity or quality of the supply.

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Table.--Records of the wells whose static levels were used to make the general piezometric map of the area

Key to the Table

C - Clay
S + G - Sand and gravel
SS - Sandstone
Sh - Shale
CSg - Casing
e - estimated
LSD - Land surface datum
D - Domestic
M - Municipal
U.S.G.S. - U. S. Geological Survey observation wells
LS - Limestone

Well Number	Location	Diameter (in)	Depth (ft)	Static water level below LSD (ft)	Use	Elevation	Log	Static water level elevation above sea level (ft)
				Ingham				
4N 2W								
16-1	Cedar St. Block 241, lot 25 150' W of Cedar, 50' S of Joy St.	20"	377'	62 (5/31/62)	USGS	829.1 833.3	C-20, S + G - 45, SS-295, Sh-315, SS-365, Sh-377	771.
17-1	100' W of Logan, 400' S Saginaw	20"	420'	142.7 (5/31/62)	USGS	858.72		716
17-2	65' W of Verlinden, 30' S of Osborn	12"	417'	149.6 (7/3/62)	USGS	872.72		723.12
19-1	SW, SW, 17' N of Grand River Old Waverly Porch	2"	87'	5.75 (7/3/62)	USGS	834.09		828.
23-1	200' E of Francis St., 650' S of Horton	12"	467'	82.	USGS	824.86		743.
21-1	150' E of Townsend St., 50' S, Olds Ave. Extend	14"	410'	68 (5/31/62)	USGS	834.10		766.
22-1	150' W of Pennsylvania, 150' N of Grand Trunk RR	12"	338'	55 (5/31/62)	USGS	823.64		769.
24-1	2100' W of Harrison, 1900' N of Mt. Hope	10"	453'	83.31 (5/31/62)	USGS	853.45		770.
26-2	120' E of Aurelius Rd., 50' N of Hamelin St.	3"	115'	31'	D	845	58' to Rock SS	814.
28-1	209 W Mt. Hope at rear of Plant	8"	425'	53.63 (5/31/62)	USGS	849.20	Drift 80, No record 145, SS-278, Sb-287, SS-406	796.
31-1	1300' N of Jolly Rd., 600' E of Waverly	3"	204'	24.54 (5/31/62)	USGS	880.15		856.
				Ingham-Lansing				
4N 2W								
31-2	1500' E of Waverly Rd., 200' N of Jolly Rd.	14"	440'	19' (8/2/62)		878'		859.
25-1	0.3 mile S of Forest, 200' W of College	3"		47' (8/21/62)	USGS	867.4'		820.
9-1	300' E of N Grand River, 100' N of River	14"	401'	143 (5/31/62)	USGS	828.81		686.
11-2	1604 Wood St., 3400' S of Lake Lansing Rd., 100' E of Wood St.	4"	241'	26'	D	885		859.
				Ingham-Meridian				
4N 1W								
30-1	200' E of College Rd., 35 miles S Forest Rd.	2½"	142'	30' (5/55)				
34-1	Lot 133, Hiawatha Park, W Arbutus Dr. 950' N of Cavanaugh Rd., 1400' E of Dobie Rd.	3"	277'	68' (2/62)	D	931	C-25, S-60, C-100, Sh-250, SS Sb-277	863.
20-4	4948 S. Hagadorn Rd., 75' E of Hagadorn, 4720' N of Mt. Hope	4"	180'	40' (6/61)	D	851	C-20, G-50, C-70, Sb-85', SS-180'	811.
6-1	6163 Pollard, 600' N of Birch Row Dr., 60' W of Pollard, East Lansing	2"	112'	14'	D	848.21	64' of Casing	834.
21-1	Tacoma Hills, 2052 Tomahawk Circle		136'	30'	D	859	55' of Casing	829.
18-3	Back of EE - MSU (N-Campus)	8"		63'		838		775.'
10-2	75' S of Haslett Rd., 600' W of Bayonne Dr., 0.4 mile E of Okemos Rd.	2"	140'	18'	D	852	100' of Casing	834.
11-2	100' S of Orlando, 250' W of Cornell			3'(8/20/62)	M	860		857.
8-2	2000' S of Lake Lansing Rd., 100' E of Hagadorn Rd.			86' (6/62)	D	884		798.
10-1	140' S of Lake Lansing Rd., 365' E of Montebello Ave.	12"	390	23.5' (8/20/62)	M	847	C-124, SS-238, Sb-242, SS-390	823.5
18-1	Marble School - East Lansing	3"	175'	37.5' (5/31/62)	USGS	847.85		810.
29-1	440' N of Bennett, 1160' E of Okemos Road	4"	185'	20' (5/62)		867	C-19, S + G-59, C-65, S + G-114, Sb-115, SS-185	847.
28-1	440' N of Bennett Rd., 1160' E of Okemos Road	8"	320'	30'		876	Drift 80	846.'

Table.--Records of wells whose static levels were used to make the general piezometric map of the area.--Continued

Well Number	Location	Diameter (in)	Depth (ft)	Static water level below LSD (ft)	Use	Elevation	Log	Static water level elevation above sea level (ft)
				Ingham - Delhi				
3N 2W 22-1	140' W Aurelius Rd., 160' S of Holt Rd.	6"	192'	16'		885	56' of CSg	869
23-2	1260' S of Holt Rd., 600' E of US 127	8"		5.14 (5/31/62)	USGS	875		870
30-1	70' N of Pleasant River Dr., 815' E of Waverly	2"	65'	12'		873	Shale at 10', CSg to 25'	861
31-1	1300' S of Harper Rd., 1700' N of Grovenburgs Rd.	3"	140'	7'		893	32' to rock, SS	886
10-2	6135 Marscot Dr., 300' S off Miller Road, 1500' W of Aurelius	2"	100'	31'		883	72' of CSg	851
6-1	3063 Piper Ave., 75' W of Piper, 350' N of M-99	2"	100'	10'		872	66' of CSg	862
4-2	5900 S Washington Rd., 40' W of Washington Rd.	2"	100'	6'		861	54' of CSg	855
9-1	6947 Calson Dr., 550' N off Willoughby	2"	103'	15'		880	72' of CSg	865
17-1	2324 S. Washington Rd., 1780' off Willoughby Rd.	2"	112'	21'		892	87' of CSg	871
10-3	7020 Aurelius Rd., 70' W of Aurelius	2"	104'	15'		876	57' of CSg	861
7-2	6204 Bishop Rd., 165' W of M-99	3"	104'	15'		884	54' of CSg	869
10-1	6011 S. Cedar, 150' E of S. Cedar	2"	112'	17'		874	56' of CSg	857
18-1	2172 Gilbert Rd., 1500' N of Holt Rd.	2"	50'	+2'		861	36' of CSg	863
15-2	2102 Hamilton St., 1060' N of Holt Rd.	2"	120'	20'		888	61' of CSg	868
36-1	150' W of College Rd., 2000' N of Pryer Rd.	4"	70'	12'		891	42' of CSg	879
11-1	2926 Aurelius Rd., 800' S of Miller Road	2"	100'	30'		884	42' of CSg	854
7-1	2637 Frank St., 100' S of Bishop, 30' W of Frank	2"	100'	20'		876'	49' of CSg	856
5-1	40' W of Hagg Rd. S off M-99, W of Washington, 300' N of Miller Rd.	2"	95'	15'		870	62' of CSg	855
4-1	630 Lafayett St., 500' E off S Cedar	2"	126'	28'		885	86' of CSg	857
				Ingham-Rural				
2N 1W 21-1	2294 Coy Rd., 2100' E of Service Road., 40' N of Coy	3"		16'	D	938	29' to Rock	922
28-1	N of Barnes on Eden Rd., 450' N of Barnes, 40' E of Eden	3"			D	869	46' to Rock	949
1N? 4N 1W 33-1	100' W of State Rd., 730' S of Olds Rd.	3"	67'	2'	D	964	37' to Rock, Shale	962
1N 1W 27-1	710' W of Jackson Rd., 50' S of Fitchburg Rd.	4"		36'	D	968	207' to Rock, SS	932
2-1	50' W of Hawley Rd., 2600' S of Plams	3"		26'	D	979	76' CSg, SS + Sb	953
2N 1E 19-1	15 miles E of Kelly Rd.	3"		30'	D	977	125' of CSg - SS	947
1N 2E 3-1	Junction M-36 and M-92 W side of intersection	3"	320'	20'	D	960	94' of CSg, all shale	940
2N 2W 27-1	4557 Barnes, 50' S of Barnes, 500' W of Aurelius	3"		31'	D	963	SS at 55'	932
1N 1E 14-1	100' E of Haynes, 400' S of DeCamp	3"		8'	D	943	Rock at 47'	935
1N 2W 2-1	50' E of Aurelius Rd., 50' S of Ferns Rd.	3"	54'	8'	D	944	Rock 50', SS	936
3-1	100' W of Aurelius, 5500' S of Plams	3"		25'	D	948	37' to Rock	923
20-1				3'	D	896		893
4N 1E 18-1	130' N Haslett Rd., 200' W of Shoeman Rd.	2"	140'	10'	D	883	90' of CSg	873
20-1	230' E of Meridian Rd., 550' N of Sherwood Rd.	4"	250'	30'	D	896	Casing to 106'	866
2N 1E 22-1	60' S of Dansville Rd., 1280' E of Clark Rd.	4"		37'	D	975		938
4N 1E 21-1	3300' W of West Branch Rd., 780' N of Sherwood	8"	300'	20' (8/22/62)		886	All Shale	866

Table.--Records of the wells whose static levels were used to make the general piezometric map of the area.--Continued

Well Number	Location	Diameter (in)	Depth (ft)	Static water level below LSD (ft)	Use	Elevation	Log	Static water level elevation above sea level (ft)
				Ingham-Rural				
4N 1E 35-1	50' N of C and O RR, 250' E of Corwin Rd.		160'	7'		866	C-70, SS-73, Sh-140, Sh+SS-160	859
3N 2E 11-1	125' E of Maple St., 1200' S of Grand River Ave.	12"	178'	11'	M	894	Drift 79'	883
4N 1E 36-1	60' E of N. Putnam, 250' N of High St.	8"	455'	2' above floor of pumphouse		868	S+G-35, Sh-135, SS-145, Sh-240, LS-245, Sh-375, SS-460, LS-460	870
29-2	100' N of U.S. 16, 500' W of Burkley Rd.		314'	45'		894		849
4N 2E 21-1	100' E of Perry Rd., 1770' N of Sherwood Rd.	6"	280'	30' (3/61)	D	913	C-52, S-84, Sh-235, SS-275, Sh-285	883
1N 2W 29-1	4 mile E of Gale Rd., 300' S of Rossman	4"	187'	40'		946	S-70, G-72, Sh-170, SS-187, Sh-188	906
30-1	1100' E of Waverly Rd., 300' S of Bellevue Rd.		130'	30'		950	Rock at 72'	920
1N 1W 28-1	1100' W of E City Limit, 300' S of Bellvue Rd., 730' E of Russel St.	12"	225'	4' 4"	M	951	C-68, S-76, SS-91	942
2N 1W 23-1	100' W of Hawley Rd., 4000' N of Rolfe Rd.	3"	125'	24'		959	43' to Rock, Shale	935
10-1	275' E of City Limit, 520' N of M-36	6"		17'		914	Rock at 45'	887
8-1	933' W. Columbia, 73' S of W Columbia	2"	120'	12'		912		900
5-1	964' N of E Columbia St.	6"	180'	10.5'	USGS	882		872
5-3	500' E of Cedar St., 100' S of County Gravel Rd.	8"	212'	20.5'		e901		880
1N 2E 26-1	NW¼, E of GTRR Station	10"	206'	18'		930	Drift 53, Sh-79, SS-87, Sh-122, rock-137, SS-204, Sh+SS-206	912
				Ingham-Rural				
3N 1W 21-1	300' E of N. Okemos Rd., 2100' N of Lamb Rd.	6"	230'	47'		916	Drift-65, Sh-69, SS-225, Sh-230	869
5-1	75' E Hullet Rd., 2400' N of Sand Hill Rd.	3"	176'	17'		888	C-50, Sh-64, Sh-125, SS+Sh-155, SS-176	861
6-1	370' E of College Rd., 270' S of Sand Hill Rd.	4"	95'	13'		837	71' of CSg	824
30-1	100' E of College, 495' N of Harper			50'		906	50' to rock	856
34-1	75' S of Harper Rd., 3600' E of Okemos Rd.	3"		23'		898	Rock at 39', Sh-55	875
21-2	250' S of Holt Rd., 250' W of Okemos Rd.	4"	360'	52'		916	84' of CSg - all shale	864
				Clinton County				
3N 1W 24-1	100' N of Lamb Rd., 1440' W of Walline Rd.	3"		3'		874	Rock at 97'	871
6N 2W 33-2	1214 W. Chadwick Rd., 15 mile W of US 27	3"	258'	68'		862	C-36, S-108, G-162', S-180, SS-258	794
33-1	300' W. Cutler Rd., 950' W of US-27	3"	200'	43'		818	C-25, S-54, Sh-180, SS-200	775
19-1	3121 W. Pratt Rd., 1600' W of Dewitt Rd.	3"	145'	16'		792	C-36, S-95, Sh-185, SS-195	776
35-1	2343 Round Lake Rd., 1600' E of William Rd.	4"	190'	34'		826	S-64, C-102, Sh-192	792
6N 3W 36-1	75' W of Airport Rd.	3"	230'	64'		856	C-50, G-74, C-80, S+G-96, C-120, S+G-135, Sh-155	792
6N 4W 6-1	NW, NW	6"	476'	28'		760	C-60, S+G-70, C-98, G-102, C+S-332, SS-476	732
4-1	SW¼	6"	355'	24'		755'	C-18, S-48, C-121, Sh-308, SS-355'	731
6N 3W 34-1	6600 Cutler Rd., 1500' E of Francis	3"	220'	55'		849	S-100, Sh-205, SS-220	794
6N 2W 16-1	400' N of Pratt Rd., .45 mile W of US-27	3"	245'	27'		808	C-20, G-40, C-60, S-125, SS-130, Sh-193	781

Table.--Records of the wells whose static levels were used to make the general piezometric map of the area.--Continued

Well Number	Location	Diameter (in)	Depth (ft)	Static water level below LSD (ft)	Use	Elevation	Log	Static water level elevation above sea level (ft)
				Clinton County.--Continued				
6N 2W								
14-1	3634 Green Rd., 3400' E of Krepps Rd.	3"	215'	60'		830	C-78, S-145, Sh-155, C-166	770
33-3	75' W of US 27, 2100' N of Cutler Rd.	2"	74'	16'		807	67' of CSg	791
7N 3W								
36-1	50' N of Centerline Rd., 3/4 mile W of Airport Rd.	3"	300'	22'		e750	CSg to 205', Shale all the way	728
6N 3W								
9-1	50' S. of Church Rd. 3/4 mile W of Francis	3"	215'	40'		e750		e710
6N 1W								
25-1	9075 W Round Lake Rd., 400' E of Hollister Rd., 150' N of Round Lake Rd.	4"	300'	25'		827	150' of CSg	802
5N 3W								
32-1	200' E of Wacousta Rd., 3600' S of US-16	4"	305'	34'		860	Drift-256, rock-305	826
10-1	150' E of Francis Rd., 2000' N of Herbison	4"	214'	32'		857		825
5N 4W								
14-1	.2 mile N of Clark Rd.	3"	132'	26'		810		784
5N 3W								
7-1	100' S of Herbison Rd.	3"	155'	24'		813	C-36, S-57, C-72, G-90, Sh-115, LS-117, Sh-130, SS-155	789
5N 2W								
7-1	280' E Airport Rd., 520' S of Hawe Rd.	4"	223'	46'		838	140' of CSg	792
12-2	50' N of Herbison Rd., 620' E of Grove Rd.	3"	200'	40'		836	CSg to 120'	796
5N 1W								
17-1	1160' N of Clark	6"	378'	35'		854	C-25, S-35, C-85, S+G-131, Sh-262, SS+Sh-298, LS-306, SS-378, Sh-378	819
11-1	.85 mile W of Peacock Rd.	12"	505'	45'		811	C-45, S+G-70, C-75, S+G-82, SS-135, Sh-197, SS-291, Sh-296, SS-385, Sh-390, SS-455, Sh-457, SS-490	816
32-1	990' E of W section line, 990' N of S section line	10"	plugged to 440'	19'		845.2	Drift-122, Sh-253, SS-410, Sh-537, LS-575, SS-975, Sh-725	826
34-1	100' W of Center Rd., 260' S of State Rd.	2"	250'	15'		856	94' of CSg	841
5N 2W								
31-1	NW, SW, .55 mile E of US 16	6"	195'	55'	USGS	862.2		807
27-1	1568 Brooks Rd., 1700' N of State Rd.	4"	255'	67'		868	C-18, G-36, C-54, G-108, Sh-150, SS-250, Sh-253	801
27-2	200' E of US 27	4"	265'	59'		858	C+G-95, G-106, Sh-215, SS-260 Sh-265	799
33-2	4216 Turner St., 2200' S of State Rd.	4"	260'	43'		877	S-118, C-138, S-149, Sh-185, SS-262	784
4-1	River Dr., Dewitt 2400' S of Cutler	3"	190'	25'		816	C-36, S-72, Sh-126, Sh-163, SS-190	791
15-1	East end of Twinbrook Dr. 0.5 mile E of US 27	4"	199'	16'		829	C-28, G-68, C-85, S-95, C-113, Sh-199	813
5N 1W								
22-1	375' S of Stoll Rd., 950' E of Center Rd.	8"	325'	23'		858		835
5N 2W								
21-1	Theresa Ave., 880' S of Clark Rd., 520' W of Turner	3"	247'	55'		860	122' to rock, SS	805
				Eaton County Delta Township				
4N 3W								
10-1	SE, NE, 160' W of Crietz Rd., ¼ mile N of Saginaw	3"	121'	39.6' (5/31/62)	USGS	855.99		816
12-1	SE, SW, 150' W of Ribbin Rd., 550' N of Saginaw	6"	381'	80' (5/31/62)	USGS	861.91		782
15-1	SE, SE 650' W of Crietz , 400' N of W St. Joe	3"		35' (4/62)		862		827
24-1	340' N Mt. Hope, 690' W of US 27 and 78	12"	385'	70' (8/1/62)		820	C-73, Sh-114	800
14-1	6323 W. Saginaw, 75' S of Saginaw	4"	205'	45'		863	120' of CSg	818
10-4	50' N of W. Saginaw	4"	141'	15'		841	110' of CSg	826
15-2	60' E of Canal Rd.	2"	140'	25'		874	88' of CSg	849

Table.--Records of wells whose static levels were used to make the general piezometric map of the area.--Continued

Well Number	Location	Diameter (in)	Depth (ft)	Static water level below LSD (ft)	Use	Elevation	Log	Static water level elevation above sea level (ft)
				Eaton County - Delta Township.--Continued				
2N 4W 8-1	150' N of Island Hwy, 500' E of By Pass US 27	4"	43'	8'		888	Rock at 23'	880
23-1	150' S of Clinton Trail, 960' E of Perry Rd.	4"	130'	35'		932	Rock at 55' - Shale	897
4-1	300' S of US 27	3"	92'	31'		913	CSg to 72'	882
21-1	420' S of Clinton Trail, 120' E of Flanders Rd.	10"	400'	12'		904	S+C-20, G-24, S-34, SS-38, Sh-39, SS+Sh-68, Sh-72, SS-134, Sh-140	892
2N 3W 34-4	.3 mile N of Cornal. 500' E of Mich St.	10"	302'	4'		860	S+G-20, Sh-52, Hard rock-72, Sh-95, SS-130', Sh+SS-176, Sh-250, LS+Sh-302	856
32-1	75' S of Clinton Trail, 0.1 mile E of Morgan		280'	40'		e920	250' to rock	880
3-1	135' E of Canal Rd., 200' S of Wilbur	3"	120'	32'		921	Rock at 90'	889
21-1	100' W of Canal Rd., 1900' N Petrieville	4"	180'	36'		909	Rock at 120', all shale	873
23-1	100' W of Waverly, 1200' N of Bunker	4"	120'	34'		910	Rock at 70' all LS	876
9-1	100' S of Columbia, 920' E of Gunnel	3"		31'		905'	85' of CSg - all SS below	874
1N 3W 6-1	600' E of Royston, 80' S of 5 Points Hwy.		70'	5'		896'	Rock 43'	891
7-1	60' N of Steele, 1300' W of Royston		269'	50'		930	Rock 158'	880
1N 4W 27-1	1900' W of Couts Rd., 30' N of Hunt Hwy	3"	100'	16'		931	Rock at 70'	915
3N 3W 3-1	140' W of Creitz Rd., 800' N of Grand River	10"		5'		837.5	Green Sh, 425', Plugged back to 400'	832
16-1	8939 E. Windsor Hwy., 350' W of Canal Rd.	2"	110'	22'		863	CSg to 82'	841
2-1	400' N Hart Rd., 425' E off Crietz	4"	130'	20'		841	72' of CSg	821
7-1	40' E of Royston, 1340' S of Billwood Hwy	2"	180'	40'		905	119' of CSg	865
4N 5W 13-1	1451 W. St. Joe	2"	140'	20'		897	84' of CSg	877
14-2	200' S. of Center sec 14	4"	395'	58'		862		804
7-1	Subdivision, E of Grand Ledge	3"		at ground level		804		804
26-1	470' N of Millet Rd., 500' W of US 27-78	8"	282'	34'		874	Rock 47', Sh-235, Sh+SS-282'	840
21-1	80' N of St. Joe Hwy., 670' E of Brandbent	3"	175'	12'		858	Rock 47-Sh	846
3N 6W 35-1	2nd place W of Shaytun Rd. on Kinsel		335'	140'		940	270' to rock, all grey shale	800
17-1	E side of Irish Rd., 3/4 mile N of Vermontville Rd.		267'	71'		880	Rock at 221'	809
2N 5W 5-1	150' W of Chester, 1900' S of Kinsel	3"	130'	34'		890	Rock 56', Sh	856
33-1	60' W of M-78, 1900' S of 5 Points Hwy.	3"	145'	6'		890	80' to rock, SS	884
23-1	200' S of Carlisle Hwy, 2900' W of M-78	3"	205'	40'		922	100' to rock	882
1N 6W 27-1	200' S of Hall Rd., 1 mile W of Sherwood	3"	100'	8'		860	Rock at 15', LS	852
1S 4W 5-1	200' W of 26 Mile Rd., 1/2 mile S of Baseline	3"	165'	40'		978	Rock at 118', Shale	938
24-1	260' W of County Line	4"	92'	39'		966	Rock at 44', shale and some SS	927
2N 3W 34-3	480' NE Wood St. extend 480' SE Mich	12"	301'	+3.5'		856	S+G-28, Sh-90, SS-166, Sh-236, SS-248, LS-250, SS-265, LS-269, SS-280, LS-295, Sh-301	860
3N 4W 14-1	4250 Pinch Hwy, 1100' E of Johnson Rd.	4"	130'	20'		875	72' of CSg	855
20-1	4808 Benton Rd., Charlotte	3"	300'	60'		900	C-74, G-79, Sh-300	840
2N 4W 33-1	250' S of Clinton Trail, 300' W of east sectional line	4"	300'	+5'		878		883

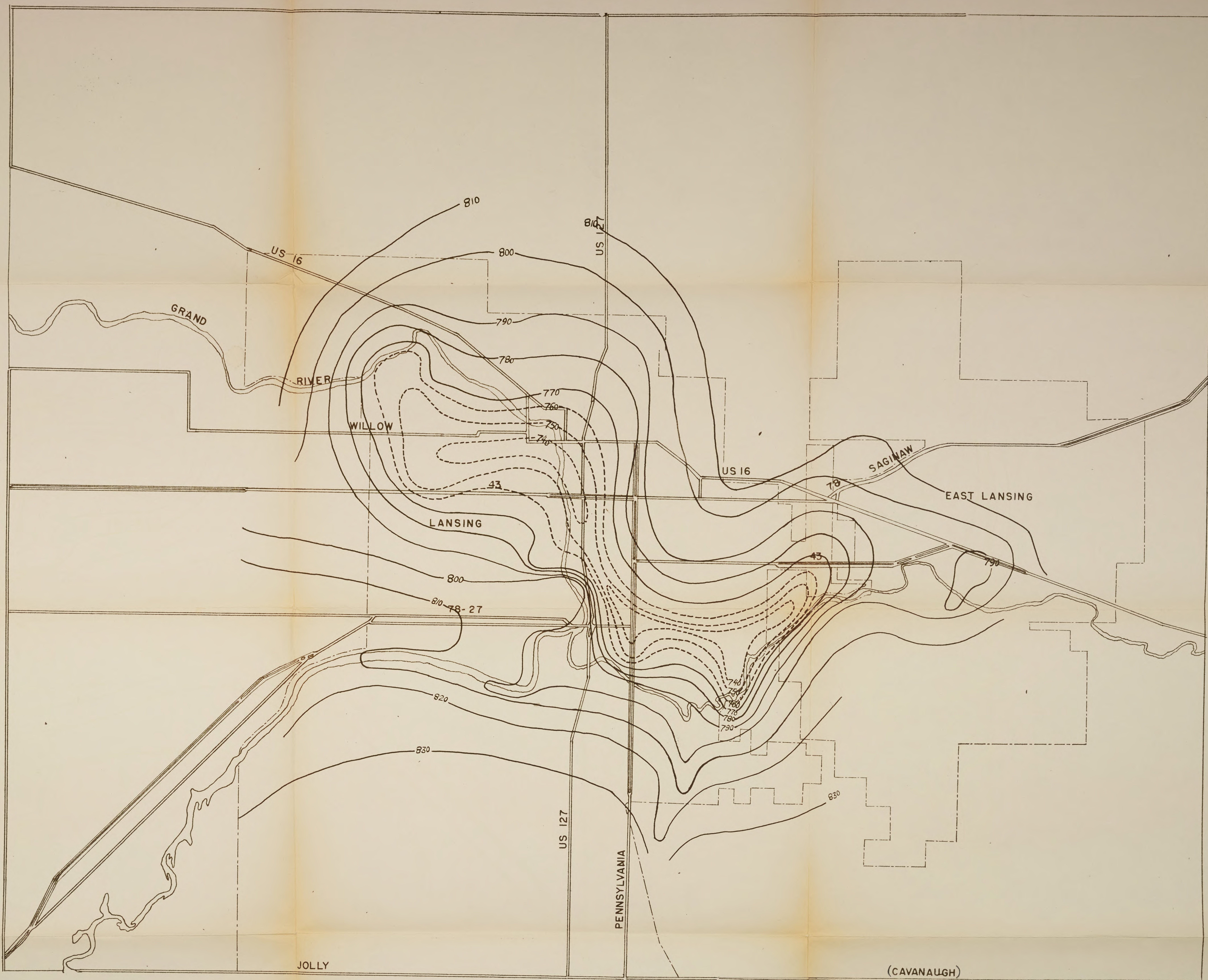
Table.--Records of wells whose static levels were used to make the general piezometric map of the area.--Continued

Well Number	Location	Diameter (in)	Depth (ft)	Static water level below LSD (ft)	Use	Elevation	Log	Static water level elevation above sea level (ft)
				Eaton County - Delta Township.--Continued				
5N 5W 24-1	100' W of Waverly, 1100' S of Holt Road	2"	93'	15'		873	63' of CSg	858
32-1	75' W of Scout Rd., 300' N of S Section Line		228'	39'		913		874
				Shiawassee County				
5N 1E 33-1	1360' S of Braden, 150' E of Dunn	3"	190'	33'		894	120' of CSg	861
6N 1E 21-1	Main St., back of fire station		318'	26'		e813	Drift 113, SS-318	787
1S 4E 19-1	600' E of E line of Cemetary	6"	290'	110'		e1030	Coldwater Shale	920
2S 1W 22-1	1170' S of Parnell Rd.	12"	300'	21'		e955		934
2S 2E 6-1	S of Big Portage Lake	8"	191'	28'		e920	Drift 57, Sh-117, SS-122, Sh-134, LS-151, SS-163, Sh-170, SS-183, Sh-186, Sh-191	892
2S 1W 11-1	5108' E and 1875' N of SW of Sec 11	8"	142'	13'		e915	S-57, Sh-60, SS-70, LS-82 Sh-132, SS-142	902
2S 2W 12-1	4650' S of Pomeroy, 200' W of Bennett	3"	93'	40'		e985'	C+S-39, Sh-63, SS-93	945
2S 3W 9-1	300' W of the E½, 500' N of E-W½ line	3"	90'	12'		e975	SS-80-90, CSg-34	963
3S 3W 34-1	Michigan and Monroe	10"	100'	44'		e1020		976
				West-Lansing				
4N 4W 16-1	100' S of Saginaw			30'		e886		856
4N 5W 12-2	100' N of Saginaw, ½ mile E of Wheaton			12'		875		863
4N 4W 14-1	100' N of St. Joe			26'		879		853
16-1	NW Sec Oneida and St. Joe			12'		886		874
28-1	100' S of Mt. Hope			6'		895		889
4N 4W 27-1	100' N of Strange			25'		884		859
33-1	100' W of Oneida Road			28'		e920		892
4N 5W 23-1	100' E of Boyer Rd.,1000' S of St. Joe			10'		880		870
3-1	N Mulliken			35'		868		833
3N 4W 3-1	100' S of Doane Rd.			14'		e885		871
15-1	100' S of Pinch, 1700' W of Johnson			6'		e860		854
13-1	N of Potterville on Hartel Rd.			26'		890		864
				S-West-Lansing				
2N 5W 21-1	100' N of Kalamo Rd., 2500' W of Stine			30'		890		860
1N 4W 20-1	On Bellvue Rd., ½ mile W of Brookfield Road			14'		e925		911
1N 5W 30-1	100' N of Butterfield Rd.			21'		895		874
				East Lansing				
4N 1E 10-1	100' N of Haslett Rd.			53'		935		882
4N 2E 14-1	100' W of Morrice Rd.			30'		925		895
4N 3E 34-1	100' S of Chase Lake Rd.			34'		932		898
29-1	100' S of Sherwood, W of Nicholson Rd.			40'		923		883
3N 3E 16-1	50' W of Gregory Rd.			18'		915		897
3N 2E 26-1	250' N of Dennis			21'		914		893
14-1	50' N of Holt Rd.			8'		899		891
15-1	100' E of Stockbridge Rd.			16'		e900		884
3N 1E 36-1	50' N of Howell Rd.			19'		e914		895

Table.--Records of wells whose static levels were used to make the general piezometric map of the area.--Continued

Well Number	Location	Diameter (in)	Depth (ft)	Static water level below LSD (ft)	Use	Elevation	Log	Static water level elevation above sea level (ft)
				East Lansing - Cont'd				
3N 1E 13-1	75' N of Holt Rd.			33'		e917		884
3-1	E of Zimmer Road			16'		880		864
5N 1W 25-1	Peacock and M-78			12'		e855		843
5N 1E 1-1	50' S of Winegar Rd., 600' E of Shattsburg Rd.			18'		e840		822
3N 4E 18-1	.45 mile SE of Ovosso Rd.			14'		e914		900
3N 3W 12-1	Ovosso and Sharpe Rd.			12'		e915		903
				North Lansing				
5N 3W 10-1	100' S of Howell Rd.			69'		868		799
11-1	50' S of Howell Rd.			50'		845		795
5N 2W 6-1	100' N of Howe Rd.			36'		840		804
5N 3W 13-1	100' N of Clark Rd.			40'		845		805
15-1	50' N of Clark Rd.			4'		806		802
33-1	US 16, ½ mile E of Wacousta Rd.			50'		e870		820
5N 4W 24-1	100' W of Bauer Rd.			37'		850		813
12-1	Howe and Wright			34'		820		786
21-1	Eagle - Old US 16			48'		e840		792
4N 4W 32-1	State Rd. and Grange			50'		e831		781
3-1	.1 mi S of Eaton Hwy, 100' E of Oneida			51'		e890		839
5N 4W 34-1	100' S of State Rd.			40'		880		840
26-1	1800' N of State Road			12'		825		813
				South Lansing				
1N 3E 16-1	West of Gregory Rd.			40'		960		920
2N 3W 12-2	Waverly Rd., ¼ mi S of Columbia			9'		861		852
2N 2W 7-1	E of Waverly			14'		890		876
2N 3W 12-1	75' E of M-99, 1700' S of Columbia Road			31'		924		893
27-1	N edge of Eaton Rapids - M-99			8'		871		863
	2nd old farm house S of Bellevue Rd.			12'		952		940
1S 1W 2-1	1900' S of Baseline, 100' W of Dutch			5'		e960		955
1N 1W 35-1	Peacock Rd., 3800' S of Olds Rd.			9'		e983		964
1S 1W 20-1	Eaton Rd. and Berry Rd.			50'		e1010		960
1S 1E 18-1	Pleasant Lake (W side) E side of Meridian Road			9'		e940		931
1N 1E 35-1	40' W of Friemuth Rd., 150' S of Fitchburg Rd.			16'		945		929
1N 2E 21-1	50' N of Barton Rd., 2000' E of Chapman Road			11'		e935		924
1N 1E 10-1	2800' E of Williamston Road			28'		e970		942
5-1	NE corner, Meridian and Evers Roads			20'		e970		950
2N 2E 19-1	100' S of Dansville Rd., 500' E of Meech Road			17'		930		913
2N 1E 3-1	.5 mile W of Williamston Rd., 50' N of Columbia			18'		e950		932
2S 3W 36-1	Robert Rest Home - Parma			25'		e1005		980
9-1	Devereaux Rd. at Joy			12'		e975		963

Pocket has:
3 Figures



EXPLANATION

——800—— Contours of piezometric surface used in flow net

-------750------- Contours of piezometric surface not used in flow net

Contour interval 10 ft

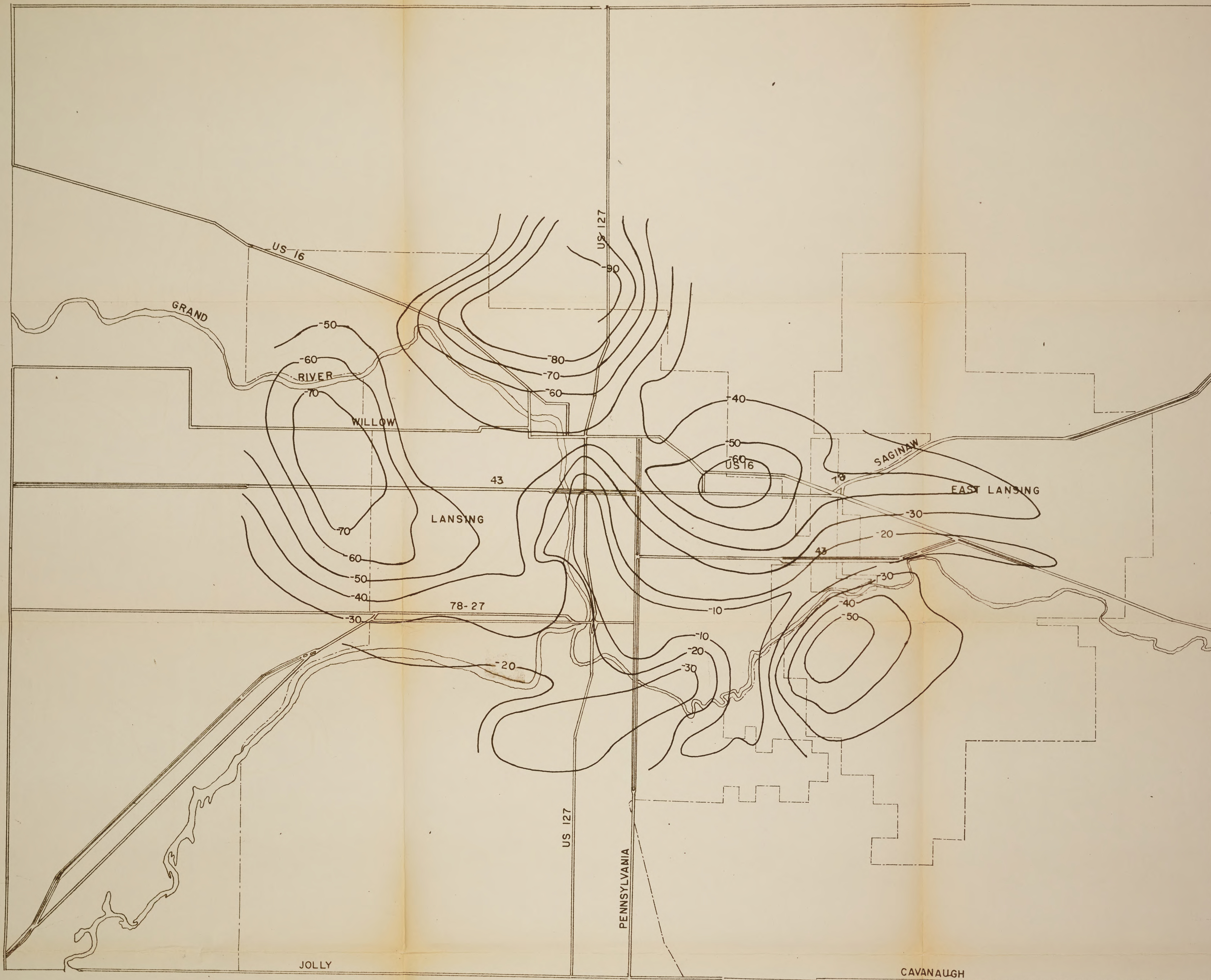
PIEZOMETRIC SURFACE OF WATER IN PENNSYLVANIAN SANDSTONE LANSING-MAY 1945 BY W.T. STUART

0 1 2 Miles

Scale

N

FIGURE 5



EXPLANATION

-70 Contours showing decline of piezometric surface

Contour interval -10 ft

0 1 2 Miles

Scale

MAP SHOWING DECLINE OF PIEZOMETRIC SURFACE IN SAGINAW FORMATION FROM 1945 TO 1962 IN LANSING AREA

FIGURE 9