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R. A. Smith, State Geologist

Progress Report on the Ground-water Resources of the Lansing Area, Michigan

by

W. T. Stuart

Prepared in cooperation with

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Contents

Page

Introduction
Cooperation and personnel 1
Area and scope. 2
History of ground-water developments. 2
Need for ground-water investigation 3

Geologic formations and their water-bearing properties. 4
Glacial till. 4
Bedrock 5
Parma sandstone 6
Saginaw formation 7
Porosity, permeability, and transmissibility. 8

Well and pumpage inventory. 11

Piezometric surface 13

Fluctuations of the water levels. 16

Physical properties of the ground-water reservoir 20

Recharge. 23

Quality of ground water 25

Safe yield. 28

Factors to be considered if pumpage is increased. 31

Need for further exploration. 32

Illustrations

Figure 1. Location of wells, greater Lansing area.

Figure 2. Location of wells, Lansing and vicinity.

Figure 3. Cross-sections of Pennsylvanianformations through Lansing.

Figure 4. Distribution and magnitude of pumpage from well, Lansing 1944.

Figure 5. Piezometric surface of water in Pennsylvanian sandstones Lansing area, Spring 1945.

Figure 6. Piezometric surface of water in Pennsylvanian sandstones Lansing, Spring 1945.

Figure 7. Hydrographs showing effect of changing river stage on water levels in wells I-7, and I-36.

Figure 8. Graphs showing pumpage, fluctuations of water levels, and precipitation Lansing.

Figure 9. Areas of water analyzing greater than 300 ppm total hardness.

Figure 10. Areas of water analyzing greater than 400 ppm total hardness, Lansing area.

Figure 11. Graphs showing progressive changes in chemical quality.

GROUND-WATER RESOURCES OF THE LANSING AREA, MICHIGAN

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INTRODUCTION

Cooperation and Personnel

The investigation that forms the basis for this report was part of a larger program undertaken by the Geological Survey Division, Michigan Department of Conservation in cooperation with the United States Geological Survey to determine the ground-water conditions in the state. Detroit and many of the cities on the Great Lakes obtain their municipal and industrial water supplies from surface-water sources, but most of the interior cities are dependent upon ground water derived from wells. Many of these present users in the interior are confronted with the problem of obtaining larger quantities of water. It was with the hope of helping to solve these present-day problems, as well as problems that will doubtless arise in the future development of the State, that the state-wide ground-water investigation was undertaken.

The 1944 summer drought that forced the Lansing Board of Water and Electric Light commissioners to curtail lawn and garden sprinkling to make sufficient water available to operate the war plants served to call attention to the fact that the ground water supply is not inexhaustible, and that an investigation was needed to determine the quantity of water available in the Lansing area.

Field work, under the general supervision of O. E. Meinzer, chief of the Division of Ground Water of the U. S. Geological Survey, was started in August

1944 by W. T. Stuart. After January 1945, R. W. Stallman assisted in the making of many pumping tests.

The writer is especially indebted to Dr. R. A. Smith, State Geologist, and to Messrs. Otto Eckert and Claud Erickson of the Board of Water and Electric Light Commissioners and their staffs for the data furnished and the assistance which made the study possible.

Area and Scope

The greater Lansing area as used in this report comprises the City of Lansing and East Lansing in Lansing Township, with the adjoining townships of Meridian, Delhi, and Alaiedon to the east and south in Ingham County; Watertown, De Witt, and Bath Townships to the north in Clinton County; and Delta and Windsor Townships to the west in Eaton County. This area comprises a square, which is three townships or 18 miles on a side, with Lansing Township in the center.

The purpose and scope of this report is to collect and interpret the existing information in order that an intelligent and integrated use of the existing ground-water supplies may be developed for all of the water users.

History of Ground-water Developments

Privately owned shallow wells furnished the domestic supply for most of Lansing prior to 1885. At this time an open brick well sunk in the sand near the present Cedar Street station became the first unit in the public supply system. This was abandoned in 1890 and was replaced by twelve shallow wells about 50 feet deep located nearby. In 1895 twelve additional wells about 150 feet in depth and penetrating the Pennsylvania sandstones were added. In the next twenty years the Townsend, Seymour, Pennsylvania, and Logan Street pumping stations were built, which drew water from the sandstones and shales at a depth of 350 feet.

In 1910 the average daily withdrawal of ground water amounted to about 2.9 million gallons a day, and by 1920 this had increased to about 4.7 million gallons a day. The municipal system produced 8.5 million gallons a day in 1930, 9.8 million gallons a day in 1940, and 12.7 million gallons a day in 1943. By the end of the 1945 construction period the Lansing water supply system had been increased to 91 wells to meet the water demand, which in 1944 averaged about 14 million gallons a day. Paralleling the growth of the Lansing system, East Lansing and Michigan State College had installed seven deep wells by 1944. The industrial demand for ground water began in the twenties with development of machining and forging facilities for the automobile industry. In the late thirties the introduction of air-conditioning resulted in a few wells being drilled for cooling water. About twenty industrial wells were producing ground water in 1944 in the Lansing area.

Need for a Ground-water Investigation

The heavy draft of ground water by the city and the war plants in particular has lowered the ground-water levels to a point where it is indicated that the existing supplies are not unlimited. This has caused the yields of wells to diminish for two reasons. The lowering levels have caused increasing lifts in the wells themselves which either necessitate an increase in the power required for the same yield or else result in a decreased yield for the same amount of power. In addition to the diminishing yield caused by the lowering ground-water levels, the incrustation or cementation of the water bearing materials in the immediate vicinity of the wells has caused further lowering of the operating levels by reducing the yield per foot of drawdown. In certain localities critical shortages, or rather overdevelopments, have arisen because of the combined interference in drawdown caused by too many heavily pumped wells in relatively small areas.

GEOLOGIC FORMATIONS AND THEIR WATER-BEARING PROPERTIES

Meinzer 1/ has shown that the hydrology of ground water is controlled by the geology. The head and movement of the ground water, its recharge and discharge, its quantity and quality are all controlled by the character and structure of the rock formations and the covering materials. In some places the precipitation falls on open and porous formations and seeps beneath the surface, where it is only loosely held, and rather quickly flows out through the rocks and soils into the streams and drains. In other places the rain seeps into tighter formations, is held longer, and furnishes a steady source of flow for the dry periods - the so-called "base flow." Or, under favorable conditions of geological structure, some of the rainfall seeps down through the rocks and finds its way into deep artesian formations from whence it may travel to distant points where it is available for wells. Some artesian water travels comparatively rapidly and may emerge as good potable drinking water; other water travels slowly and remains underground for thousands of years in contact with the rock from which it usually dissolves enough salts to become too highly mineralized for use by plants or animals. Apparently some water has been held within the rocks for millions of years or even eras of geologic time. Thus the geology of the area is a dominating factor in controlling the hydrology of the ground water.

GLACIAL TILL

The topography of the greater Lansing area is gently rolling with the slopes of the land only generally conforming to the drainage valleys. The Grand River is

1/ Meinzer, O. E. Hydrology, Physics of the Earth, IX, 1st Ed., p. 6. McGraw-Hill Book Co., New York, 1942.

the major drainage and enters the area from the southwest. It flows northerly to Lansing and then westerly to Grand Ledge. The Cedar River flows westerly through the center of the area and enters the Grand at Lansing. Sycamore Creek flows northwesterly from Mason and enters the Cedar near Lansing.

Leverett 2/ indicates that the Lansing area lies mainly on glacial till deposits of sand and clay which were laid down under the ice sheets. Two narrow moraines, composed of boulder clays, sand and gravel, which formed at the border of the ice sheet, cross the area in an east-west direction. The Lansing Moraine on the south of Lansing is not well defined as it extends eastward, but westward it is from 10 to 20 feet high and one-eighth mile wide as it passes about two miles south of Grand Ledge. The Grand Ledge Moraine is more strongly developed. It extends from Pine Lake to the site of Michigan State College, thence northwest to two miles north of Lansing, and thence along the north bank of the Grand River to Grand Ledge.

The glacial drift was deposited on the somewhat eroded bedrock (Pennsylvanian) land surface, and ranges in thickness from about 10 feet to about 200 feet in the Lansing area. Depressions in the bedrock surface as shown by the depth to rock in northern Alaiedon and southern Meridian Townships, near Pine Lake, and in southern Delta and northern Windsor Townships are evidence of two or three pre-glacial channels. However, none of these channels have been sufficiently explored or defined to determine the possibility of a water supply being developed in them.

BEDROCK

Underlying the drift is the bedrock composed of the sandstones, clays, shales, and coal seams of Pennsylvanian age. The main water bearing beds of this age are a

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2/ Leverett, Frank and Taylor, Frank B., The Pleistocene of Indiana & Michigan U. S. Geological Survey Mon. 53, pp. 239, 240, 1915.

white sandstone (the Parma sandstone) and a group of grey sandstones with seams of coal enclosed in lenticular beds of shales and clays (the Saginaw formation).

Below the Saginaw and Parma formations are beds of Mississippian age - the Bayport limestone and the shales of the Michigan formation. Both formations contain anyhydrite, gypsum, and pyrite. Wells tapping these formations yield water too hard and too highly mineralized for domestic use.

Parma sandstone

The Parma sandstone, which is the basal formation of the Pennsylvanian series, has been recognized in numerous wells covering a large area in central Michigan. The thickness is variable but is seldom more than 100 feet except where the sand has filled deep valleys in the pre-Pennsylvanian land surface. About 50 feet of it is usually present but in some places it is thin or absent. The Parma sandstone is a white quartzose, glistening sandstone, locally coarse to conglomeratic. The small milky-white pebbles have been compared to "split peas." The white color is characteristic, although coaly terrestrial material has been found, and the rock is locally stained with iron. The sandstones are cleaner than those of the overlying Saginaw formation, and are ordinarily much better cemented. The Parma is predominately quartzose, with tourmaline and zircon the most common of the heavy minerals. Winchell 3/ mentions the occurrence of a fossil plant, Calamites, in an outcrop along Rice Creek in western Jackson County and eastern Calhoun County. A rock sample taken from well I-200 in Lansing contained a fossil twig an inch thick.

Weak brines containing chlorides and sulphates of sodium, calcium, and magnesium, but relatively high in calcium sulphates are associated with the formation.

3/ Winchell, A., First Biennial Rept. Progress of Geol. Sur. of Mich., embracing observations on Geology, Zoology, and Botany of the Lower Peninsula, pp. 112-127, 1861

Saginaw formation

Kelley 4/ describes the Saginaw formation as follows:

"The sandstones of the Saginaw group are frequently lenticular, and non-persistent, and possess irregular bedding. Most of the beds exposed at the surface are less than ten feet thick. In certain sections sandstone beds are of greater relative importance. Examples of such 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 sandstone is usually fine, although thin conglomeratic layers have been observed at the base of individual lentils. Red colors are not characteristic. Quartz is the principal constituent, but is associated at time with some decomposed feldspar, and usually with abundant white mica. The mica flakes are arranged with their cleavage surfaces along the bedding planes. The sandstones contain less than one percent heavy minerals. Tourmaline and zircon are the most common heavy minerals. Both well formed crystal and slightly rounded fragments occur. Fossels in the sandstones are limited to plant fragments. These various characteristics taken together point to a terrestial origin of the sand, in which shifting currents with rapidly alternating erosion and deposition played a major part.

"The shales of the Saginaw fall roughly into three groups: (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 the sandstones, and examples exist where a cursory examination might readily class a given bed as a sandy shale at one time and a shaly sandstone at another time. Plant flossils are often found in these shales, fern-like fronds, isolated pinnules, and stem fragments being the most common. Like the sandstones the shales 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 and judging from fossil evidence are closely allied in origin to the shaley limestones. The non-limy shales vary in structure from very fissile to almost structureless layers up to three feet or more in thickness. The structureless beds frequently contain nodular masses, the boundaries of which are sliken-sided. The center of a nodular mass often contains a plant fragment, and it is thought that the local sliken-side resulted as the mud about the plant compacted. The common fossils of the structureless shales are the brachiopod Lingula, and foraminifera including Glomospira, Trochammina, and Hyperammina. The fissile and other stratified shales are non-fossiliferous, or else contain macerated shells of the pelecypod Anthracomya. It is probable that the Lingula shales accumulated in the quiet areas of marine or brackish water. In the Grand Ledge district Anthracomya beds succeed plant bearing shales and are followed by beds containing a normal marine fauna suggesting a stage in progressive submergence.

4/ Kelley, W. A., Occasional Papers on the Geology of Michigan: Mich. Dept. Cons., Geol. Sur. Div. Pub. 40, Geol. Ser. 34, pp. 155-218, 1940.

"Shales of the third group, the underclays are structureless, white to light gray beds of claylike or sandy texture. They commonly contain irregular nodules of iron carbonate a few feet from the top and are often below coal seams."

The coal beds are ordinarily thin and little opportunity has been affored to trace the beds over a great distance. Evidence exists, and has been cited in the discussion of the sandstones, that the coal beds are in many places cut off by unconformities within the Saginaw formation itself. However, the coal beds have been a means of correlating the sandstones and the shales within the Saginaw formation.

In the northwestern part of the greater Lansing area along the Lookingglass River a reddish sandstone is found in wells above the predominating sandstones of the Saginaw formation. This sandstone is of post-Saginaw age and has been called Woodville sandstone by some geologists. It is coarse grained, free of mica, and contains many iron stains. It has little importance as a water bearing formation in the area as the percentage of dissolved iron is above the acceptable limits for domestic water supplies.

Porosity, Permeability, and Transmissibility

The ability of the sandstones to yield water to wells depends upon their porosity, permeability, and transmissibility.

The amount of water than can be stored in any water-bearing formation depends on the porosity, which is expressed as the percentage of the total volume that is occupied by the interstices.

Well-sorted deposits of sandstone have a high porosity regardless of the size of the individual particles, but an argillaceous sandstone, in which particles of clay fill the spaces between the sand grains, has a greatly reduced porosity.

Porosity alone determines only how much water a given formation can hold, not how much it can yield to wells. For example, a well-sorted fine-grained sandstone may have a higher porosity than a poorly-sorted coarse-grained sandstone and consequently may hold more water. However, not all the water is available to wells because part of the water is held against the force of gravity by molecular attraction as the water table is lowered. In a fine-grained sandstone the molecular attraction is great, and only a small part of the water can be drained out by the force of gravity, whereas in a coarse-grained sandstone having the same porosity only a small part is retained by molecular attraction and the remainder becomes available to wells.

The permeability of a formation is defined as its capacity for transmitting water under pressure and is measured by the rate at which it will transmit water through a given cross-section under a given pressure drop per unit of distance. As explained in the previous paragraph, a bed of fine-grained sandstone may have as high a porosity as a bed of corase-grained sandstone, but because of the small size of its interstices, it may require the application of a great pressure defferential to transmit water, and it is therefore said to have a low permeability. Thus a well penetrating a very fine sandstone which, though saturated with water, will yield almost no water because of its low permeability. On the other hand a well penetrating a coarse sandstone with a high permeability may yield a very large supply.

Porosity and permeability of water-bearing formations affect the yield of wells only in a general manner, as the maximum yield of a well is directly proportional to the transmissibility of the aquifer. Transmissibility is the product of the permeability and the thickness of the aquifer. Thus, the third factor of thickness of the water-bearing beds may be more important than either permeability or porosity. For instance, in an area in which there is considerable thickness of sandstone, even though of low permeability, wells of largeryield may be found, than in an area where there are thin sandstone lenses of high permeability. It is possible that the product of a low permeability and a large thickness (i.e. transmissibility)may be greater than the product of a high permeability and a small thickness when each is measured in the same units.

When a piece of sandstone from a well in the Lansing area is examined by means of a microscope or magnifying lens, the partially rounded quartz grains are found to be of fairly uniform size. A coarse sandstone is composed of uniformly coarse particles with few finer grains, and a fine sandstone is composed of fine particles with no corase and few finer grains filling the interstices between the other particles.

Of special interest is the size and shape of the interstices between the particles. It will be noted that the particles are notarranged in the haphazard manner of loose spheres in a container, but are lightly cemented at points of contact with adjacent particles and enclose interstices as large or larger than the particles themselves. Further examination discloses the interstices are not isolated, but extend into the sandstone and connect adjacent interstices. The connecting interstices honeycomb the sandstone, providing not only porosity for the storage of water but also communicating passages for its transmission. The connecting passages are generally parallel to the bedding planes. There is considerable vertical connection within each bed, but only a restricted connection between adjacent beds. Since each bed may be several feet in thickness, it may be considered as a hydraulic system composed of many small pipes each of which will transmit water . This type of ground-water flow is found on a larger scale in cavernous limestones, where the water is transmitted through solution channels, crevices, and other openings. This type of hydraulic flow system readily explains the high values of transmissibility and low coefficients of storage that were obtained during pumping tests which are discussed in a later section of this report under the heading "Physical properties of the ground-water reservoir."

In the Lansing area the Pennsylvanian sandstones should be considered as falling in the range of low to medium permeabilities when compared with the water-bearing materials found in the glacial cover of Michigan and adjacent states. However, the sandstones are found to have 200 to 300 feet of thickness (see figure 3) which provides sufficient transmissibility to maintain the yield of water-supply wells. Wells in the southwestern part of Lansing have been found to have small yields where the wells have penetrated large lenses of shale and the thickness of the sandstones is small. This is also true in other parts of the area where the wells have not penetrated the full thickness of the sandstone.

A discussion of the capacity of the sandstones and their ability to transmit water to wells is contained in a later section of this report.

WELL AND PUMPAGE INVENTORY

During the investigation an inventory was made of all the wells in Lansing, and East Lansing, and of representative wells in other parts of the surrounding townships; and the following information was tabulated wherever available: location, owner, driller, altitude, log, casing record, water levels, pump data, pumping-test data, pumpage records, temperature of water, and chemical analyses of water. Figures 1 and 2 show the locations of all the wells inventoried in the Cities of Lansing and East Lansing. Except for numbers 1 through 10, the wells in Ingham County are numbered beginning in the upper left corner and progressing eastward in tiers of two sections for each township to the county line. Numbers

1 through 10 are the same numbers that have been assigned to those wells for which water levels have been published in Geological Survey Water Supply Papers Nos. 886, 906, 936, 944 in Ingham County. Wells in Ingham County are preceded by the letter I, those in Clinton County by the letter C, and those in Eaton County by the letter E in the discussion of this report.

It is estimated that an average of about 18 million gallons of water a day was pumped in 1944 in the greater Lansing area for public and industrial supplies. Of this amount, table 1 indicates the amount consumed by the various types of users. These estimates do not include about one million gallons of water withdrawn daily from wells for the supply of individual homes and small farms in the rural areas surrounding Lansing and East Lansing. Although there are a large number of wells of this type in the rural and suburban sections, the ground-water resources are not appreciably affected by them. They are widely scattered and the amount of water withdrawn is relatively small per unit of area. The estimates of pumpage given in this report are based on data obtained from various sources. The data for the public water supplies were readily available from the monthly reports which summarized the metered flows from the individual production systems. Records of pumpage by all the industries in the area were collected by members of the staff of the Geological Survey. Many of the estimates obtained in this way were made from records of pump operation kept by the individual industries. Some were based on the yields of the individual wells as originally determined by the driller. In the case of those wells used for air conditioning the average daily pumpage is the product of the yield and the average number of hours daily that the well was used during the year. Such estimates may at times be somewhat in error, but the aggregate amount of pumpage estimated in this way forms only a small percentage of this total. It is believed, therefore, that the totals are essentially correct.

Estimated average daily pumpage from wells in Lansing area
by industries in 1944

		Million gallons a day
Public Supplies		15.7
Industrial Processing		1.4
Air Conditioning		0.27
Ice Making		0.20
Irrigation - Golf Courses		0.06
	Total	17.6

Figure 4 shows the distribution of the pumpage in the Lansing area. The total pumpage for each area is represented by circles the size of which indicate the magnitude of the pumpage in each area.

PIEZOMETRIC SURFACE

The "piezometric surface" or pressure-indicating surface of the water in the sandstone aquifers in the greater Lansing area is shown in figures 5 and 6. The contours represent the height above mean sea level to which the water will rise in wells tightly cased to the sandstone. The general direction of the movement of the ground water is normal to the contour lines. The contour lines show the slope of the piezometric surface, however, the quantity of water moving through the sandstones depends not only on the slope but also on the thickness and permeability of the sandstones.

The water levels are continually fluctuating due to several causes, such as variations in rate of pumping of the wells, changes in barometric pressure, recharge from various sources, and changes in stage of the river and lakes in the area. The fluctuations cause minor changes in the piezometric surface; however the major features change noticeably only after long periods of time.

The map of the piezometric surface indicates the direction of flow of the ground water, which is normal to the contours. From figure 5 it may be seen that the flow is toward Lansing from all directions. However, the greatest slope is from the south with the least from the east and north, indicating that (assuming equal transmissibility in all directions) much more water is flowing toward Lansing from the south than from the east or north.

Data are not available to establish the position of the piezometric surface prior to the beginning of the pumping in the Lansing area. However, the study of figure 5 would indicate that it was a somewhat flat surface sloping to the north and slightly to the west with points of discharge near the present Lookingglass River. This flat surface was curved downward where the Grand River, Cedar River, and Sycamore Creek had eroded the land surface below the level of the piezometric surface. At these points springs and seeps probably existed.

After pumping began the water levels were lowered in the vicinity of the wells as water was taken from storage and as flow was induced toward the wells by the withdrawals. As the pumping was increased, the compositecone of depression due to pumping expanded until at the date of figure 5 the area in which the water levels were substantially lowered (below the 820 contour) was about 8 miles long and 6 miles wide. The water levels now indicate flow toward the well fields in Lansing from all sides except in the northwest corner along the Grand River. During the development of the composite cone of depression on the old more or less flat piezometric surface, a ground-water divide was formed north of Lansing between the Grand River and the old points of discharge along the Lookingglass River. The ground-water divide has been maintained by the slowly expanding cone of depression.

Modified remnants of the old piezometric surface exist in the rural areas removed from the area of influence of the Lansing pumping. In figure 5 these remnants indicate a slope toward the major surface drainage especially along the upper reaches of the Cedar River, Grand River, and Sycamore Creek, and along the Lookingglass River. It might be expected that flowing wells could be obtained in parts of these reaches where the piezometric surface is above the land surface. It should be expected that some and probably considerable artesian leakage from the sandstones to the glacial cover reaches the rivers in these reaches. The relatively high base flow and the uniform stages of the streams in the Lansing area suggests a source supported by a large proportion of ground-water inflow.

The piezometric surface indicates to some degree the shape of the sandstone lenses in the fact that the water levels in wells are at approximately the same elevation throughout any one lens. The piezometric surface of an adjacent lens may be at a different level depending upon the degree of interconnection and upon the recharge and discharge from the lens. Perched or elevated piezometric surfaces probably caused by large lenses of clays or shales are indicated in southwestern Delta and in southwestern Meridian Townships. Further exploration by test drilling in these areas would show whether these high points in the piezometric surface were due solely to geologic conditions or to conditions of recharge as well.

The piezometric surface within the city of Lansing (see figure 6) shows the deepest parts of the cone of influence produced in the Maple Street, north Cedar Street, and Riverside well fields where the largest withdrawals of ground water were made. In the south and west parts of the city along the Grand River, the piezometric surface is higher than might be expected.

Figure 7 shows the fluctuations of two wells in the northern section of Lansing which indicate that the water levels in the wells are affected by the stages of the river. However, as explained in the following discussion of the hydrograph for Ingham Well 7, there does not seem to be recharge to the ground-water reservoir from the river.

FLUCTUATIONS OF THE WATER LEVELS

At the start of the investigation in 1944 few records of the depth to water in the wells in the greater Lansing area existed except those maintained by the Board of Water and Electric Light Commissioners in the municipal supply wells. In the rural areas surrounding Lansing only those records existed where the driller noted the depth to water at the time the well was drilled or the pump repaired. However, as a part of this study as many wells were located as possible in which periodic measurements of the depth to water could be made. Typical hydrographs of the fluctuations of the water level in those wells are included in figure 8.

The hydrographs of all the wells show declines through the period of record as all the wells are located within the area of diversion caused by pumpage within the greater Lansing area. As the pumpage in the area increased, greater hydraulic gradients were produced to create the flow toward the area necessary to support the increased withdrawals. The declining hydrographs do not of necessity indicate abnormal withdrawals from storage, but in part are an indication of the steepened gradient. Only by means of mathematical analysis and by study of long-term records of precipitation and water levels can the proportions of the decline ~~by~~ be distinguished as that caused by unwatering and that accompanying increased gradients. The hydrographs of each of the wells in figure 8 show rises during the years of 1940 to 1942 in which the above normal precipitation created conditions favorable for above normal recharge to the ground-water reservoirs.

The cumulative departure from normal monthly precipitation at East Lansing has been included in figure 8. This diagram was constructed by adding algebraically the monthly departure from normal, as reported by the Weather Bureau, to the cumulative total obtained for the previous months. The fluctuations of the diagram would in general be similar to those of a well recharged entirely by rainfall and located in an area in which the ground-water discharge is equal to the normal monthly precipitation.

Ingham Well 4, whose hydrograph is shown on figure 8, is located in southeast Lansing along the Grand Trunk Railroad about 500 feet east of Pennsylvania Avenue. This well is pumped by means of an air-lift and the static water levels are not affected by the pumping of the other wells in the field as the whole field is pumped as a unit. The hydrograph of this well shows about 15 feet of decline from 1919 to 1936. From this time until the fall of 1941 the water level lowered about 20 feet more due to the increased pumpage from this field and from the Riverside and Pere Marquette Fields. From 1941 to 1945 there was a rise in the water level in this well probably due to both the above normal precipitation preceding this period and the decrease in pumpage from this field which allowed the water levels to recover.

Ingham Well 6, whose hydrograph is shown in figure 8, is located in west Lansing near the corner of Logan Street and Saginaw Street. Although this well is more than one-fourth mile from any pumping wells, it is within the influence of the pumpage in the Maple Street and Northwest Fields and the pumpage at the Drop Forge Plant one-half mile to the west. The water level in this well declined about 14 feet from 1929 to 1941, and as a result of the increased pumpage at the Maple Street Field and the Forge Plant after this date declined an additional 30 feet by 1943.

The water levels declined slowly in this well during 1943 and 1944 similarly to the general decline in the whole west Lansing area.

Ingham Well 7, whose hydrograph is shown in figure 8, is located in the northern part of Lansing on the bank of the Grand River. The water level in this well fluctuates according to the magnitude of the pumpage of the Maple Street wells and the Northwest well field although it is more than one-fourth mile from the nearest pump. The static water level in this well lowered about 14 feet in the 21 years prior to 1941 probably due to the general lowering of the water level in the Lansing area. After the spring of 1941, a decline of about 40 feet was caused by influence of the newly constructed Maple Street well field and the increased pumpage in the vicinity. The water levels in this well slowly declined during 1943 and 1944 due to the increased pumpage and the general lowering of the piezometric surface in the area.

This well also fluctuates similarly to the stage of the Grand River although the water level is about 65 feet below the water surface of the river (see figure 7). This well is cased to the sandstone and no movement of water from the river to the well could take place except by passing through the drift and into the sandstone at some point removed from the well.

The fluctuations of the river stage in figure 7 were caused by the release of water for hydro-electric generation from two storage dams a short distance upstream from both wells. In each case, as the increased flow passed the wells, the water level in the well rose almost immediately, or at least within such a short time that it was not readily detected on the recorder chart. The amount of rise in water level in Ingham well 7 was not proportional to the amount of rise in the river stage, but in Ingham well 36 there seems to have been more relationship between the river stage and the rise in water level in the well than existed in well 7. The hydrograph in each case indicates that the weight of the additional water in the river compressed the underlying strata, so that the confined water in the sandstone assumed a share of the additional load, which it offset by an increase in the hydrostatic pressure. The rate of downward transmission of pressure was relatively fast as it produced as immediate rise in the water level in the well. Further examination of the hydrograph indicates that as the river stage continues to rise after the first initial rapid rise, the rate of rise of water level in the well became less and in the case of well 36 the water level began to decline. This may be explained by assuming that the hydrostatic pressure was dissipated laterally through the sandstones away from the river. Further examination of the hydrograph indicates that when the river stage returned to the point from which it started, the final water level in the well was slightly below its initial level. This indicates that as the vertical loading was released the water level in the well was lowered an amount equal to the pressure released.

The fact that the final water level in the well was at or below the initial point is significant because it indicates that there was no movement of water from the river to the ground-water reservoir. Had there been an addition of water in the form of recharge this would have been indicated by higher final water level in the wells after the rising river stage had passed.

Ingham Well 8, whose hydrograph in shown in figure 8 is located in south central Lansing on Townsend Street near the Oldsmobile Motor Works. This well is more than one-half mile from any large amount of pumpage, and it fluctuates according to the magnitude of pumpage in the Pennsylvania Field. The hydrograph indicates a steady decline in water level of about 20 feet from 1919 to 1944, without the sharp decline in 1941 caused by increased pumpage in the northwestern parts of the city.

Table of decline in water levels in feet

Location	Date	Elevation Of Static Level Feet Above Sea Level Datum	Date	Elevation Of Static Level Feet Above Sea Level Datum	Decline Feet
Cedar Street	10-1919	811.9	1-1945	798.3	13.6
Pennsylvania	11-1919	817.9	1-1945	779.6	42.3
Riverside	8-1924	808.9	1-1945	737.4	71.5
Seymour St.	1-1919	812.2	1-1945	749.4	62.8
Townsend St.	1-1919	822.1	1-1945	798.0	24.1
Logan St.	8-1929	822.3	1-1945	768.9	43.4
Northwest Field	12-1929	816.9	8-1944	771.6	45.3
East Lansing West Field	10-1939	818.0	1-1945	805.9	12.1
East Lansing East Field	1930	826.6	9-1944	808.6	18.0
Michigan State College #2	1930	809.1	1-1945	791.0	18.1

PHYSICAL PROPERTIES OF THE GROUND-WATER RESERVOIR

No laboratory tests have been made on the sandstones in the Lansing area to determine their water yielding characteristics as large pieces of unfractured rock are not available with present methods of drilling.

Many field tests to determine the water yielding characteristics of the sandstones in place have been made by means of pumping tests on wells in the area. By mathematical analysis of the observed rates of drawdown and recovery of the water levels in pumped wells and the observed rates of drawdown and recovery in observation wells, while other wells are being pumped, coefficients of transmissibility and storage were determined for the sandstones.

The coefficient of transmissibility indicates the ability of the sandstone to transmit water to the well. The coefficient of storage is a measure of the amount of water released from storage when the artesian head is lowered. Together they determine the amount and rate of drawdown in water levels caused by wells pumping from the sandstones.

The coefficient of transmissibility is expressed as the number of gallons of water a day that will move through a vertical prism of the aquifer one-foot wide with a hydraulic gradient of 100 percent.

The coefficient of storage is expressed as the volume of water, measured in cubic feet, that is released from storage in each vertical prism of the aquifer with a base one-foot square when the artesian head is lowered one foot.

The Theis recovery method 5/ has been applied to the recovery of the water levels in the pumped wells after turning the well off. The Theis graphical method has been applied to the drawdown and recovery of the water levels in observation wells caused by turning on and off nearby pumps.

The Theis recovery formula is:

$$T = \frac{264\,Q}{s} \log_{10} \frac{t}{t'}$$

Where

T is the coefficient of transmissibility in gpd/ft.

Q is the discharge of well in gpm.

s is the residual drawdown in feet

t is the time since pumping began in any unit

t' is the time since pumping stopped in same unit

5/ Theis, C. V., The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage. Am. Geophys. Union Trans., p. 522, 1935.

The graphical method developed by C. V. Theis, of the U. S. Geological Survey, is based on the formula:

$$s = \frac{114.6\ Q}{T} \int_{\frac{1.87\ r^2\ S}{Tt}}^{\alpha} \frac{e^{-u}\ du}{u}$$

Where s is drawdown in feet at any point in the vicinity of a well pumped at a uniform rate.

Q is the discharge of well in gpm.

T is the coefficient of transmissibility in gpd/ft.

r is the distance in feet from pumped well to point of observation.

S is the coefficient of storage

t is the time in days that well has been discharging.

A discussion of these formulas, the assumptions on which they are based, and their applications is given in U. S. Geological Survey Water-Supply Paper 887, Methods of Determining Permeability of Water Bearing Materials, by L. K. Wenzel.

In 98 determinations of the coefficient of transmissibility covering all well fields in Lansing, the values ranged from about 4,000 in the Northwest Field to 79,500 in the North Cedar Street Field and averaged 23,400 gpd per ft. In 43 determinations of the coefficient of storage, covering the same area, the values ranged from 0.000025 in the Northwest Field to 0.0043 in the Pere Marquette Field and averaged 0.000382.

The range in computed coefficients is caused largely by the variation of the materials composing the sandstones, and the manner in which the sedimentation took place. If the correlation of the coefficients of transmissibility and storage may be used to interpret the geology, it might be deduced that in the Northwest Field ground-water flow conditions approached those in which the flow takes place in solution channels or crevices where the coefficient of transmissibility is sometimes high and the coefficient of storage is very small. In the Pere Marquette Field it might also be deduced that the flow conditions approached those occuring under water table conditions or that a source of recharge existed nearby to provide a seemingly large coefficient of storage. However, the many tests demonstrate that it is practically impossible to obtain an average coefficient of transmissibility and storage which would be applicable to any larger area beyond the limits of the cones of influence of the wells tested.

RECHARGE

Recharge to the sandstone aquifers in the Lansing area may take place in the following manners: (1) direct recharge from surface water lying 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.

Direct recharge of the sandstones from precipitation or surface flows may take place in those areas where the sandstones crop out at the ground surface. Near Grand Ledge and in places along the Grand and Cedar Rivers and along Sycamore Creek favorable conditions exist for direct recharge. Also in those area which are within the cone of influence of the greater Lansing pumpage, especially in the southwestern part of town, the relatively high position of the piezometric surface indicates recharge from the river. At present these areas have not been developed sufficiently to induce appreciable flow from the river to recharge the ground water in the sandstones.

Recharge by means of downward and lateral percolation at points where the sandstones are in contact with the saturated portions of the glacial cover is probably the greatest source of ground-water replenishment in the greater Lansing area. Depressions eroded in the Pennsylvanian land surface (sandstones, shales and clays) and later filled with water bearing sands and gravels were located during the well inventory in the areas west, southwest, and northeast of Lansing. These depressions are constantly being recharged by the downward percolation of precipitation and are a source of replenishment when the piezometric surface in the sandstones is lowered below that in the sands and gravels filling the depression. Relatively high piezometric surfaces indicating recharge are shown on figure 5 in the southwestern, southern, southeastern, and northeastern parts of the area. Depressions filled with saturated sands and gravels are sources of recharge for the nearby Cedar Street, Pennsylvania, and Riverside Well Fields within the city limits.

There are areas west of Lansing where the sandstones are exposed to considerable recharge, and this recharge is transmitted laterally to adjacent lenses which are sealed from vertical recharge above by impermeable layers of shale and clay. In these areas there has been an unwatering of the sandstones although there is sufficient perched water in the glacial drift to furnish recharge to the sandstones.

Small solution channels and crevices containing flows of water estimated to be from 0.1 to 20 gallons a minute have been observed in the upper sandstone layers in wells in the Northwest Field. Reports that similar flows exist in other wells lead to the conclusion that recharge of the sandstones in this manner must be considered.

It is estimated that about 8.1 inches of rainfall over 46 square miles would recharge (assuming recharge is 100 percent effective) the sandstones an amount to equal the quantity of water pumped out in the year 1944, but calculation discussed later in this report indicate that the effective recharge amounted to in the magnitude of 2.5 inches.

QUALITY OF GROUND WATER

The chemical quality of the ground-water from the sandstone aquifers in the Lansing area is indicated by the average of 50 analyses shown in the following table.

Average chemical composition of well water City of Lansing
(Analyses by Board of Water and Electric Light Commissioners)

	ppm
Calcium (Ca)	125
Magnesium (Mg)	37
Sodium (Na)	7
Total Metallic Ions	169
Bicarbonate (HCO_3)	395
Sulphate (SO_4)	124
Chloride (Cl)	19
Total Non-metallic Ions	538
Silica (SiO_2)	12
Total Iron (Fe)	1
Free Carbon Dioxide (CO_2)	40
Dissolved Oxygen	6
Total Solids	519
Alkalinity (as $CaCO_3$)	323
Non-carbonate hardness (as $CaCO_3$)	141
Total Hardness (as $CaCO_3$)	464
pH	7.1
Temperature	51.0° F
Turbidity	25

As would be expected from the fact that most of the members of the various sandstone formations in the Lansing area are irregular in composition, the amounts of dissolved mineral matter in waters from the different members vary and are not characteristic for any one member, even when considered on a lithologic basis. The waters from the sandstone and shale formations and glacial drift are not radically different in the amounts of the various mineral constituents as each show both high and low values for all the mineral constituents. There are, however, a few generalizations that may be made, though too much reliance should not be placed on averages. It should also be remembered that the average, based on figures that range from high to low, is of little value in attempting to predict the approximate quantity of any one constituent. In many wells, water enters at a number of different depths from the sandstones and shales andpossibly from the drift. The well water is therefore a mixture and is not characteristic of any one formation.

Figure 9 and 10 indicate the areas, in and around Lansing, in which zones of less mineralized water may be found. In general these softer water areas may be close to the source of recharge, whether it be rainfall or surface water infiltration, or it may be that in isolated cases the wells sampled did not penetrate the deeper and more mineralized water-bearing formations.

In figure 9 the shaded area designates a zone where waters of higher than 300 parts per million hardness are found. Except in the vicinity of Lansing, the isolated zones cover points where the piezometric surface is the highest and has the greatest slope toward the city. The higher mineralization in some isolated zones may have been caused by the ground water remaining in contact with the water bearing rocks for a longer period; that is, the rate of movement is slower in these zones, and more chance for the solution of the rock constituents are possible.

In figures 9 and 10 the shaded areas in and near Lansing designate more highly mineralized zones than those found outside. These zones seem to coincide with those points where the static water levels have been lowered most by pumpage. The increased hardness and the higher percentage of dissolved mineral solids has undoubtedly been caused by the lowering of the head on the upper formations, thus permitting the more mineralized waters from the early Pennsylvanian rocks to infiltrate upward into the sandstones and shales tapped by the wells. Such conditions must exist in the Pennsylvania and Pere Marquette well fields as indicated in the graphs of progressive chemical change (see figure 11). In figure 11 Pennsylvania well 20 and Pere Marquette well 10 show sharp increases in total hardness and sulphate when the number of hours of use for the well field was increased in 1941. The increased hardness and sulphate continued until 1943 and 1944 when the total withdrawals for these fields were decreased and the percolation of less mineralized recharge water became a larger percent of the yield of the wells. It is evident that the mineralized waters did not come from the brine bearing formations which lie 500 to 600 feet below the land surface because the chloride content of the well waters did not increase in proportion to the sulphate and hardness. Increased hardness and sulphate content brought about by the increased pumpage are not apparent in the progressive change in chemical quality of the waters from the Riverside, Cedar, Maple and Northwest fields. Because of this fact, there has been a general shift in the center of heavy pumpage by the municipal operators to these last named fields to eliminate the additional expense in the treatment plant caused by the more highly mineralized waters from the Pennsylvania and Pere Marquette well fields.

The chemical quality of the waters from the drift does not differ materially from those in the sandstones according to the values obtained in 164 analyses made by the Michigan Department of Health as a part of a land economic survey made in 1925. 6/ In each formation the hardness ranges from 80 to 375 parts per million with the percentages of the other mineral constituents varying accordingly. However, later analyses of the certain deep wells in the Saginaw and Parma sandstones indicate that the deeper waters are slightly more mineralized. Analysis of waters obtained from descending levels in well I-90 at the Waverly Hills Golf Course show the total dissolved solids increase with descending depth as follows: 108 foot level, 392 ppm; 130 foot level, 412 ppm; 235 foot level, 426 ppm; 310 foot level, 462 ppm; and 410 foot level, 463 ppm.

Wells drilled below 450 feet in the vicinity of Lansing penetrate the Bayport limestone and the shales of the Michigan formation which contain waters highly mineralized from contact with gypsum and pyrite which are present in considerable quantity in these formations.

SAFE YIELD

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. In an artesian system such as the Pennsylvanian sandstones, the safe yield is limited by the transmissibility of the sandstones, the intake capacity of the sandstones, the amount of water that can be taken from storage, and the danger of chemical contamination by water from formations below. Accurate determination of these limiting conditions require an intensive study of the entire aquifer which, in this case, covers most of central Michigan. However, some consideration of

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6/ Unpublished information from files of Dept. of Health, collected during a well survey of Ingham County in 1925.

these limiting conditions is warranted if only to point the way for future work.

In a given hydrologic system, the quantity of recharge must be equal to the total amount of discharge if the system is to remain in a condition of equilibrium. Such a condition probably existed in the Pennsylvania sandstone prior to the beginning of pumping in the greater Lansing area. However, the introduction of pumping wells represented an additional discharge superimposed on a previously more or less stable system. In a period of time the quantity of water discharged by the wells must be balanced by a loss in storage by the aquifer, a decrease in the natural discharge, or an increase in the recharge. 7/ The loss in storage is proportional to the fall of the piezometric surface, which is greatest near the wells and decreases in all directions outward. The fall of the piezometric surface modifies the hydraulic gradients in the vicinity and changes the direction of the natural movements of the ground water.

The geometric solid represented by the falling piezometric surface is called the cone of influence of the well. The depth of the cone is proportional to the rate of discharge of the well, but the rate of its lateral spread is dependent only on the physical characteristics of the aquifer and the duration of the pumping. The cone spreads laterally, until by a change in gradient it reduces the natural discharge by an amount equal to the water pumped, or in some cases, increases the recharge by a like amount.

The area of diversion is that area from which ground water is drawn into the cone of influence to replace the water diverted by the pump.

The area of diversion of the greater Lansing area has not as yet reached a steady state, as it has not spread laterally to reduce the natural discharge or

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7/ Theis, C. V., The source of water derived from wells. Civil Engineering, Vol. 10, No. 5, pp. 277-280, May 1940.

increase the recharge by an amount equal to the withdrawals.

The quantity of water flowing into the area of diversion in the Lansing area may be computed as the product of the average coefficient of transmissibility, the hydraulic gradient and the length of circumferential line enclosing the area of concentrated withdrawal. Thus: 8/

Length of 820 contour (figure 5) is. . . . . 30 mi.

Coefficient of Transmissibility. . . . . . . 23,400 gpd/ft.

Hydraulic gradient is. . . . . 15 ft/mi.

Substituting Q = 30 x 23,400 x 15

Q = 10,000,000 gallons a day

The value of 10 million gallons a day, when considered as the average rate of inflow to the area, is higher than the average in the past years because the present hydraulic gradient is higher.

In figure 8, the average water levels for wells Ingham No. 4 and Ingham No. 8 show practically no decline from 1919 to 1932 and wells Ingham No. 6 and Ingham No. 7 show about ten feet of decline in their early periods of record. The pumpage during these years ranged from 4.7 million gallons a day in 1920 to 8.5 million gallons a day in 1930. Since the average daily withdrawal of less than 8.5 million gallons a day did not produce a noticeable unwatering of the aquifers, this probably was about equal to the inflow to the area of diversion.

However, the increased pumpage in excess of 8.5 million gallons a day since 1935 has produced an unwatering of the aquifers as indicated by the declining water levels in figure 8. A computation of the volume of the geometric solid outlined by the isopiestic lines on figure 5 and 6 indicates that a major portion

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8/ Wenzel, L. K., Methods of Determining Permeability of Water-bearing Materials, U. S. Geol. Survey Water Supply Paper 887, 1942.

of the water came from storage, and that the inflow to the area is not as high as has been computed above. This unwatering may be due to lower actual coefficients of transmissibility than those obtained by pumping tests in the municipal wells due to the fact that the tests on the wells were not continued for a long enough period to unwater areas which contained large lenses of shales or clays. The coefficients of transmissibility of the shales and clays would be small compared to those obtained for the sandstones, and when averaged in a computation would necessarily reduce an overall coefficient of transmissibility below that obtained within a well field.

The effective inflow into the area of diversion in the Lansing area is probably in the magnitude of from 5 to 9 million gallons a day which would include all the locally intercepted recharge.

FACTORS TO BE CONSIDERED IF THE PUMPAGE IS INCREASED

Relationship between water levels and pumpage The relation between the decline of the water levels and the quantity of pumpage in the Lansing area cannot be established on a mathematical basis as the non-homogeneity of the sandstone nulifies any assumptions that may be made on the extent of the aquifer and its water-transmitting characteristics. However, in a uniform aquifer of unlimited extent, and having coefficients of storage and transmissibility equal to the average values obtained in the tests of the Lansing area, a well yielding one million gallons a day would cause a decline of 17 feet at one mile, 14 feet at two miles, 8 feet at five miles, and 4 feet at ten miles after one year of continuous pumping.

In the design of well fields to increase the pumpage from the area, consideration should be given to both the interference between wells and the regional lowering of the levels. In a hypothethical aquifer many small-yield wells at reasonable spacing will extract more water from a given area than several large yield wells for the same regional lowering of the water levels, provided that all the water is not derived from storage within the aquifer.

Infiltration of waters of higher mineralization The lowering of the water levels by increased pumpage in certain areas have already induced infiltration, from below, of the waters of higher hardness and increased sulphate. This infiltration occurs only in those localities where the Pennsylvanian sandstones were deposited on high points of the Michigan formations of shales and limestones.

NEED FOR FURTHER EXPLORATION

The development of the ground-water reservoir in the Lansing area has been carried on without full knowledge of the possibility that the safe yield of the aquifers may be exceeded, but this has primarily been due to the fact that the quantitative study of ground-water problems is relatively new. In the past many successful developments were made by the simple process of drilling more wells, and as a result certain areas of over-development have arisen.

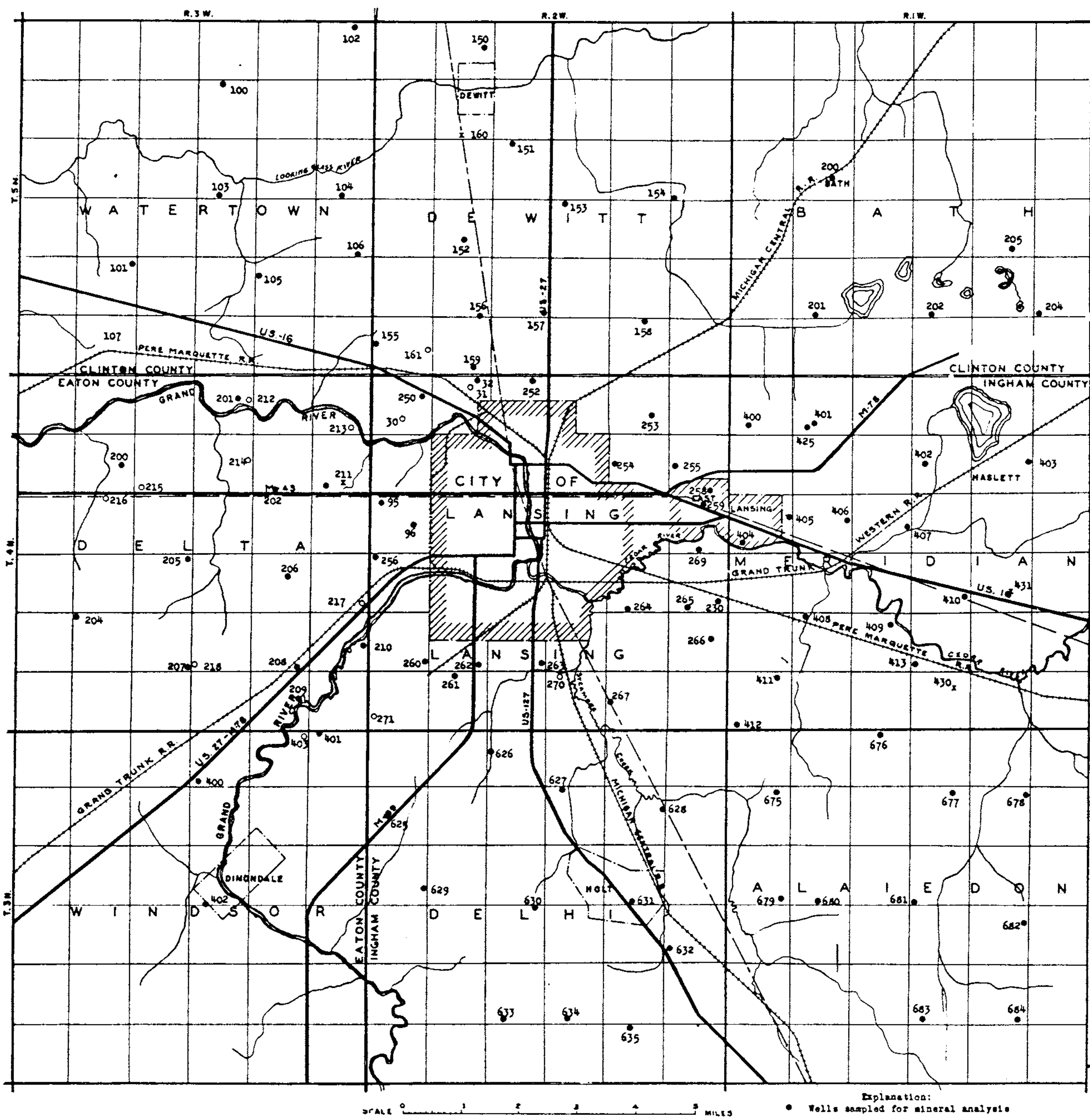
It is essential that the greater Lansing area find new localities for ground-water developments to take care of the municipal growth and the increased demand for water of low temperature by the industries in the area. The easily obtained ground-water supplies close to the central distribution system have already been tapped, and additional supplies will of necessity be more difficult to locate and more expensive to develop. For this reason there will be a larger percentage of small yield wells and the cost of production of water will increase. It is necessary that information be obtained as to the location of additional supplies in order that the expanding main systems and other water facilities may incorporate the new supplies into the existing units as the need arises.

In the rural area south and east of the city, additional ground water is contained within the sandstones which are being constantly recharged by percolation from the glacial drift. Much of the recharge rejected by the sandstones is being discharged from the drift into the Grand River and into Sycamore Creek. Test borings are needed to determine the thickness of the water-bearing formations and the quality of water contained within the formation. Pumping tests are also needed to determine an estimate of the perennial yield of the formation.

A general program of test borings covering the greater Lansing area would assist in location of the more promising areas of development while a more intensive program would determine the feasibility of the development.

Although this progress report gives estimates of the order of magnitude of the recharge and the withdrawals from storage, these estimates can be improved by the continuous observation of pumpage and water levels.

This report summarizes an investigation intended to point the way to a successful and safe ground-water development for the greater Lansing area.



Explanation:

- ● Wells sampled for mineral analysis
- ○ Observation wells
- x Uncased borings

(See Figure 3)

- — — West to East geologic section
- – - – North to South geologic section

FIGURE I.
LOCATION OF WELLS
GREATER LANSING AREA

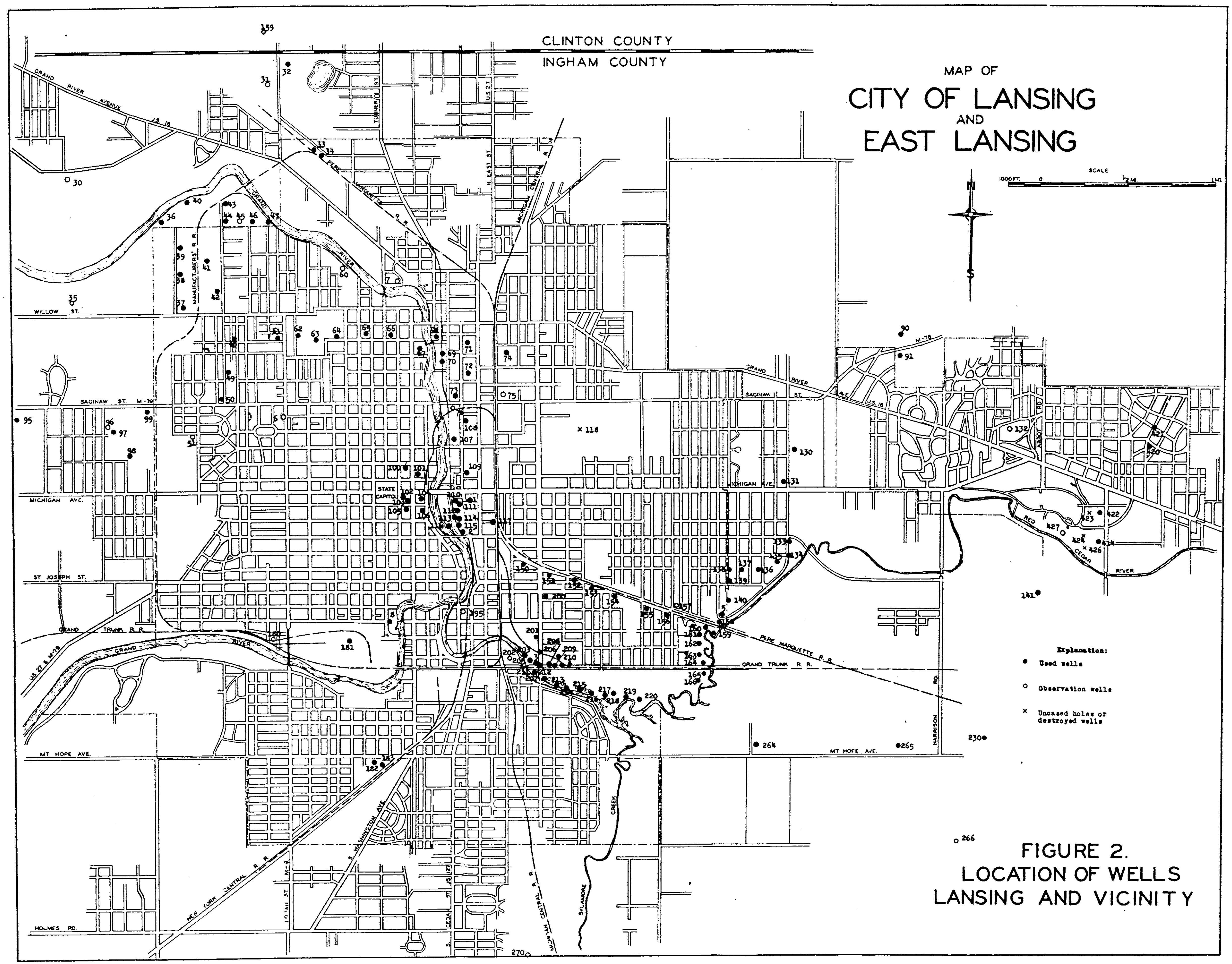


FIGURE 2.
LOCATION OF WELLS
LANSING AND VICINITY

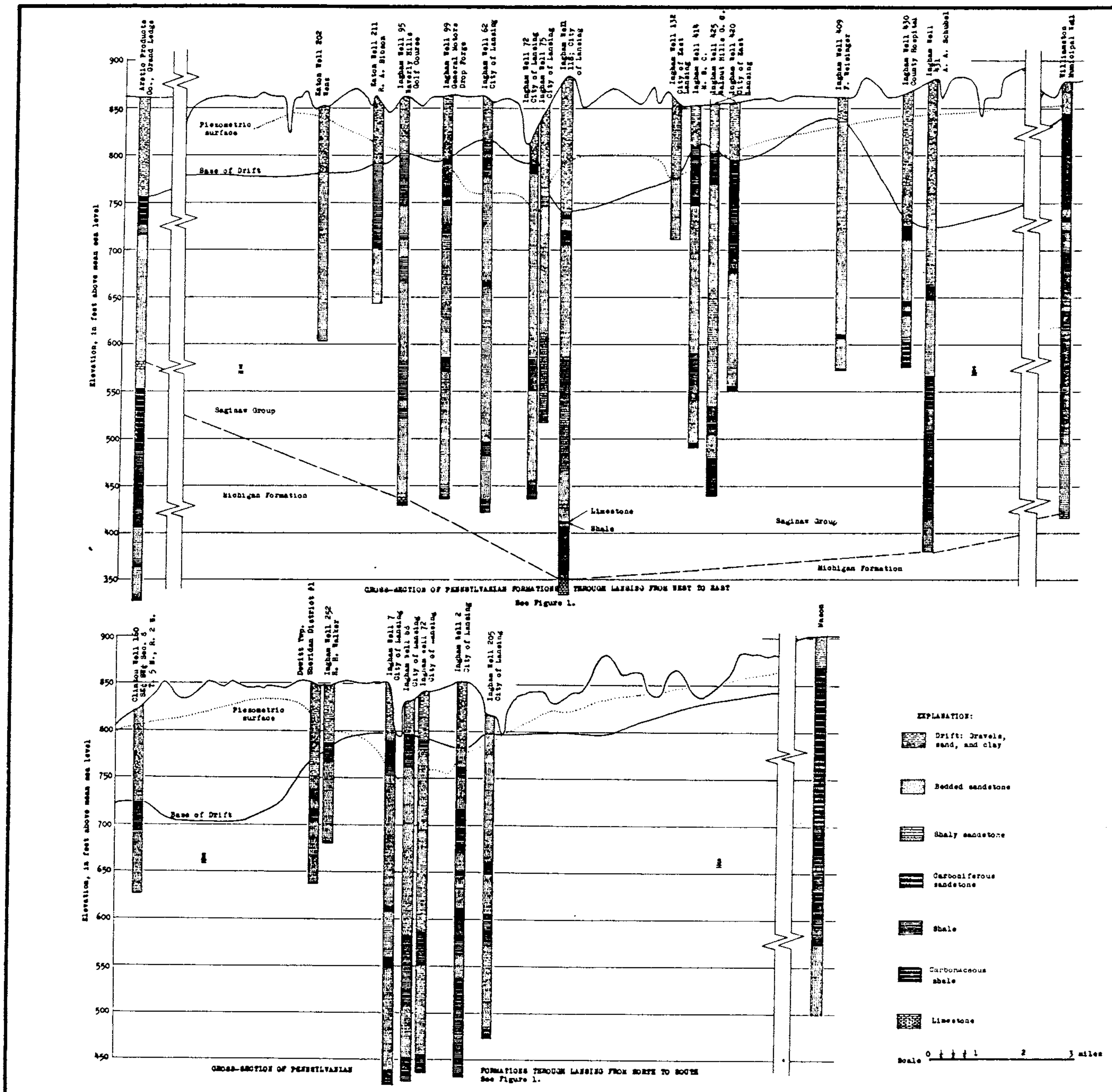


FIGURE 3

CROSS-SECTION OF PENNSYLVANIAN FORMATIONS THROUGH LANSING

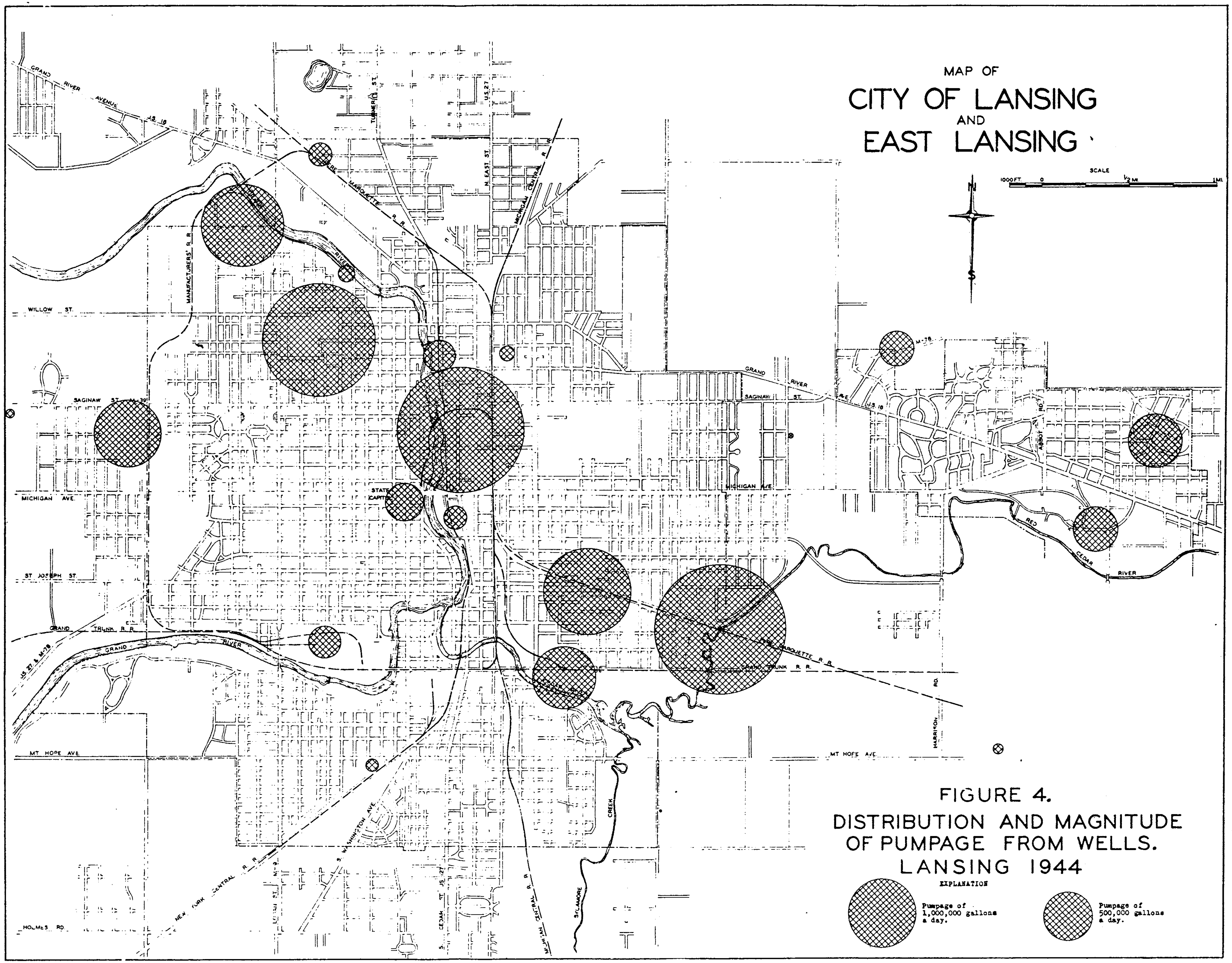
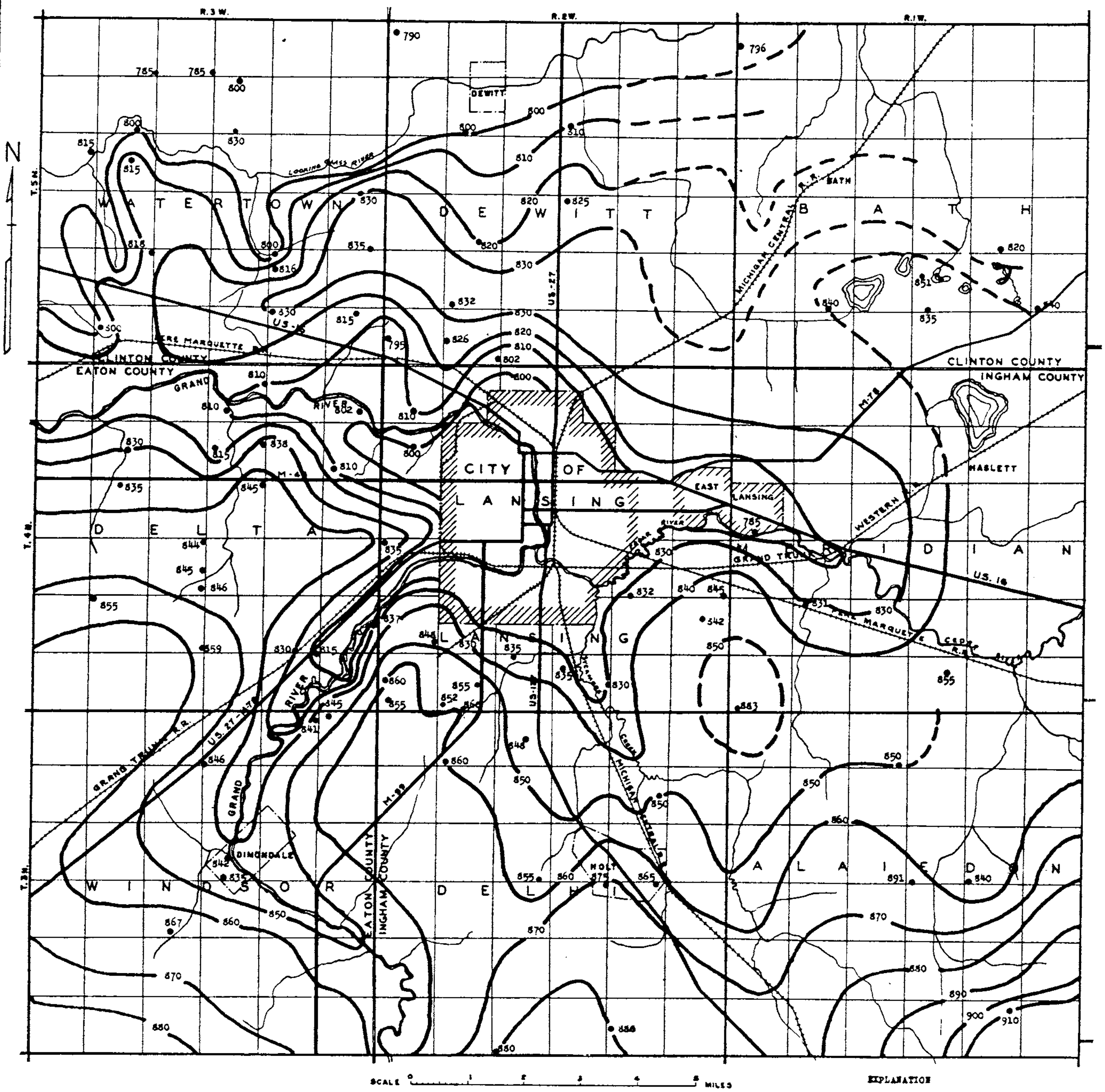


FIGURE 4.
DISTRIBUTION AND MAGNITUDE OF PUMPAGE FROM WELLS.
LANSING 1944
EXPLANATION



EXPLANATION

Contours represent approximately the height to which water would rise above mean sea level in a tightly cased well penetrating the sandstones.
Contour interval is 10 feet.

FIGURE 5.
PIEZOMETRIC SURFACE OF WATER IN PENNSYLVANIAN SANDSTONES LANSING AREA-SPRING 1945.

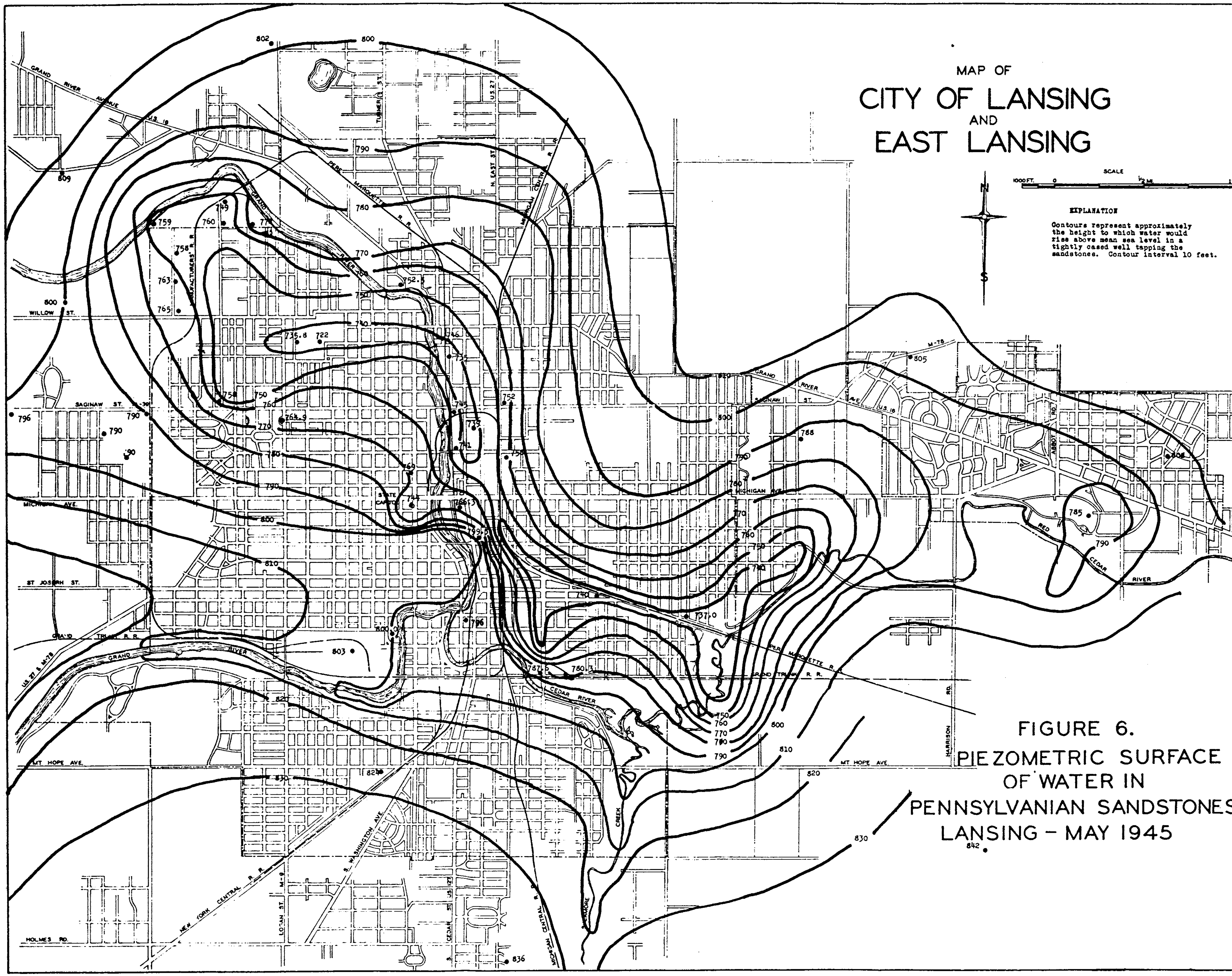


FIGURE 6.
PIEZOMETRIC SURFACE
OF WATER IN
PENNSYLVANIAN SANDSTONES
LANSING – MAY 1945

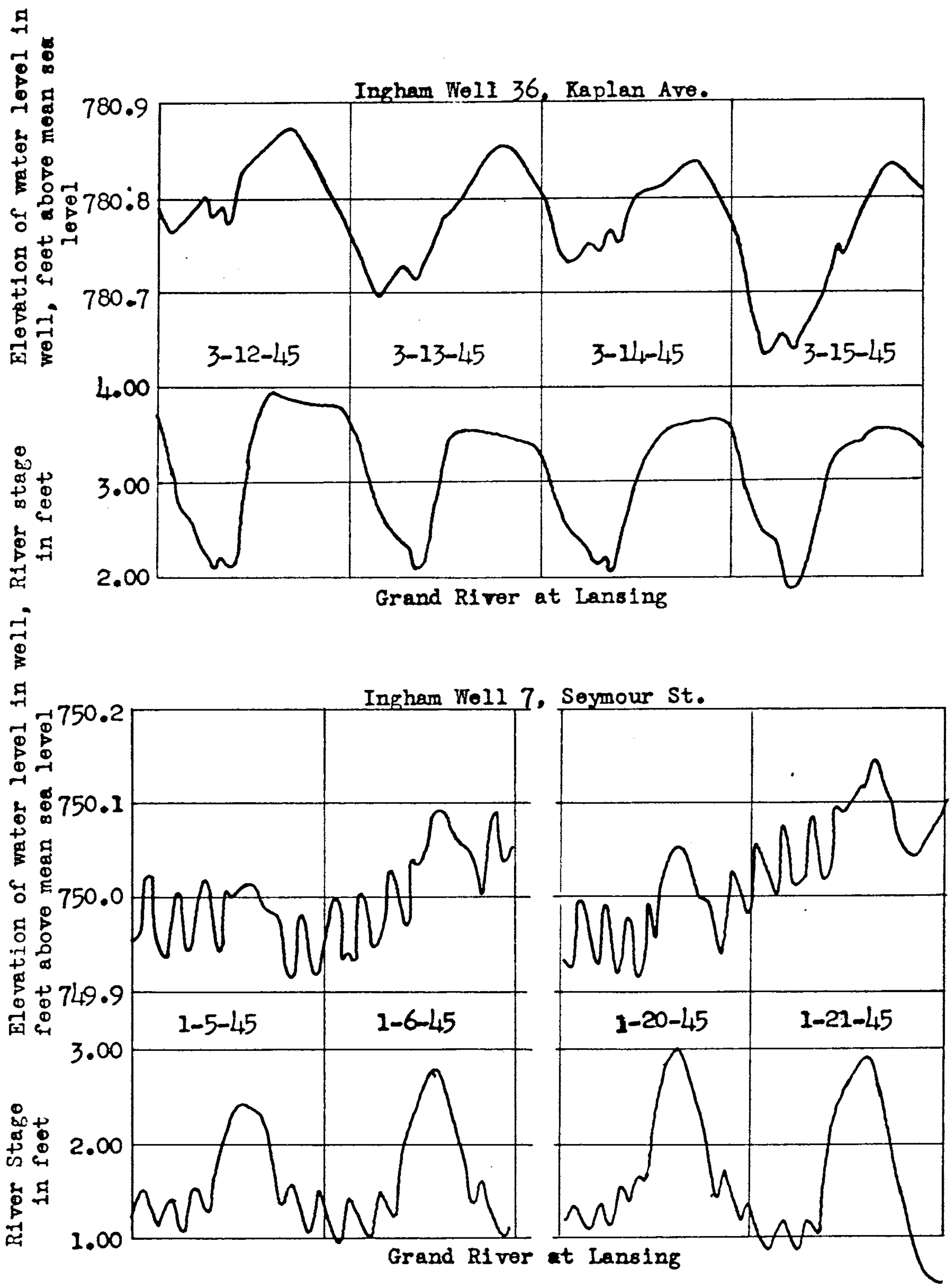


FIGURE 7

HYDROGRAPHS SHOWING EFFECT OF

CHANGING RIVER STAGE ON WATER LEVELS IN

WELLS I-7 and I-36

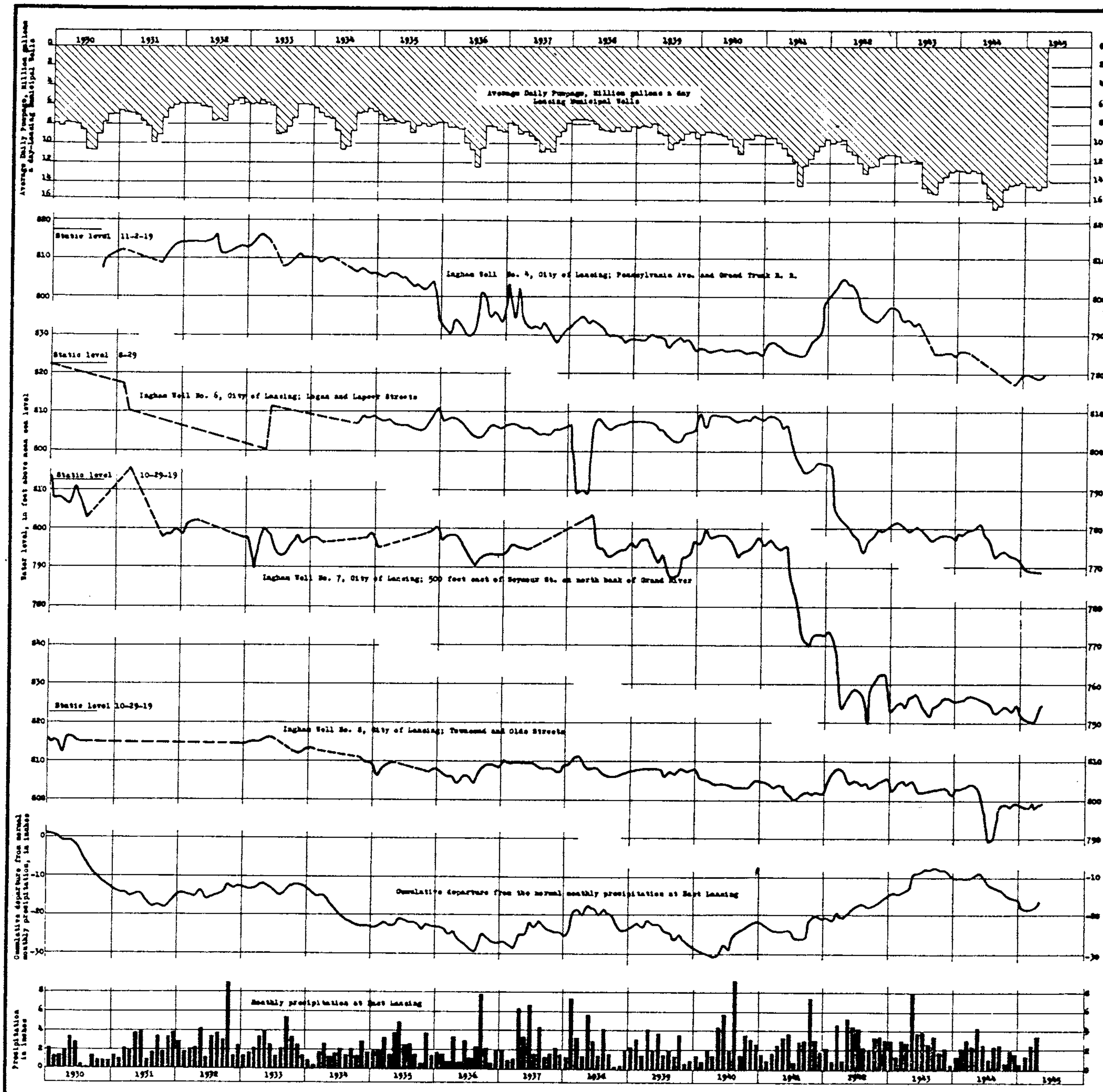
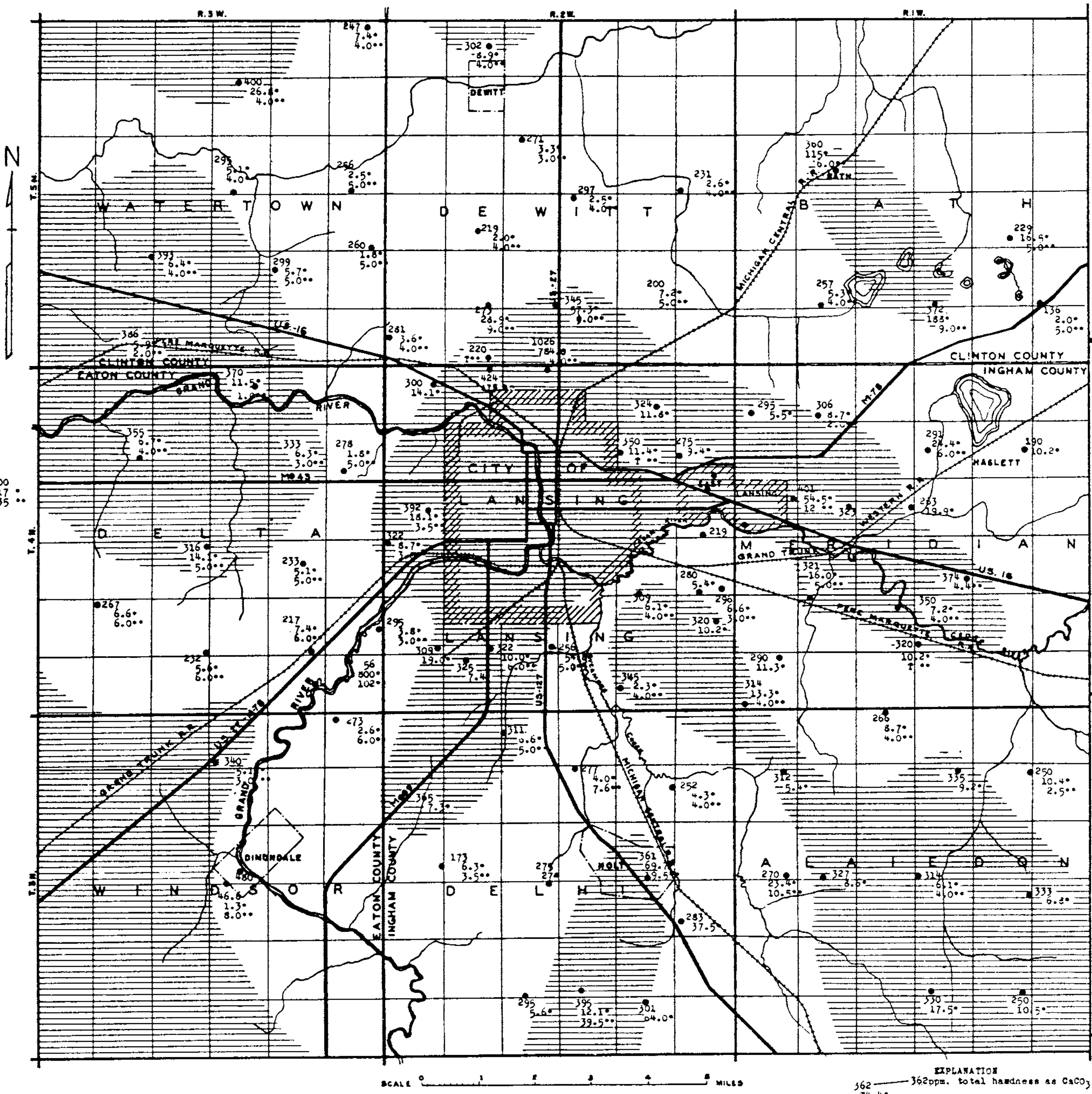


FIGURE 8.
GRAPHS SHOWING PUMPAGE, FLUCTUATIONS OF WATER LEVELS, & PRECIPITATION-LANSING.



EXPLANATION

362 — 362ppm. total hardness as $CaCO_3$

74.4* — 74.4*ppm. Sulphate (SO_4)

15.0** — 15.0**ppm. Chloride (Cl)

• — Location of point of analysis.

▤ — Greater than 300 ppm. total hardness reported as $CaCO_3$

FIGURE 9.

AREAS OF WATER ANALYZING GREATER THAN 300 PPM. TOTAL HARDNESS GREATER LANSING AREA

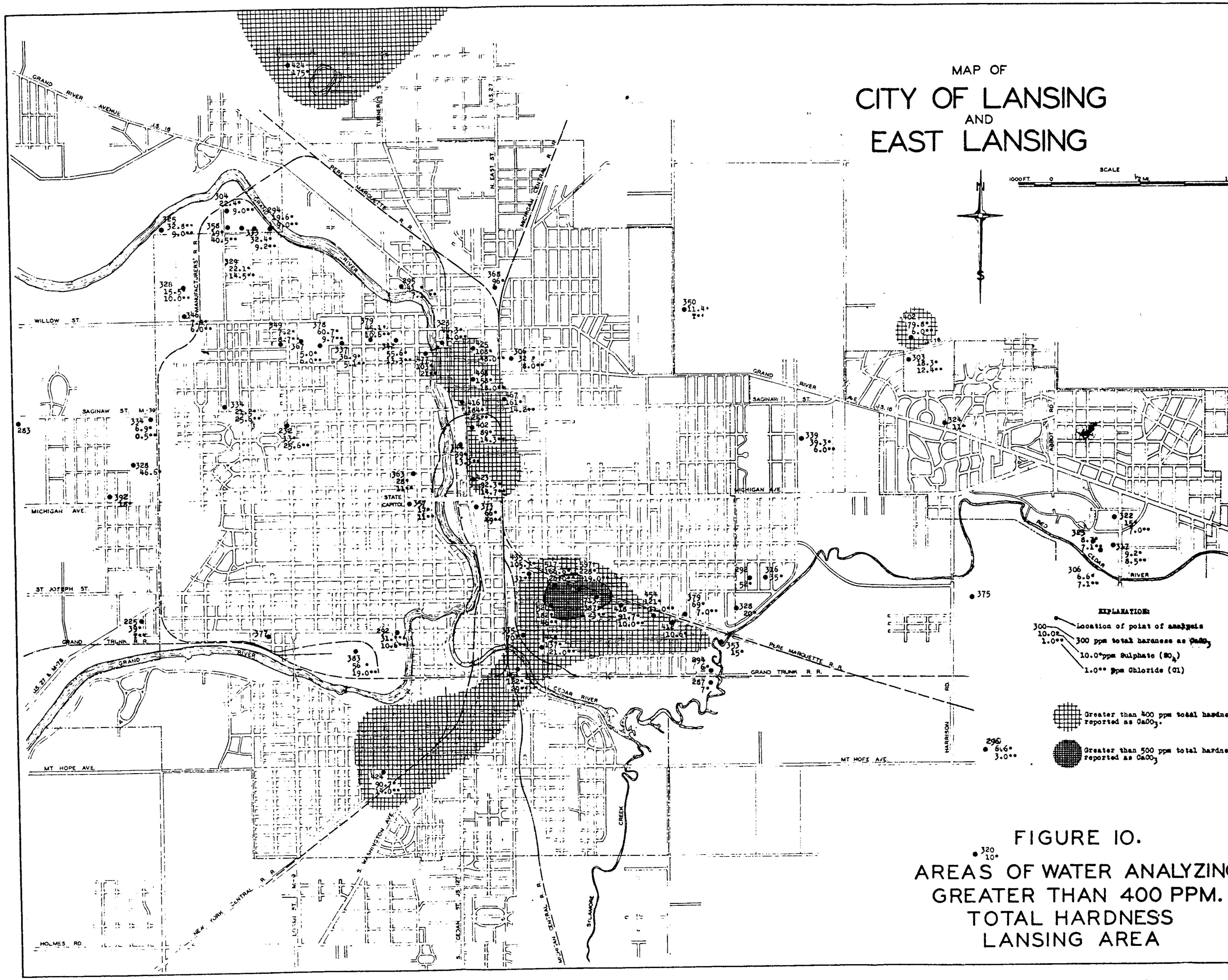


FIGURE 10.
AREAS OF WATER ANALYZING GREATER THAN 400 PPM. TOTAL HARDNESS LANSING AREA

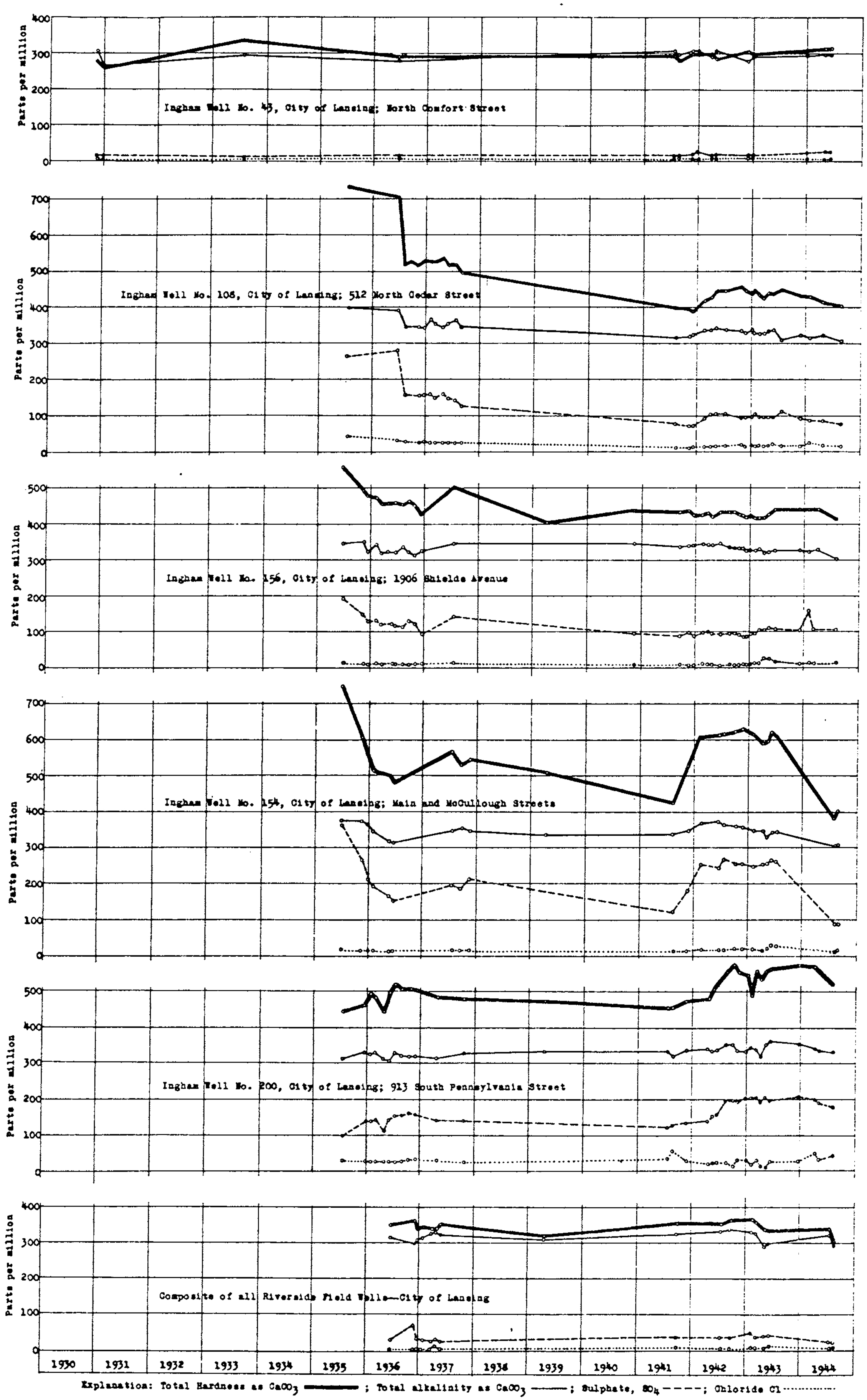


FIGURE 11.
GRAPHS OF PROGRESSIVE CHANGES IN CHEMICAL QUALITY.