PROGRESS REPORT NUMBER TWELVE

STATE OF MICHIGAN

DEPARTMENT OF CONSERVATION
P. J. HOFFMASTER, Director

GEOLOGICAL SURVEY DIVISION
R. A. SMITH, State Geologist

GROUND WATER RESOURCES OF THE BENTON HARBOR AREA, MICHIGAN

1945

BY
W.T. STUART AND R.W. STALLMAN

PREPARED IN COOPERATION WITH
THE UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
JUNE, 1945

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Prepared in cooperation between the Geological Survey, U. S. Department of the Interior, the Geological Survey Division, Michigan Department of Conservation, and the City of Benton Harbor

June 1945

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INTRODUCTION

A large increase in the demand for water in the Benton Harbor area has resulted from the recent influx of war workers. The investigation on which this report is based was made to obtain information as to the adequacy of the ground-water supply in the area. The field work was done in February and March 1945 by W. T. Stuart and R. W. Stallman, of the U. S. Geological Survey.

An inventory of 65 wells in and near the city was made in which the following information was tabulated for each well wherever available: location, owner, driller, altitude, log, casing record, water levels, pump data, pumping test data, pumpage records, temperature, and chemical analysis of water. Most of these wells supply water to the municipal supply system, industrial plants, office buildings, hotels, or suburban communities. Water level measurements were made in a few of the unused wells throughout the city, and pumping tests were made on the wells within the municipal field. The well records are shown in table 3 and 4, and the driller's logs for a portion of which are given in table 5. A map showing the location of the wells with numbers, corresponding to numbers used in the text and in the tables, is included in figure 1.

The writer gratefully acknowledges the assistance of Mr. William Russell, superintendent of the City Water Department of Benton Harbor; Mr. John Toyne, of the Smith-Monroe Drilling Co., Inc.; Mr. N. E. Gunderson, of the Layne-Northern Co.; and Mr. C. R. Wightman, of the Department of Public Works, Benton Harbor, who contributed much information from their files.

GEOLOGY AND ITS RELATION TO GROUND WATER

The potable water of the industrial and public supplies in the Benton Harbor area is obtained from the gravel, sand, and clay of the glacial drift, which in this locality ranges from 50 to 150 feet in thickness. Directly below the drift is the Coldwater shale of consolidated shales with a few thin shaley sandstones which contain highly mineralized waters or brines unsuited for public supply. Underlying the Coldwater shale in descending order are the Antrim shale, Traverse group, Dundee formation, and Detroit River and Bass Island dolomites, all containing mineral waters and brines. A typical well log would show the following section:

Coldwater shale................................	200 feet
Antrim shale...................................	125 feet
Traverse group and Dundee formation...........	180 feet
Detroit River dolomite.........................	160 feet
Bass Island dolomite...........................	500 feet

Analyses of waters from wells penetrating the consolidated rocks prove there are saline waters in the upper formations. Heavy brines at about 500 feet, "black sulphurous" brine at 1,000 feet, and a "white sulphurous" brine at 1,300 feet.

Drillers logs show that the glacial drift is composed of a few feet of coarse gravel lying in lenses and in channels upon the eroded surface of the consolidated rocks (see fig. 2). Above the gravels is a bed of lake clay approximately 100 feet in thickness. On top of the clay are alluvial sands, gravels and silts, which vary from a thin film to 10 feet in thickness. The gravel lenses beneath the clay furnish most of the water to the wells.

The gravels and fine sands at the bottom of the drift are composed of outwash materials deposited on the eroded, pre-glacial, shale land surface. These materials were carried into the area by the eastward flowing meltwaters of the Lake Michigan glacial lobe as it halted and built up the Lake Border morainic system.

At an earlier stage in its retreat, the glacier had built up the high Valparaiso Moraine whose line of hills cross Berrien County from the northeast corner to the center of the southern boundary. When the ice halted and built the Lake Border Moraine, short swift streams flowing down the western slope of the Valparaiso Moraine added their gravelly burden to the gravels deposited by the melt waters from the west, thus developing some of the gravel lenses. On the eastern side of the Valparaiso Moraine, less swift streams were tributary to the St. Joseph River which was then flowing southward past South Bend, Indiana, to the Kankakee River and eventually to the Mississippi River.

As the ice halted at the Lake Border Moraine, its melt waters collected, filled the lowland to the east and formed a lake between the two moraines, which was enlarged when the rising waters of Lake Chicago breached the Lake Border Moraine and overflowed eastward. In this lake, 100 feet of lake clays were deposited before the streams flowing into it from the east, and down the western slope of the Valparaiso Moraine, cut their headwaters eastward. These streams eventually captured the drainage of the southward flowing St. Joseph River and caused it to be cut off from the Kankakee River near South Bend, thus reversing its direction of flow. The St. Joseph then took a course northwestward across Valparaiso moraine and the lake plain, through the breach in the Lake Border moraine to Lake Chicago.

When reversal of drainage occurred, the St. Joseph River washed sand and gravel from the Valparaiso Moraine and built a delta above the clay over which it flowed, depositing gravel, sand, and silt. As the Lake Chicago level lowered, the river adjusted its level to the lake by trenching its channel in the lowland.

The glacial history explains why the drift has two water yielding zones where the upper sands and the lower gravels are present. In both sands and gravels the hydraulic gradient is from the moraines in the east toward the lake, but the hydrostatic pressure is not as great as might be expected. The moraines undoubtedly act as a collection basis for the rain and snow waters, and in the moraines the ground water percolates downward and laterally through the interbedded deposits of sands and gravel.

The ability of the sand and gravel to yield water to a well depends upon their porosity and permeability.

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

Well sorted deposits of uncemented gravel, sand or silt have a high porosity, regardless of the size of the individual particles, but a poorly sorted material, in which small particles fill the spaces between the larger ones, 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 sand may have a higher porosity than a coarse poorly-sorted gravel 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. In a silt or fine-grained sand only a small part of the water can be drained out by the force of gravity, whereas in a coarse gravel having the same porosity only a small part is retained and the remainder, acted upon by gravity, becomes available to wells.

Permeability The permeability of a formation is its capacity for transmitting water and is measured by the rate at which it will transmit water through a given cross-section under a given loss of head per unit distance. A bed of fine sand may have as high a porosity as a deposit of coarse gravel, but because of the small size of its interstices, it will require the application of a greater head-difference to transmit water. Thus a well penetrating a very fine sand will yield almost no water because of the low permeability of the sand, even though that sand is saturated with water. On the other hand, a well penetrating a coarse sand or gravel with a high permeability may yield a very large supply.

Further discussion of the capacity of sand and gravel formations to act as storage reservoirs and their ability to transmit water to wells is contained in a later section of this report.

HISTORY OF GROUND WATER DEVELOPMENT

The history of the development of ground water is rather closely related to the growth of the city. The first wells were privately owned and served each dwelling unit, and later the municipal supply was derived from a series of small diameter wells at the central pumping plant. In 1930 the installation of the first deep Kelly-type well was completed, and the small shallow wells and their suction lines were abandoned. From 1930 to 1945 three additional wells with large yields were drilled.

PUMPAGE

Figure 3 shows the distribution of the pumpage in the Benton Harbor area. The total pumpage for each locality is represented by circles, the size of which indicates the magnitude of the pumpage for that locality. The heaviest withdrawals of ground water are in the vicinity of the City Water Works, with other concentrations of pumping in the industrial areas to the north and east. Estimates of the average quantity of water pumped in thousands of gallons a day are given in table 1, which shows the amount of water used by each type of industry. These estimates are based upon information furnished by the owners of the wells and the engineers in charge of the pumping plants.

TABLE 1 ESTIMATED AVERAGE DAILY PUMPAGE FROM WELLS IN BENTON HARBOR AREA IN 1944.

	Million Gallons A Day
Municipal Supply	2.39
Metal Working Industries	1.40
Miscellaneous Industries	0.33
Canning	0.33
Miscellaneous Public Supplies	0.13
Ice Making	0.12
Air Conditioning	0.03
Total	4.73

The average daily pumpage by months, for the municipal supply, is shown in figure 4 for the years 1935 through 19[illegible]. As shown, the average daily pumpage increased from 1.1 million gallons a day in 1935 to 2.4 million gallons a day in 1944, with the largest percentage increase occurring si[illegible].

DECLINE OF WATER LEVELS IN WELLS

Measurements of static water levels in the Benton Harbor area have been made in the production wells of the municipal supply system. The hydrographs of the municipal wells (see figure 4) show that in general the water level was about 10 feet lower in 1944 than in 1940. This was due in part to the steepened hydraulic gradient produced when the pumpage of water was increased. In the preparation of figure 4 the pumpage by months was inverted to show increasing magnitude in a downward direction to illustrate the fact that the lowest points of water levels coincide generally with the peaks of pumping. These hydrographs also indicate that as the rate of pumping decreased the static water level rose approximately to the level that existed before the pumpage was increased. A significant fact was noted during the tests of the municipal wells on February 11, 1945. When all the wells were turned off for a ten hour period, the water levels rose to a level only about 32 feet below the pump base, which was about the static level of 1940 - only 2 feet below the levels recorded in 1930, when the first well was placed in operation.

Pumping Levels: During the inventory of the industrial and municipal supply wells, it was noted that the pumping levels had lowered considerably, without a corresponding increase in yield, over those levels noted at the time the wells were first placed in production. This fact denoted a decrease in specific capacity (ratio of discharge to drawdown) which has probably been brought about by the incrustation of the well-screens and the water-bearing materials in the vicinity of the wells. Much of the incrustation has been caused by iron and carbonate deposits. This deterioration of the wells has brought about a simulated condition of ground-water shortage without any actual unwatering of the ground-water reservoir.

TRANSMISSIBILITY AND STORAGE CAPACITY OF THE WATER-BEARING BEDS

In February 1945 a series of pumping tests were made on the production wells at the municipal well field. Each test consisted of pumping a well a given length of time, then stopping the pump and observing the rate of recovery of the water level within the well. In most tests it was possible also to observe the interference in the recovery of the well itself produced by stopping and starting pumps on other wells.

Hydrographs, showing the water levels, plotted against time were analyzed by the recovery method and the Theis graphical method to determine values of the transmissibility and the coefficient of storage.

The transmissibility indicates the capacity of the water-bearing formation as a unit to transmit water. The coefficient of storage is a measure of the amount of water released from storage in the formation and its confining beds when the artesian head is lowered. Together they determine the amount and rate of draw-down of water levels caused by wells pumping from the aquifer.

The transmissibility maybe expressed in terms of the number of gallons of water a day that will move through a vertical strip of the aquifer one foot wide with a hydraulic gradient of 100%. The transmissibility is the product of the permeability and the thickness of the aquifer.

The coefficient of storage is defined as the volume of water that is released from storage in a vertical prism of the aquifer of unit cross-section when the artesian head is lowered one unit.

The Theis recovery formula is:

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

Where T is the transmissibility in gpd. per ft.

Q is the discharge of the well in gpm.

s is the residual drawdown in feet.

t is the time since pumping began.

t' is the time since pumping stopped.

The equation for the drawdown produced in a well discharging at a constant rate from an infinite aquifer, published by C. V. Theis, of the Geological Survey in 1935, is:

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

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

Q is the discharge of the well in gpm.

T is coefficient of transmissibility in gpd. per ft.

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

S is the coefficient of storage.

t is time in days that well has been discharging.

In this test values of transmissibility were determined by application of the recovery formula to the recovery of the water levels produced by shutting down the pumped wells. The values of transmissibility and coefficient of storage were determined by graphical procedure based on the equation just preceding. Use was made of observations of both the amount and rate of drawdown and the amount and rate of recovery in the observation well. Values of transmissibility were also obtained by application of this graphical procedure to the drawdown and recovery of the water levels in the pumped wells.

A discussion of these formulas, the assumptions on which they are based, and their application are given in U. S. Geological Survey Water-Supply Paper 887, Methods of Determining Permeability of Water-Bearing Materials, by L. K. Wenzel. Values of the transmissibility and storage coefficients determined by these formulas are given in Table 2.

TABLE 2 VALUES OF TRANSMISSIBILITY

From recovery tests

Well 1	79,000 gpd per ft.
Well 2	77,500 gpd per ft.
Well 3	57,400 gpd per ft.
Well 4 (new well)	108,000 gpd per ft.

From interference tests

Well 1 on Well 4 (drawdown)	72,500 gpd per ft. *
(recovery)	74,250 gpd per ft **
Well 2 on Well 4 (recovery)	75,000 gpd per ft.
Well 3 on Well 4 (recovery)	65,700 gpd per ft.

COEFFICIENTS OF STORAGE

From interference tests

Well 1 on Well 4 (drawdown)	.00269 *
(recovery)	.00220 **
Well 2 on Well 4 (recovery)	.00088
Well 3 on Well 4 (recovery)	.00022

* average of four tests
** average of two tests

YIELD OF THE GROUND-WATER RESERVOIR

The amount of water that can be withdrawn from the water-bearing beds depends upon the amount of water from rain and snow that percolates into them in their outcrop areas, upon the capacity of the beds to transmit water to the pumped areas, and upon the amount of water that is withdrawn from storage in the bed when the head declines.

The study of the water levels indicates that at Benton Harbor, the whole ground-water reservoir has not been developed to a point where the yield is dependent upon the quantity in storage or the recharge available, but is dependent upon the ability of the water-bearing sands and gravels to transmit water to the wells. In other words, the permeability of the materials and the saturated thickness of the beds are the governing factors. It follows then, that the maximum quantity of water that can be transmitted through the aquifer will be attained when the hydraulic gradient is developed to a maximum without actually unwatering the aquifer or decreasing the saturated thickness of it. The maximum yield will occur when the water levels have been lowered over the whole ground-water reservoir and the largest possible area of recharge has been brought into bearing with the steepest hydraulic gradient.

However, the development of the maximum gradient within a given well field is limited somewhat by the physical properties of the wells themselves. The well should be constructed so as to allow the water to pass through the screen into the well as freely as it can move within the aquifer, thereby eliminating screen losses. The wells within a field should be spaced far enough apart to develop their own cones of influence without excessive interference with adjacent wells.

Such conditions are not found in actual practice and the seemingly maximum yield of a group of existing wells is not the maximum yield that could be obtained with improved practices. Tests of the drawdown in the present wells of the municipal supply system show that the screen losses are in the magnitude of 60 percent of the total drawdown for Well No. 1, 50 percent for Well No. 2, 68 precent for Well No. 3, and 5 percent for new Well No. 4. This means that in the case of Well No. 1 that the well was yielding only 40 percent of the water it could have yielded if there had been no hydraulic losses within the well, and similarly Well No. 2 was only yielding half the quantity it should have.

There are several causes for these losses: plugging of the screen openings by the fine materials within the aquifer, incrustation of the screen, incrustation of the aquifer in the immediate vicinity of the well, deterioration of the well screen, or perhaps a combination of two or more of these causes.

However, taking into consideration these losses within the wells and using the values of the hydrologic characteristics determined from the pumping tests, it is calculated that when the pumping level in each well of the Benton Harbor Water Supply is lowered to the top of the screen (top of the water-bearing sands) that the combined yield of all the wells pumped continuously will be in the magnitude of 4.2 million gallons for the first day, 3.5 million gallons on the 10th day, and 3.1 million gallons after three months of continuous useage. Insufficient information on the geologic limits of the aquifers prevents taking into consideration the effect that this pumpage may have when the cone of influence reaches the edge of the aquifer (this may decrease the yield) or when locally intercepted recharge tends to increase the yield. It is believed that the St. Joseph River recharges the aquifers in the Benton Harbor area significantly, although in the short period of the investigation no changes in the water levels were measured that could be correlated with the changes in the river stage.

The statements that the present limits of production of the municipal wells amount to over 3 million gallons a day do not mean that the possibilities of further production of ground water are limited in the Benton Harbor area. Three million gallons is the amount of water that can be withdrawn from the existing wells under present conditions. It is feasible to bring additional wells into production at sites sufficiently removed from the present locations so as to reduce interference to a minimum. In fact, additional wells tapping the same sands and gravels now used may be developed if a spacing of about 1,000 feet is maintained between them.

The withdrawal of about 5 million gallons a day from the ground-water reservoir by the municipal and industrial well systems in the greater Benton Harbor area has neither produced an unwatering of the water-bearing formations nor a large increase in the hydraulic gradient toward the area. With this criterion, it may be expected that the withdrawals could be increased in the magnitude of 50 percent through properly spaced and constructed wells without jeopardizing the existing developments. This expansion of pumpage could take place by developing new cones of influence between the existing industrial and municipal cones of influence.

Locations For Future Exploration

The most productive aquifer in the Benton Harbor area is the lower sand in the glacial drift. This sand is of variable thickness and permeability, and is a part of an old outwash channel running in a southerly direction in the vicinity of the present St. Joseph River. At Benton Harbor the sand lies about 100 feet below the land surface, but records of the formations found in wells south of town show that, although the drift becomes thicker, the lower sand is composed of several thinner layers separated by clays or muddy sands, and in some cases is absent. Test borings in the river valley south of Benton Harbor are required to determine where there is sufficient thickness of the water-bearing sands to provide sites for production wells. A program of testing should involve five or six wells to the linear mile, and at favorable points additional wells at right angles to the line should indicate the areal extent of the water-bearing materials.

The present information does not show any favored locality for the development of a new field capable of supplying several millions gallons a day, although wells capable of producing one-half million gallons a day can be developed if widely spaced sites are found where the sands have adequate thickness to furnish water to the well. Examination of drillers' logs in wells 7 and 8 indicate gravels should be found in the area where West Main Street crosses the St. Joseph River and along the east bank of the Paw Paw River in the vicinity of West Graham Street. The log of the uncased boring No. 83, also shows sufficient sand and gravel between 120 and 142 feet in depth to develop a well. Possibly two or three small production wells could be developed in the area between Tenth Street and the St. Joseph River and north of the present Water Plant to the Paw Paw River.

East and west of Benton Harbor geologic conditions are unfavorable for the development of wells of large yield. The sands, gravels, and clays, have low permeabilities and cannot transmit large quantities of water, but will always be a source of small supplies for domestic or farm use.

CONCLUSIONS

Records of the static water levels in the municipal wells show that most of the decline has been due to the increased pumpage and that if the rate of pumping were reduced the static level would rise to about the same level as existed before the increase. This may be due in part to recharge from the nearby St. Joseph River or Lake Michigan or in part by both.

Tests of the water-yielding capacity of the sands and gravels tapped by the municipal wells show that supplies in the magnitude of three million gallons a day may be pumped when all the existing wells are in continous operation for a long period of time without causing a serious decline in water level. However, additional water can be withdrawn from the existing sites if the screen losses in the present wells are minimized either by rejuvenation of present screens or by drilling new wells at the present sites.

New ground-water developments are possible. A new field may be developed south of Benton Harbor at sites where the sands and gravels have sufficient transmissibility to support large yields from wells. Relatively small supplies may be developed north of the present water plant and south of the Paw Paw River between 10th Street and the West Main Street bridge over the St. Joseph River. All new well developments must be spaced adequately from existing wells to prevent interference and to develop the largest possible cone of influence.

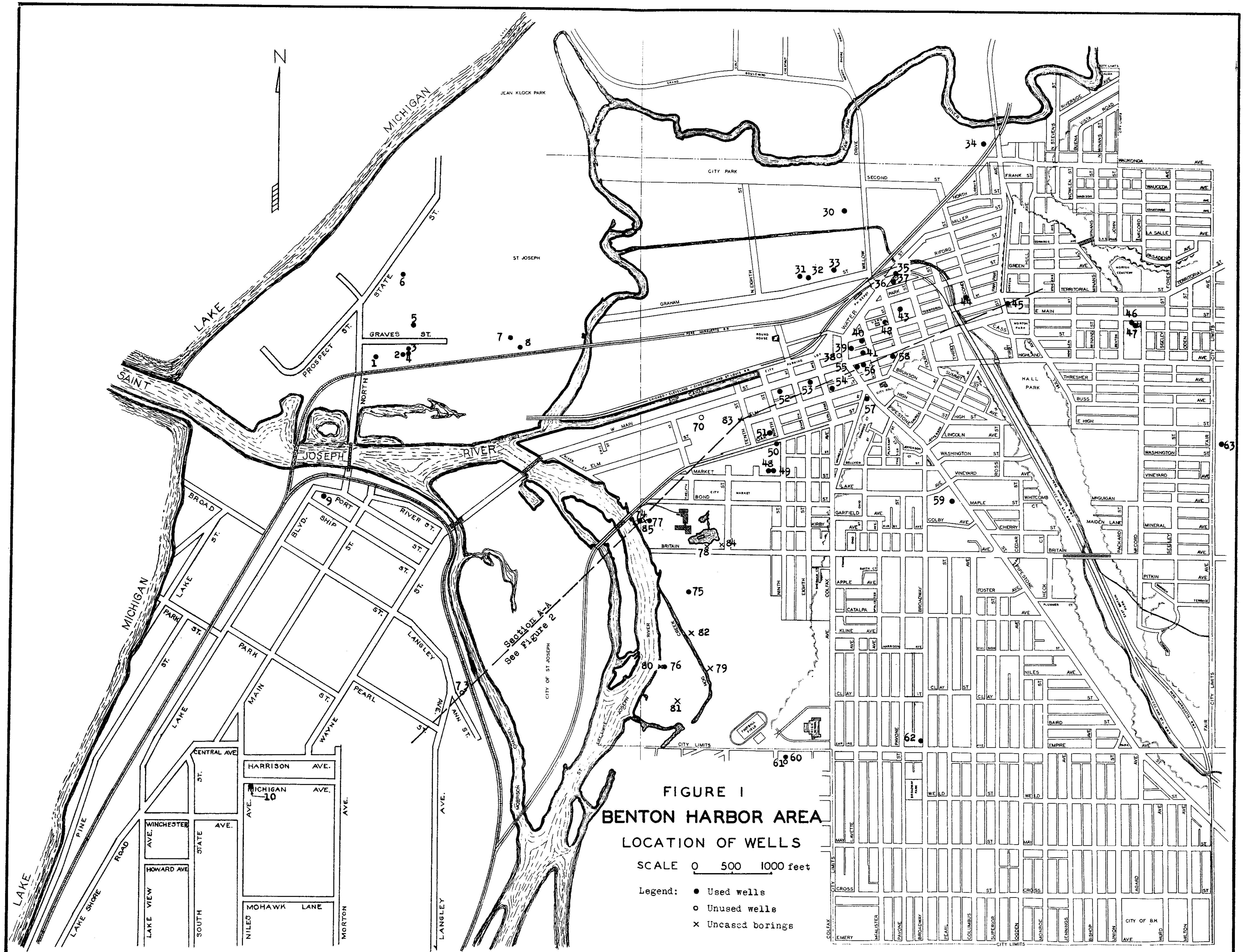

FIGURE 1
BENTON HARBOR AREA
LOCATION OF WELLS

SCALE 0 500 1000 feet

Legend: ● Used wells
○ Unused wells
× Uncased borings

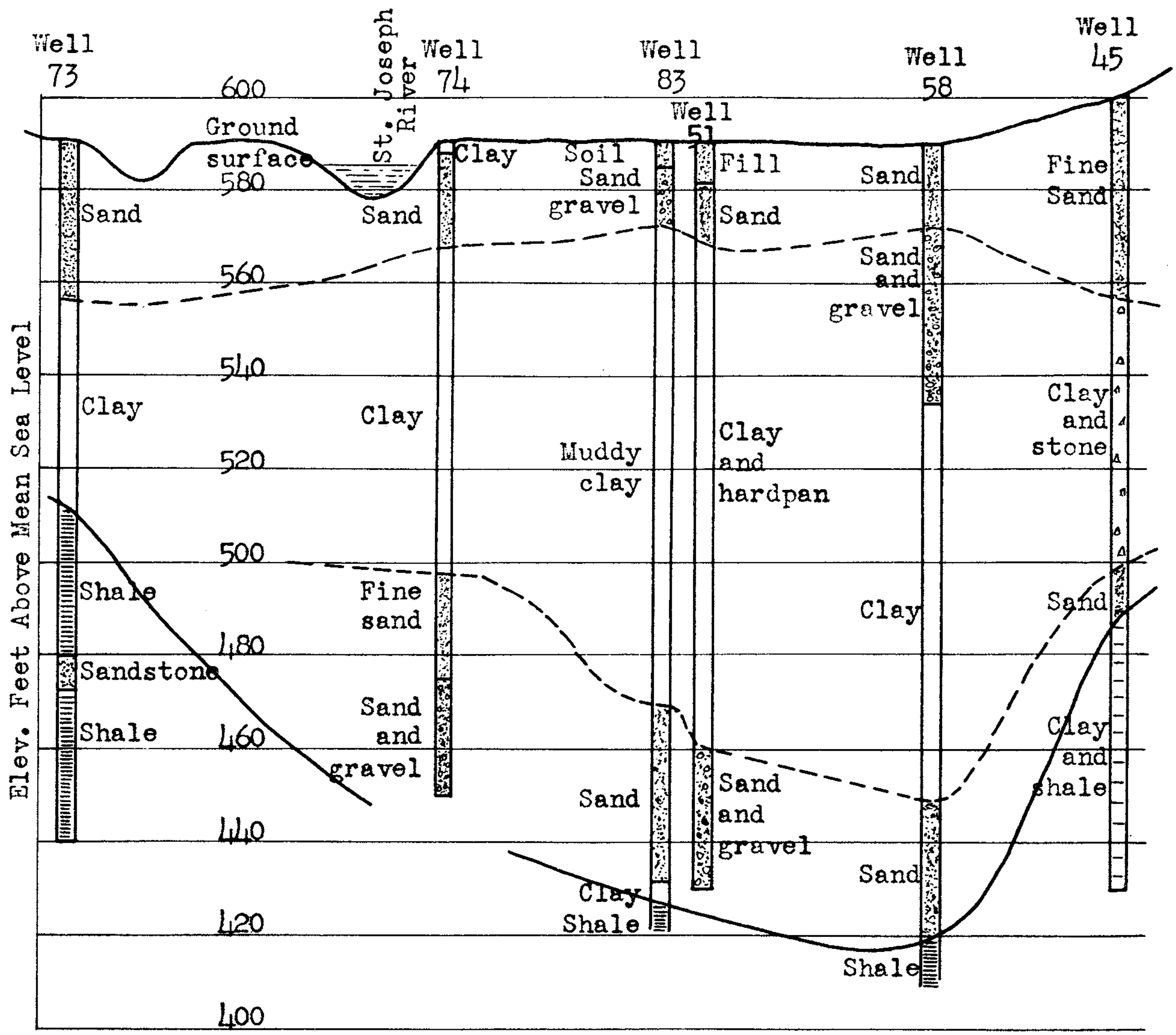

FIGURE 2

BENTON HARBOR AREA

Section Along Line A-A

See Figure 1

Scale 0 — 2,000 feet

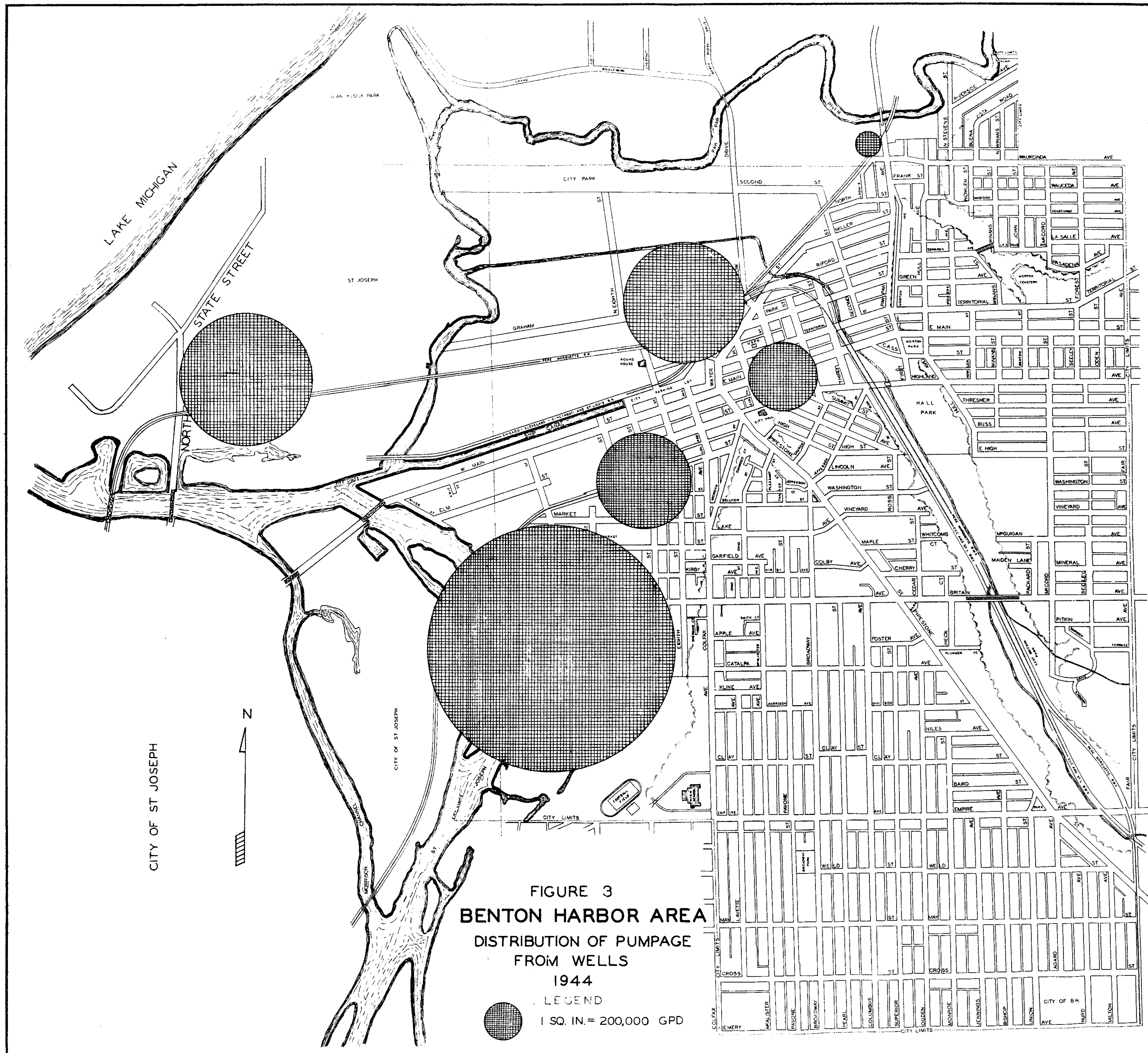

FIGURE 3
BENTON HARBOR AREA
DISTRIBUTION OF PUMPAGE FROM WELLS
1944

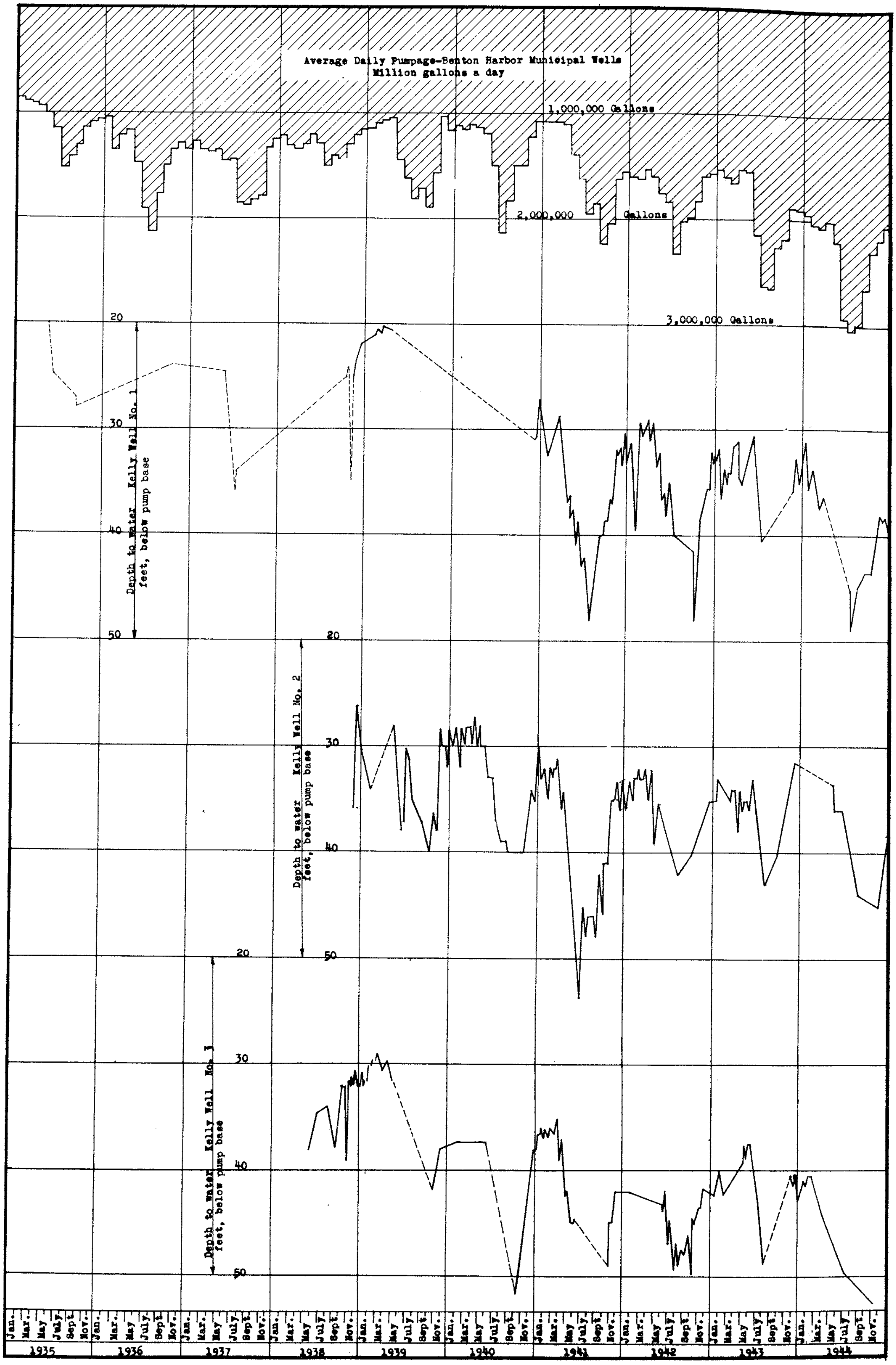

FIGURE 4. FLUCTUATIONS OF WATER LEVELS AND PUMPAGE
BENTON HARBOR, MICHIGAN

Table 3 Records of wells in St. Joseph, Berrien County

No.	Owner	Location	Altitude Above Sea Level (Feet)	Depth of Well (Feet)	Diameter of well (in.)	Water Level: Depth Below Ground Level (Feet)	Water Level: Date of Measurement	°Use of Water	Remarks
1	1900 Corporation	Graves St.	595	115	8	26	Apr. 2, 1938	Ind.	Reported drawdown 37 ft. when pumping 100 gal. a min. on Apr. 2, 1938. See log.
2	Auto Specialties Mfg. Co.	Do.	595	126	12	6	Jan. 9, 1937	Ind.	Reported drawdown 4 ft. when pumping 200 gal. a min. on Jan. 9, 1937. See log.
3	Do.	Do.	595	118	6	--	--	Ind.	Reported drawdown 10 ft. when pumping 200 gal. a min. on Oct. 25, 1940. See log.
4	Do.	Do.	595	118	6	--	--	Ind.	Reported drawdown 10 ft. when pumping 200 gal. a min. on Oct. 15, 1940. See log.
5	Do.	Do.	595	94	6	--	--	Ind.	Reported drawdown 70 ft. when pumping 470 gal. a min. on Sept. 9, 1941. See log.
6	Do.	Do.	595	125	12	48	Oct. 17 1941	Ind.	Reported drawdown 27 ft. when pumping 500 gal. a min. on Oct. 17, 1941. See log.
7	Industrial Rubber Goods Co.	Kamber Rd.	595	129	10	35	Nov. 10, 1937	Ind.	Reported drawdown 4 ft. when pumping 175 gal. a min. on Nov. 10, 1937. See log.
8	Do.	Do.	595	114	6	12	Dec. 10, 1931	Ind.	Reported drawdown 16 ft. when pumping 150 gal. a min. on Dec. 10, 1931. Well used as standby for No. 7. See log.
9	Hotel Whitcomb and Mineral Baths	509 Ship St.	615	999	8	--	--	Bath	Auger type lift. Pump set at 120 ft. See analysis.
10	Berndt Market	1507½ Niles Avenue	630	92	3	--	--	A.C.	Jet type pump.

° Bath.-Mineral Water Baths; A.C.-Air conditioning; Ind.-Industrial Processing; Pub.-Public Supply; Un.-Unused

Table 4 Records of wells in Benton Harbor and vicinity, Berrien County

No.	Owner	Location	Altitude Above Sea Level (Feet)	Depth of Well (Feet)	Diameter of well (in.)	Water Level: Depth Below Ground Level	Water Level: Date of Measurement	Use of Water	Remarks
30	New Products Corporation	448 N. Shore Drive	590	148	12	35.4	Oct. 11, 1944	Ind.	Reported drawdown 40 ft. when pumping 220 gal. a min. on Oct. 11, 1944. See log.
31	Benton Harbor Malleable Ind.	171 Graham Avenue	590	158	12	28	Aug. 9, 1937	Ind.	Reported drawdown 70 ft. when pumping 125 gal. a min. on Aug. 9, 1937. See log.
32	Do.	Do.	590	160	12	43	July 3, 1941	Ind.	Reported drawdown 40 ft. when pumping 150 gal. a min. on July 3, 1941. See log.
33	Do.	Do.	590	--	--	--	--	Ind.	--------------
34	Benton Harbor Malleable Ind., Gray Iron Plant	Paw Paw Avenue	595	50	8	10	Aug. 5, 1941	Ind.	Reported drawdown 12 ft. when pumping 85 gal. a min. on Aug. 5, 1941. See log.
35	Brown Ice & Coal Company	Water St.	590	142	10	26	Dec. 31, 1929	Ind.	Reported drawdown 90 ft. when pumping 200 gal. a min. on Dec. 31, 1929. See log.
36	Do.	Do.	590	146	10	32	June 6, 1944	Ind.	Reported drawdown 51 ft. when pumping 160 gal. a min. on June 6, 1944. See log.
37	Brown Ice & Coal Company	Water St.	590	142	10	26	Mar. 15, 1945	Un.	Well Abandoned. Water level measurements possible.
38	Lion Bar	106 Water St.	590	40	5	--	--	Un.	Well not used since 1942.
39	Hotel Michigan	Water & Territorial	590	--	4	21	1943	A.C.	----------------
40	Central Chop House	158 Territorial	590	21	$1\frac{1}{4}$	--	--	A.C.	
41	Harbor Lunch	161 E. Main	590	45	2	--	--	A.C.	Jet type pump.
42	Dwan Hotel	209 Territorial	590	800	--	--	--	Bath.	Temperature 53 F. See analysis.
43	Saltzman Hotel	191 - 5th St.	590	810	12	35	1933	Bath.	Pump set at 110 ft. See log and analysis.
44	Max Mulder	375 Territorial	590	--	--	--	--	Ind.	--------------
45	H. O. Wilson Inc.	465 E. Main	600	128	6	45	Feb. 27, 1931	Ind.	Reported drawdown 40 ft. when pumping 125 gal. a min. on Feb. 27, 1931. See log.
46	Laboratory Equip. Co.	720 E. Main	620	48	3	40	1939	Ind.	See log.
47	Do.	Do.	620	48	3	40	1939	Ind.	Formation same as No. 46.
48	Producers Serv.	261 Market	595	33	8	12	1944	Ind.	--------------

No.	Owner	Location	Altitude Above Sea Level (Feet)	Depth of Well (Feet)	Diameter of well (in.)	Water Level: Depth Below Ground Level	Water Level: Date of Measurement	Use of Water	Remarks
49	Producers Serv. Corp.	261 Market	595	38.5	12	13	1944	Ind.	------------------------
50	Mich. Fruit Canners Assoc.	248 - 9th St.	590	36	34	9	Apr. 1944	Ind.	Reported drawdown 6.5 ft. when pumping 500 gal. a min. See log.
51	Do.	Do.	590	160	6	12	Mar. 20 1931	Ind.	Standby to No. 50. See log.
52	Humpty-Dumpty Sandwich Shop	210 W. Main	590	20	4	9	1937	A.C.	Jet type pump. Casing sank of its own weight.
53	State Theatre	148 W. Main	590	--	--	--	--	A.C.	------------------------
54	Mary's Hotel	Colfax & Wall	590	72	4	--	--	Pub.	Jet type pump. Water bearing formations. Lake sand.
55	Walgreen Drug Company	Water & Pipestone	590	--	3	--	--	A.C.	Jet type pump.
56	Candyland Cafe	152 E. Main	590	32	2	--	--	A.C.	Jet type pump.
57	Fidelity Bldg.	Pipestone Ave.	595	40	3	17	1932	Pub.	Jet type pump.
58	Premier Hotel	250 E. Main	590	695	8	47	May 31, 1938	Bath	Reported drawdown 40 ft when pumping 18 gal. a min. See log and analysis.
59	Peapples Ice Cream Co.	378 Pipestone Ave.	615	50	4	22	June 1940	Ind.	60 gage screen.
60	Empire Laundry	190 W. Empire	625	65	4	--	--	Ind.	------------------------
61	Empire Laundry	190 W. Empire	625	65	3	--	--	Un.	------------------------
62	Baumeister Groc.	890 Broadway	615	28	1¼	--	--	Ind.	Jet type pump.
63	David J. Ross Company	262 Fair Ave.	620	28	1¼	--	--	Pub.	Jet type pump.
64	Higman Park Assoc.	NE¼ NW¼ sec. 13, T.4S., R.19W.	600	136	8	10	July 20, 1929	Pub.	Reported drawdown 3 ft. when pumping 150 gal. a min. See log.
65	House of David	Britain Ave.	605	160	8	40	1942	Pub.	80 gage screen.
66	City of David	Britain Ave.	630	75	8	15	Mar. 15, 1945	Pub.	No. 10 slot screen. See log.
67	Do.	Do.	635	85	--	15	Mar. 15, 1945	Pub.	No. 10 slot screen. See log of well 66.
68	Consumers Dairy Co.	235 Pine St.	635	130	4	--	--	Ind.	Pump setting 52'7".
69	Berrien Hills Country Club	NW¼NW¼ sec. 36, T.4S., R.19W.	625	50	2	38	1936	Pub.	See log.
70	Producers Creamery	408 W. Main	590	--	12	18	Aug. 3, 1932	Un.	Reported drawdown 50 ft. when pumping 275 gal. a min. on Aug. 3, 1932. Well use discon't. in latter part of 1944. See log.
71	Industrial Rubber Co. Property	SE¼NE¼ sec. 34, T.4S., R. 19W.	678	170	6	78	Nov. 9, 1944	Un.	Reported drawdown 87 ft. when pumping 85 gal. a min. on Nov. 9, 1944. Well drilled as test. Location Hilltop Rd., 100 ft. of P.M.R.R. See log.

Table 4 Records of wells in Benton Harbor and vicinity, Berrien County-Continued

No.	Owner	Location	Altitude Above Sea Level (Feet)	Depth of Well (Feet)	Diameter of well (in.)	Water Level: Depth Below Ground Level	Water Level: Date of Measurement	°Use of Water	Remarks
72	Auto Specialties Mfg. Co. Riverside Plant	NW¼SE¼ sec. 5, T.4S., R.18W.	640	147	--	--	--	Ind.	Reported drawdown 75 ft. when pumping 30 gal. a min. See log.
73	Berrien Packing Company	St.Joseph, Michigan	585	150	3	23	Apr. 5, 1938	Un.	Uncased boring. See log
74	City of Benton Harbor	371 ft.No. of Britain Ave., on bk. of St.Joe. River	590	140.7	30	32	Feb. 11, 1945	Pub.	37 ft. of Kelly reinforce concrete screen. City Well 1. See log.
75	Do.	943 ft. S., 535 ft. E. of Well 73	590	139.7	30	29.2	Feb. 11, 1945	Pub.	30 ft. of Kelly reinforce concrete screen. City Well 2. See log.
76	Do.	1000 ft. S. 330 ft. W. of Well 75	585	--	30	30.7	Feb. 11, 1945	Pub.	City Well 3
77	Do.	105 ft. E. of Well 74, 305 ft. W. of main plant	585	145	30	29	Feb. 11, 1945	Pub.	City Well 4. See log.
78	Do.	342 ft. S., 917 ft. E., of Well 74	580	134	--	24	May 31, 1937	--	Uncased boring. See log.
79	Do.	70 ft. N., 600 ft. E. of Well 76	580	154	--	24	Jan. 15, 1937	--	Uncased boring. See log.
80	City of Benton Harbor	50 ft. W. of Well 76	580	138	--	24	Jan. 30, 1937	--	Uncased boring. See log.
81	Do.	440 ft. S., 120 ft. E. of Well 76	580	120	--	-	--	--	Uncased boring. Dry hole. See log.
82	Do.	440 ft. N., 380 ft. E. of Well 76	580	150	--	--	--	--	Uncased boring. Dry hole. See log.
83	Do.	1240 ft. E., 1430 ft.N., of Well 74	590	162	--	30	Aug. 5, 1937	--	Uncased boring. See log.
84	Do.	11th and Britain	580	146	--	--	--	--	Uncased boring. See log.
85	Do.	70 ft. E. of Well 74	580	147	--	38	Sept. 23, 1944	--	Uncased boring. See log.

°Bath.-Mineral Water Baths; A.C.-Air conditioning; Ind.-Industrial Processing; Pub.-Public Supply; Un.-Unused

Table 5 Well Logs, Benton Harbor Area, Berrien County, Michigan

Log of Well 1

1900 Corporation, owner. Graves St.

	Thickness (feet)	Depth (feet)
Sand- - - - - - - - - -	35	35
Blue clay - - - - - - -	20	55
Sandy clay- - - - - - -	32	87
Clay- - - - - - - - - -	11	98
Sandy clay- - - - - - -	12	110
Gravel- - - - - - - - -	5	115

Logs of Wells 2, 3, and 4

Auto Specialties Mfg. Co., owner.
Graves St.

	Thickness (feet)	Depth (feet)
Fill- - - - - - - - - -	6	6
Fine sand - - - - - - -	14	20
Clay- - - - - - - - - -	58	78
Hardpan - - - - - - - -	27	105
Gravel and clay (very dirty)	5	110
Gravel- - - - - - - - -	16	126

Log of Well 5

Auto Specialties Mfg. Co., owner.
Graves St.

	Thickness (feet)	Depth (feet)
Fill- - - - - - - - - -	8	8
Water sand- - - - - - -	27	35
Soft blue clay- - - -	20	55
Sand 20 slot- - - - -	6	61
Gravel- - - - - - - -	11	72
Gravel and sand(30 slot)	10	82
Clean sand(30 slot) -	13	95
Clay below- - - - - -		95

Log of Well 6

Auto Specialties Mfg. Co., owner.
Graves St.

	Thickness (feet)	Depth (feet)
Fill- - - - - - - - - -	2	2
Fine yellow sand- - -	24	26
Yellow clay - - - - - -	36	62
Dirty sand and gravel	16	78
Clean sand(20 slot) -	5	83
Blue clay - - - - - - -	16	99
Gravel and sand (fine silt)-	13	112
Gravel- - - - - - - - -	14	126
Hard clay - - - - - - -	½	126½
Shale and lime below-		126½

Log of Well 7

Industrial Rubber Goods Co., owner.
Camber Road.

	Thickness (feet)	Depth (feet)
Cinders- - - - - - - - -	1	1
Sand - - - - - - - - - -	9	10
Water sand - - - - - - -	27	37
Clay - - - - - - - - - -	14	51
Water sand (dirty)	9	60
Brown clay - - - - - - -	10	70
Water sand - - - - - - -	15	85
Clay, sand and silt- -	15	100
Sand and gravel- - - -	7	107
Gravel - - - - - - - - -	22	129

Log of Well 8

Industrial Rubber Goods Co., owner.
Camber Road.

	Thickness (feet)	Depth (feet)
Sand - - - - - - - - - -	10	10
Fine water sand- - - -	27	37
Clay - - - - - - - - - -	10	47
Water sand (40 gpm)	8	55
Blue soft clay - - - -	10	65
Hardpan- - - - - - - - -	8	73
Gravel (30 slot) - - -	8	81
Clay - - - - - - - - - -	11	92
Sand and gravel- - - -	9	101
Gravel - - - - - - - - -	13	114

Log of Well 30

New Products Corp., owner.
448 No. Shore Drive.

	Thickness (feet)	Depth (feet)
Fill - - - - - - - - - -	8	8
Yellow sand- - - - - - -	17	25
Clay - - - - - - - - - -	92	117
Water sand - - - - - - -	31	148

Log of Well 31

Benton Harbor Malleable Industries, own
171 Graham Avenue.

	Thickness (feet)	Depth (feet)
Muck - - - - - - - - - -	5	5
Muck and sand- - - - -	5	10
Sand - - - - - - - - - -	23	33
Clay and sand- - - - -	3	36
Clay - - - - - - - - - -	57	93
Sand and clay- - - - -	33	126
Gravel (20 slot) - - -	3	129
Clay - - - - - - - - - -	2	131
Stony hardpan- - - - -	12	143
Sand and gravel(30 slot)	1	144
Fine sand (10 slot)- -	14	158

Table 5 Well Logs, Benton Harbor Area, Berrien County, Michigan - cont'd

Log of Well 32
Benton Harbor Malleable Iron, Owner
171 Graham Avenue

	Thickness (feet)	Depth (feet)
Fill- - - - - - - - -	15	15
Water sand (20 slot)-	22	37
Blue clay - - - - - -	43	80
Hardpan - - - - - - -	15	95
Clay and sand (10 slot)	22	117
Fine sand and silt- -	9	126
Clay- - - - - - - - -	14	140
Fine sand (10 slot) -	7	147
Clean sand (15 slot)-	13	160

Log of Well 34
Gray Iron Plant, Benton Harbor
Malleable Industries, owner,
Paw Paw Avenue

	Thickness (feet)	Depth (feet)
Fill- - - - - - - - -	7	7
Clay- - - - - - - - -	5	12
Sand- - - - - - - - -	2	14
Clay- - - - - - - - -	17	31
Sand (water bearing)-	18	49
Clay- - - - - - - - -	51	100
Sand- - - - - - - - -	3	103
Hardpan - - - - - - -	13	116
Sand- - - - - - - - -	2	118
Hardpan - - - - - - -	3	121
Clay- - - - - - - - -	3	124
Blue shale- - - - - -	10	134

Log of Well 35
Brown Ice & Coal Co., owner.
Water Street.

	Thickness (feet)	Depth (feet)
Top soil- - - - - - -	8	8
Sand- - - - - - - - -	18	26
Fine gravel - - - - -	14	40
Clay and sand - - - -	44	84
Clay- - - - - - - - -	36	120
Water sand and gravel	25	145

Log of Well 36
Brown Ice & Coal Co., owner.
Water Street.

	Thickness (feet)	Depth (feet)
Yellow sand - - - - -	22	22
Dry sand- - - - - - -	35	57
Sand and clay - - - -	59	116
Water sand- - - - - -	30	146

Log of Well 43
Saltzman Hotel, Owner. 191 - 5th St.

	Thickness (feet)	Depth (feet)
Lake and water sand -	42	42
Blue clay - - - - - -	12	54
Soft clay and mud - -	72	126
Water sand and gravel (20 slot)	45	171
Clay- - - - - - - - -	1	172
Blue shale- - - - - -	201	373
Hard shale crevice- -	1/4	373 1/4
Blue shale with streaks of brown- - - - -	291-3/4	665
Mineral water limestones	16	681
Dry brown shale - - -	19	700

Log of Well 45
H. O. Wilson Inc., owner,
465 E. Main Street.

	Thickness (feet)	Depth (feet)
Fine sand - - - - - -	43	43
Blue clay and stones-	59	102
Water sand- - - - - -	2	104
Fine water sand - - -	8	112
Clay and shale- - - -	58	170

Log of Well 46
Laboratory Equipment Co., owner
720 E. Main Street

	Thickness (feet)	Depth (feet)
Sand- - - - - - - - -	50	50
Clay- - - - - - - - -	20	70
Sand- - - - - - - - -	30	100

Log of Well 50a
Mich. Fruit Canners Assoc., owner
248 - 9th St.

	Thickness (feet)	Depth (feet)
Fill- - - - - - - - -	4	4
Sand- - - - - - - - -	11	15
Sand and gravel - - -	21	36
Muddy sand- - - - - -	11	47
Sandy clay- - - - - -	83	130
Hard sandy clay - - -	24	154
Fine sand - - - - - -	16	170
Medium sand - - - - -	5	175
Fine sand - - - - - -	17	192
Clay- - - - - - - - -		192

Log of Well 51

Mich. Fruit Canners Assoc., owner. 248 - 9th St.

	Thickness (feet)	Depth (feet)
Fill	8	8
Fine sand	7	15
Fine red sand	7	22
Clay and hardpan	107	129
Clay and sand	21	150
Sand and gravel	10	160

Log of Well 58

Premier Hotel, owner. 250 E. Main St.

	Thickness (feet)	Depth (feet)
Sand	18	18
Water sand and gravel (25 slot)	38	56
Clay	84	140
Sand (20 slot)	30	170
Blue shale	235	405
Brown shale	145	550
Brown shale	35	585
Brown shale and mineral water	96	681
Hard white lime	5	686
Black shale	9	695

Log of Well 64

Higman Park Assoc., owner. NE$\frac{1}{4}$NW$\frac{1}{4}$, Sec. 12; T4S; R19W.

	Thickness (feet)	Depth (feet)
Sand and fill	10	10
Fine sand	20	30
Clay	40	70
Hardpan	11	81
Water sand	37	118
Blue gravel	18	136

Log of Well 66

City of David, owner. Britian Ave.

	Thickness (feet)	Depth (feet)
Sand	3	3
Clay	16	19
Sand	181	200
Shale below		200

Log of Well 69

Berrien Hills Country Club, owner. NW$\frac{1}{4}$NW$\frac{1}{4}$, Sec. 36; T4S; R19W.

	Thickness (feet)	Depth (feet)
Sand	20	20
Hardpan	3	23
Fine gravel	9	32
Fine sand		

Log of Well 70

Producer's Creamery, owner. 408 W. Main S

	Thickness (feet)	Depth (feet)
Muck	10	10
Clay and sand	20	30
White sand	35	65
Sand and gravel	19	84

Log of Well 71

Industrial Rubber Goods Co., owner. SE$\frac{1}{4}$NE$\frac{1}{4}$, Sec. 34; T4S; R19W.

	Thickness (feet)	Depth (feet)
Blue clay	42	42
Water sand (static 60')	33	75
Dirty sand and clay	3	78
Dirty red sand	7	85
Clay and sand	25	110
Clay	40	150
Sand	4	154
Clay	2	156
Shale	6	162
Water sand	5.6	167.6
Blue clay	2.4	170

Log of Well 72

Auto Specialties Mfg. Co., owner. Riverside Plant.

	Thickness (feet)	Depth (feet)
	8	8
Dry sand	31	39
Gravel and sand	1	40
Blue clay	24	64
Sand (8 slot)	12	76
Blue clay	8	84
Very fine sand	12	96
Blue clay	10	106
Sand and gravel	1	107
Hard clay	35	142
Sand (2 slot)	5	147
Clay and sand		147

Log of Well 73

Berrien Packing Co., owner. Located on bank of St. Joseph River at n. w. corner of bldg., 150 ft. east of Ann Street.

	Thickness (feet)	Depth (feet)
Soft fill, sand	23	23
Soft fill, sand	6	29
Sand, clay	5	34
Clay	6	40
Blue clay, soft	6	46
Gray clay, soft	5	51
Gray clay, tough	5	56
Blue clay, soft	9	65

Table 5 Well Logs, Benton Harbor Area, Berrien County, Michigan - cont'd

Log of Well 73, cont.	Thickness (feet)	Depth (feet)
Dry clay, tough - - - -	8	73
Dry clay - - - - - - - -	7	80
Blue clay and shale - -	5	85
Blue shale, hard - - -	5	90
Red and blue shale - -	10	100
Gray shale, hard - - -	5	105
Red shale - - - - - - -	5	110
Sandrock - - - - - - -	7	117
Blue shale - - - - - -	33	150

Log of Well 74

City of Benton Harbor, owner. 371 feet north of Britain Ave., on E. bk. of St. Joseph River

	Thickness (feet)	Depth (feet)
Black clay - - - - - -	2	2
Sand - - - - - - - - -	14	16
Sand and clay - - - - -	7	23
Blue clay - - - - - - -	22	45
Sand and clay - - - - -	45	90
Muddy sand - - - - - -	9	99
Fine sand - - - - - - -	16	115
Sand and gravel - - - -	25	140

Log of Well 75

City of Benton Harbor, owner. 943 feet south, 535 feet east of Well 74.

	Thickness (feet)	Depth (feet)
Black clay - - - - - -	2	2
Sand - - - - - - - - -	16	18
Blue clay - - - - - - -	22	40
Sand and clay - - - - -	40	80
Quick sand - - - - - -	9	89
Blue clay - - - - - - -	8	97
Fine muddy sand - - - -	14	111
Sand and gravel - - - -	28	139

Log of Well 77

City of Benton Harbor, owner. 105 feet east of Well 74

	Thickness (feet)	Depth (feet)
Sand - - - - - - - - -	20	20
Soft clay - - - - - - -	20	40
Medium clay - - - - - -	25	65
Fine sand - - - - - - -	1	66
Clay soft - - - - - - -	44	110
Gravel and sand - - - -	35	145
Clay - - - - - - - - -		

Log of Well 78

City of Benton Harbor, owner. [illegible] feet south, 917 feet east of Well 74.

	Thickness (feet)	Depth (feet)
Black soft clay - - - -	1	1
Fine sand - - - - - - -	1½	2½
Clay - - - - - - - - -	1½	4
Fine sand - - - - - - -	14	18
Clay - - - - - - - - -	42	60
Sand and gravel - - - -	20	80
Fine sand - - - - - - -	30	110
Coarse sand - - - - - -	8	118
Fine sand - - - - - - -	12	130
Coarse gravel - - - - -	4	134
Shale - - - - - - - - -		

Log of Well 79

City of Benton Harbor, owner. 70 feet north, 600 feet east of Well 76.

	Thickness (feet)	Depth (feet)
Black soil - - - - - -	1	1
Muck - - - - - - - - -	5	6
Fine sand - - - - - - -	19	25
Clay and muck - - - - -	25	50
Fine muddy sand - - - -	5	55
Clay and muck - - - - -	15	70
Fine muddy sand - - - -	20	90
Coarse sand - - - - - -	6	96
Clay and silt - - - - -	28	124
Coarse sand and gravel -	6	130
Sand, gravel and stone -	16	146
Sand and gravel - - - -	2	148
Fine sand - - - - - - -	6	154
Shale - - - - - - - - -		

Log of Well 80

City of Benton Harbor, owner. 50 feet west of Well 76.

	Thickness (feet)	Depth (feet)
Black soil - - - - - -	1	1
Lake sand - - - - - - -	5	6
Sand and silt - - - - -	11	17
Clay - - - - - - - - -	53	70
Fine sand - - - - - - -	15	85
Sand and gravel - - - -	5	90
Sand, gravel and stone -	3	93
Fine sand - - - - - - -	13	106
Coarse sand - - - - - -	5	111
Clay, sand, gravel and stone	17	128
Sand and gravel - - - -	10	138
Shale - - - - - - - - -		

Table 5 Well Logs, Benton Harbor Area, Berrien County, Michigan -cont'd

Log of Well 81

City of Benton Harbor, owner. 440 feet south, 120 feet east of Well 76.

	Thickness (feet)	Depth (feet)
Soil and clay - - - - -	5	5
Coarse and dirty sand -	7	12
Black muck- - - - - - - -	41	53
Fine muddy sand - - - -	10	63
Clay- - - - - - - - - - -	20	83
Muddy sand and gravel -	1	84
Clay- - - - - - - - - - -	5	89
Fine dirty sand - - - -	14	103
Coarse sand - - - - - - -	2	105
Clay- - - - - - - - - - -	5	110
Lake sand - - - - - - - -	10	120
Shale - - - - - - - - - -		

Log of Well 82

City of Benton Harbor, owner. 440 feet north, 380 feet east of Well 76.

	Thickness (feet)	Depth (feet)
Fine muddy sand and gravel-	18	18
Clay- - - - - - - - - - -	47	65
Sandy clay- - - - - - - -	19	84
Clay- - - - - - - - - - -	6	90
Muddy sand- - - - - - - -	30	120
Muddy sand and gravel -	2	122
Sand and gravel - - - -	12	134
Clay, sand and gravel -	2	136
Fine sand - - - - - - - -	9	145
Clay, sand and gravel -	5	150
Shale - - - - - - - - - -		

Log of Well 83

City of Benton Harbor, owner. 1240 feet east, 1430 feet north of Well 74.

	Thickness (feet)	Depth (feet)
Top soil- - - - - - - - -	5	5
Sand and gravel - - - -	13	18
Muddy clay- - - - - - - -	102	120
Fine sand - - - - - - - -	2	122
Coarse sand - - - - - - -	8	130
Coarse sand and gravel-	12	142
Lake sand - - - - - - - -	16	158
Clay- - - - - - - - - - -	4	162
Shale - - - - - - - - - -		

Log of Well 84

City of Benton Harbor, owner. 11th Street and Britain Avenue.

	Thickness (feet)	Depth (feet)
Black clay - - - - - - - -	7	7
Sand - - - - - - - - - - -	19	26
Fine sand and silt - -	8	34
Black muddy clay - - -	32	66
Fine sand- - - - - - - -	6	72
Clay - - - - - - - - - - -	15	87
Fine sand - - - - - - -	5½	92½
Clay - - - - - - - - - - -	5½	98
Fine sand- - - - - - - -	8	106
Blue clay- - - - - - - -	11	117
Fine muddy sand- - - -	12	129
Fine sand- - - - - - - -	5	134
Fine muddy sand- - - -	6	140
Medium sand- - - - - - -	6	146
Clay - - - - - - - - - - -		

Log of Well 85

City of Benton Harbor, owner. 70 feet east of Well 74.

	Thickness (feet)	Depth (feet)
Sand - - - - - - - - - - -	20	20
Soft clay- - - - - - - -	20	40
Medium clay- - - - - - -	25	65
Fine sand- - - - - - - -	1	66
Soft clay- - - - - - - -	44	110
Gravel and sand- - - -	37	147
Clay - - - - - - - - - - -		