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MEMORANDUM CONCERNING A PUMPING TEST AT GAS CITY, INDIANA,

WITH A DETAILED DISCUSSION OF THE METHODS USED IN THE QUANTITATIVE ANALYSIS OF WATER-WELL INTERFERENCE PROBLEMS

PREPARED IN COOPERATION WITH
UNITED STATES DEPARTMENT OF THE INTERIOR
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Memorandum concerning a pumping test at Gas City, Indiana with a detailed discussion of the methods used in the quantitative analysis of water-well interference problems.

by John G. Ferris

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Introduction

In recognition of the value of water as an essential natural resource, a state-wide investigation of water resources was begun in July 1943 by the Indiana Department of Conservation and the U. S. Geological Survey. Some of the main purposes of the work are to determine the annual range in fluctuation and the general long-time trend of the water table, to determine the quantities of underground storage and the rates of replenishment of the water-bearing formations and to obtain information on the occurrence and availability of ground water in Indiana. During the present emergency, a major function of the cooperative investigation has been to make many short investigations assisting in the maintenance of adequate water supplies for municipal and industrial use which are vital to the war effort.

Some of the localized problems of the communities and industries have a direct bearing on and are interrelated with the broader county-wide and state-wide problems of water resources. In some instances the solution of certain phases of these local problems may be accomplished by a relatively small amount of field work and yet, yield a high return to the general state-wide program. For such cases as the director of the water resources division deems justifiable it is general practice to incorporate only those phases of the local problems that are of greatest benefit to the state-wide investigation. The complete solution of these localized problems of ground-water supply will entail active interest by the locally interested groups through cooperation with the Indiana Department of Conservation.

The broader regional aspects of the brief investigation covered by this report will be included in a later report covering perhaps a county unit. However, in recognition of the great interest shown by waterworks operators, state and city engineers, consulting engineers and well drillers in the technique used in analyzing problems of interference between wells or well groups, in the planning of ground-water developments, this report presents a detailed discussion of the step-by-step procedure involved. It is intended to demonstrate that definite solutions of ground-water problems can be affected by sound engineering methods based on the data collected under the present cooperative water-resources program. The derivations of the various formulae are omitted in an effort to simplify the presentation of the methods. For those who are interested, references are quoted covering the appropriate reports that contain these derivations.

The city of Gas City, Indiana is located in the southeast quarter of Grant County near the central part of the northeast quadrant of the State. The municipally owned water supply is pumped from a group of four wells located at the waterworks station on the south side of south H. Street, about midway between the Mississinewa River and the P.C.C. and St. L. R. R. The water supply system, which is about 60 percent metered, serves a population of 3,400, with a range in average daily consumption in 1943, from 171,000 gallons in January to 297,000 gallons in August, and an average daily consumption for the year of 241,000 gallons. Pertinent data concerning the present wells in use by the waterworks station are tabulated below:

Well No.	Date Drilled	Driller	Diameter in inches	Depth in feet	Source formation	Pumping equipment: Type	Pumping equipment: Capacity in GPM	Pumping equipment: Rated HP
1	1944	Stremmel	10	333	*Ls	Turbine	110	$7\frac{1}{2}$
2	1942	Krauss and Sons	10	322	*Ls	Turbine	300	15
3	----	----------	8	325	*Ls	Turbine	---	10
4	1922	Stremmel	10	60	**G	Vertical plunger	---	$7\frac{1}{2}$

*Limestone ** Gravel

Information supplied by T. S. McKee, Supt. of the Gas City Water Works, indicates that the static level at the station was about 76 feet below the land surface in 1912 and about 110 feet below the land surface in May 1944. Although data on drawdowns and pumping levels are not available, the driller of well 2 reported that a 5-inch turbine pump was installed in this well with the bottom of the 5-foot bowl section at a depth of 145 feet below land surface and the bottom of the 25-foot tail pipe at 170 feet below land surface. It was noted by the driller that the pumping of well 2 caused considerable interference with the other rock wells at the station. Substantial declines in the yield of the wells at this station have been experienced over a period of years and it has been necessary in extended dry periods to pump all wells to capacity, on almost continuous service, in order to meet the existing demands upon the system.

Under the direction of Clyde E. Williams, consulting engineer, test drilling was started by the Layne-Northern Company, in the spring of 1944, in an effort to locate a favorable site for the development of a more adequate water supply to replace the overdeveloped bedrock well supply. The first test well, designated as test well 1, was drilled at the site shown on the accompanying map, Fig. 1. A log of the materials penetrated in this test well is shown in Fig. 2. Inasmuch as no suitable water-bearing formations were found at this site, the test hole was abandoned and drilling was continued at the site shown as test well 2. As indicated by the log of test well 2, a relatively thick bed of water-bearing sand was encountered at a depth of 120 to 165 feet below the land surface, and it was felt that this site could be developed for the new supply well. However, the Owens-Illinois Glass Company, located adjacent to the new well site, raised the question as to whether the development of the well at the proposed site would result in any loss of yield or lowering of the water level in wells owned by the Glass Company. The U. S. Geological Survey was requested by the Indiana State Board of Health, through Leo Louis, sanitary engineer, to assist in the determination of possible interference between a well at the new site and the existing wells of the Owens-Illinois Glass Company.

Accordingly, on June 19, 1944, arrangements were made with the Layne-Northern Company and the Owens-Illinois Glass Company for the U. S. Geological Survey to install an automatic water-stage recorder on test well 2 in order to observe the fluctuations of water level in this well caused by pumping well 3 of the Owens-Illinois Glass Company. This well normally operates intermittently during the day in response to a pressure control installed in an elevated storage tank at the plant. The average daily usage is estimated by R. G. Garland, Plant Supt., as about 500 gallons per minute throughout a 24-hour period. The reported yield of well 3 is 750 gallons per minute with an estimated operating period of 16 hours per day, which is equivalent to the average daily rate of 500 gallons per minute. The pumping well was idle at the time of the installation of the recorder on test well 2 and was allowed to remain idle as long as possible in order to reduce the amount of storage in the elevated tank, so that a relatively long pumping period could be assured for the test. The well pump was started at 1:29 p.m. on June 19, 1944, and was pumped continuously at a rate of 750 gallons per minute until 9:34 p.m., a pumping period of eight hours and five minutes. At this time the elevated storage tank had reached the overflow point and the well pump was shut down and the well allowed to remain idle until midnight. A graph of the fluctuation of water level in test well 2 produced by this period of controlled pumping is shown as Fig. 3.

Geology

The Gas City area is underlain by thick deposits of glacial material, consisting of clay, hardpan, sand and gravel, which range in thickness from about 70 to 190 feet. The clays and hardpans are relatively impermeable and yield little water. The sands and gravels are generally clean and permeable and large quantities of water are stored in the interstitial spaces between individual fragments. The clays and hardpans were more or less "dumped" in place by the ice sheet as it became overloaded or as it melted. These deposits are generally unsorted mixtures of clay, rocks, sand and gravel and are usually unstratified. The sand and gravels were carried from the ice front by running water and are usually clean, well sorted and stratified, as the finer materials have been washed away. The sand and gravel deposits are generally long and narrow, having been laid down by streams which flowed away from the ice front.

A deeply-buried valley, known as the "Deep Drive" or the "Loblolly" crosses the northeastern corner of Grant County in a northwesterly direction. Although the Gas City area is southwest of the main part of the channel, it is possible that the water-bearing formations are connected to those in the "Deep Drive". If this is true, the areal extent of these formations may be quite large. The depths to bedrock as determined from the lengths of drive pipes in oil wells indicate that the underlying bedrock surface is irregular and that a tributary valley to the "Deep Drive" may extend from the vicinity of Fowlerton through Gas City and pass east of Marion.

Logs of the materials penetrated in drilling test wells 1 and 2 for the Gas City Water Works and the pumping well 3 for the Owens-Illinois Glass Company, were furnished by the driller, the Layne-Northern Company. A diagrammatic representation of these logs is shown as Fig. 2. The log of test well 2 indicated a 45-foot layer of water-bearing sand at a depth of 120 to 165 feet below the land surface. The observation well was finished without a well screen and ended as an open-end pipe in the lower part of this water-bearing sand. The pumping well 3 at the Owens-Illinois Glass Company is screened in a water-bearing formation of sand and gravel, extending from a depth of 108 feet below land surface to more than 140 feet below land surface. Inasmuch as test well 2 responds almost instantaneously to changes in pumping in the Glass Company well, it is evident that the two formations are hydraulically connected. The log of test well 1 shows primarily clay and sandy clay throughout the zones corresponding to the depth of permeable layers in the other wells, and it is probable that the well is located beyond the limits of the water-bearing formation.

Analysis of pumping test results.

As indicated by the data in Fig. 3, the water level at the site of test well 2 during the test period fluctuated between 70 and 72 feet below land surface or about 50 feet above the top of the water-bearing formation in which the well was finished. Aquifers of this type in which the water level rises to a stage above the top of the formation are termed artesian. The clay layer overlying the water-bearing material acts as an effective confining layer to prevent the escape of water vertically, and water in this material must move laterally between the confining boundaries down gradient to a discharge point which is at present unknown. The relatively high head in the formation indicates that the formation may trend upward to receive recharge at an elevated intake area or by vertical percolation from some water-bearing zone at a higher elevation.

If a line of test wells were installed in this water-bearing material and if observations of the depth to water in these test wells were plotted to some definite datum plane, the resulting water level surface would be termed the piezometric surface. When a well in such a formation is pumped, the piezometric surface is drawn down in the vicinity of the pumping well in the shape of an inverted cone, with its apex at the pumping well. From measurements of the rate of decline of this surface or from measurements at two or more points on the surface at a given time, it is possible to determine the hydraulic characteristics which define the specific rate at which water is transmitted by the formation under a given hydraulic gradient.

The rate at which a formation will transmit water is proportional to its "coefficient of transmissibility", which is defined as the volume of water that will flow in a unit of time under a unit hydraulic gradient through a vertical strip of the water-bearing material of unit width, extending the full saturated thickness of the formation. The rate at which water is yielded from storage by a formation as the piezometric surface declines is proportional to its "coefficient of storage", which is defined as the volume of water, which a unit decline in head releases from storage in a vertical prism of unit cross-sectional area whose height equals the thickness of the formation.

This report outlines methods of analysis of the behavior of the piezometric surface within the zone of influence of a pumping well based on the following assumptions: (1) the water-bearing formation is equally permeable in all directions, (2) the formation is of infinite areal extent, (3) the wells penetrate the full thickness of the formation, (4) the coefficient of transmissibility is constant at all places and at all times, and (5) the formations release water from storage instantaneously with a decline in water level. Any divergence of actual field conditions from these idealized assumptions result in variations and inconsistencies in the alignment of the observed data.

In addition to the record secured by the use of an automatic water-stage recorder on test well 2, observations were made of the fluctuations of water level in the two idle supply wells, 1 and 2 at the Owens-Illinois Glass Company by using the existing air lines and an altitude gage. These readings are shown in tables 1 and 2. Air line measurements were also made during the drawdown and recovery period on the pumping well 3 and the results are shown in table 3. The observations of the decline in water level in wells 1 and 2 and in test well 2 at a given time represent two known points on the cone of depression.

Thiem Method

By using the Thiem equation[1/], a value of transmissibility is calculated as follows:

$$Pm = T = \frac{527.7Q \log_{10} \frac{r_2}{r_1}}{s_1 - s_2} \qquad (1)$$

Where: P = field coefficient of permeability, expressed as the rate of flow, in gallons per day, through a cross section of one square foot, under a hydraulic gradient of one foot per foot.

m = thickness of saturated water-bearing material in feet.

T = coefficient of transmissibility, expressed as the rate of flow in gallons per day through a vertical strip of saturated water-bearing material, one foot wide under a hydraulic gradient of one foot per foot.

r_2, r_1 = distances of observation wells from pumping wells, in feet.

s_1, s_2 = drawdown of water level in observation wells, in feet.

$$T = \frac{527.7 \times 750 \times \log \frac{894}{804}}{1.88 - (\frac{1.6 + 1.6}{2})} = 65{,}000 \text{ gpd/ft.}$$

Inasmuch as the distances between the two observation wells and the pumping well used in the above computation are of about the same magnitude, no corrections have been applied to the observed drawdown figures to compensate for the residual drawdown as is done in the other method used in this paper. Unfortunately, the two observation wells so closely correspond in distances from the pumping well and in total drawdown, that there may be considerable error in using this formula. A small error in the air-line measurement would result in a very large error in computing the difference in drawdowns, which represents the denominator of the above equation. As may be seen from inspection of this equation, the drawdown-difference is less than one foot, and any small changes in this value would result in very large changes in the value of transmissibility.

1/ Wenzel, Leland K., The Thiem method for determining permeability of water-bearing materials. U.S. Geol. Survey Water Supply Paper 679-A, 1936.

The Thiem equation is limited in its application because it assumes that the cone of depression, in the area of the observation wells, has reached "equilibrium", or has attained an unvarying shape. More precisely, it assumes that the radial flow toward the well has become "steady", or unchanging with time. Two or more observation wells are required because the usage of the formula is based on the drawdown at two or more points on the cone of depression at a given time. That is, it necessitates a knowledge of the shape of the cone of depression at a given time.

Theis Graphical Method.

An equation for "non-steady" radial flow developed by Theis [2/] introduces the time element and permits an analysis based on the rate of decline of the water level in a single observation well, or on the shape of the cone of depression at any given time, using two or more observation wells as the Thiem method does. The Theis equation is expressed as follows:

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

Where:
- s = drawdown of water level, in feet.
- Q = discharge of pumped well, in gallons per minute.
- r = distance of observation well from pumped well, in feet.
- T = coefficient of transmissibility in gallons per day per foot, under unit hydraulic gradient.
- S = coefficient of storage, as a ratio or decimal fraction.
- t = time well has been pumped, in days.

The exponential integral of the above equation is replaced by the term $W(u)$ which is read "well-function of u", and the equation is rewritten as follows:

$$s = \frac{114.6\,Q}{T}W(u) \qquad (3)$$

2/ 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. 1935, pp. 519-524.

The value of the integral is given by the following series:

$$W(u) = -0.577216 - \log_e u + u - \frac{u^2}{2 \cdot 2!} + \frac{u^3}{3 \cdot 3!} - \frac{u^4}{4 \cdot 4!} \quad (4)$$

where $$u = \frac{1.87\ r^2 S}{Tt} \quad (5)$$

Values of W(u) for values of u between 10^{-15} and 9.9 are given by Wenzel[3/]. It is seen from equations (3) and (5) that if the coefficients of transmissibility and storage are known, the drawdown can be computed for any time and for any point on the cone of depression. Conversely, if the drawdown at two or more points at a given time are known or if the rate of drawdown at a given point is known, the coefficients of transmissibility and storage can be computed. A graphical method of superimposition devised by Theis greatly simplifies the use of the non-steady flow equation through the use of a "type curve", and eliminates the need of repeatedly solving the above series for different values of u. This type curve is a plot on logarithmic coordinates of the value of W(u) against values of u. Equations (3) and (5) are rewritten as follows:

$$s = \left[\frac{114.6\ Q}{T}\right] W(u) \quad (6)$$

$$\frac{r^2}{t} = \left[\frac{T}{1.87\ S}\right] u \quad (7)$$

The bracketed portions of the above equations are constant in value for a given pumping test. It is seen that s is related to r^2/t as W(u) is related to u. Then by plotting values of the drawdown s against values of r^2/t on logarithmic tracing paper to the same scale as the type curve, W(u) against u, a curve of the observed data is developed which is similar to the type curve. The graph of the observed data is superimposed on the type curve and with the coordinate axes of the two curves parallel a position is found by trial for which most of the plotted points fall on the type curve. With the curves in this position, an arbitrary point is chosen on one graph and

3/ Wenzel, Leland K., Methods for determining permeability of water-bearing materials: U. S. Geol. Survey Water Supply Paper 887, 1942.

from the corresponding points on the other graph the values of S and T are determined. The value of T is calculated from equation (3) and this value is used in equation (5) for the determination of the value of S.

Fig. 3 shows the fluctuation of water level in test well 2 of the Gas City Water Works caused by pumping well 3 of the Owens-Illinois Glass Company. The dashed line curves represent the extrapolation of the estimated recovery or drawdown curves and these are the base lines from which the total drawdown or recovery is measured. That is, if well 3 had not been pumped, the water level in test well 2 supposedly would have recovered as shown by the dashed line labeled "estimated recovery". The total drawdown at a given time is the sum of the observed drawdown and the estimated recovery at that time. Values of the total drawdown and the corresponding values of r^2/t are shown in table 4. These data are plotted on logarithmic coordinates in Fig. 4, and by superimposing this graph on the type curve, Fig. 6, a "matching point" was selected at the value u = 0.1. The coordinates for this point are as follows:

from type curve	from test data
$u = 0.1$	$r^2/t = 4.70 \times 10^6$
$W(u) = 1.82$	$s = 1.96$

Substituting these values in equations (3) and (5), we have

$$T = \frac{114.6 \times 750 \times 1.82}{1.96} = 79,800 \text{ gpd/ft.}$$

$$S = \frac{0.1 \times 79,800}{1.87 \times 4.70 \times 10^6} = 9.1 \times 10^{-4}$$

Following the same procedure and using the water level recovery data shown on Fig. 5 a second set of values of T and S are computed as follows:

$$T = \frac{114.6 \times 750 \times 1.82}{1.79} = 87,400 \text{ gpd/ft.}$$

$$S = \frac{0.1 \times 87,400}{1.87 \times 6.47 \times 10^6} = 7.2 \times 10^{-4}$$

The average values for T and S are then

$$T_d = 79{,}800 \text{ gpd/ft.} \qquad S_d = 9.1 \times 10^{-4}$$
$$T_r = \underline{87{,}400} \quad '' \qquad S_r = \underline{7.2 \times 10^{-4}}$$
$$T_a = 83{,}600 \quad '' \qquad S_a = 8.2 \times 10^{-4}$$

Using the average value of T = 83,600 gpd/ft., and from the log of test well 2 the thickness of the aquifer, 45 feet, the average permeability of the material is computed as follows:

$$P = \frac{T}{m} = \frac{83{,}600}{45} = 1{,}860 \text{ gpd/ft.}^2$$

Recovery Method

A modified form of equation (3) has been developed by Theis 4/ which permits the determination of the coefficient of transmissibility from measurements of the rate of recovery of the water level in the pumping well after shutdown or in an observation well relatively close to the pumping well. This equation is written as follows:

$$T = \frac{264\ Q \cdot \log 10\ \ (t/t')}{s} \tag{8}$$

Where: T = coefficient of transmissibility, in gallons per day per foot.
Q = discharge of pumping well in gallons per minute.
t = time since pumping started.
t'= time since pumping stopped.
s = residual drawdown of water level, in feet.

The residual drawdown, s, is the difference between the static water level prior to the start of pumping and the water level at a given point during the recovery. These data are shown in table 7. The application of this equation is greatly simplified by plotting the data on semi-logarithmic coordinates with values of (t/t') plotted on the log scale and values of s plotted on the rectangular coordinate scale, as shown in Fig. 7.

The value of T is computed from the slope of the straight line through the plotted points. Inasmuch as the logarithms are taken to the base 10, it

4/ Theis, C. V., op. cit., p. 522.

is convenient to measure the s-intercept between the intersections of the line of plotted data and a set of axes related by some integral power of 10 as shown on Fig. 7.

Then: $$T = \frac{264 \times 750 \times \log_{10} \left(\frac{40}{4}\right)}{2.19} = 90{,}400 \text{ gpd/ft.}$$

This method did not give consistent results when applied to the recovery of water level in the pumped well. As shown in Fig. 8 the diameter of the well screen is 18 inches whereas the diameter of the casing, in which the water level changes are measured, is 30 inches. It is possible that the inconsistency of the recovery measurements in the pumped well may be the result of this large change in casing volume.

Laboratory determinations of permeability.

Samples of the water-bearing material were collected by the driller at 5-foot intervals during the drilling of test well 2. Screen analyses and permeameter tests were made for each sample by the Layne-Northern Company and these data are shown in table 6. The average permeability of 2,060 based on the permeameter results is in good agreement with the average permeability of 1,860 determined by the pumping test.

Summary of computations.

A recapitulation of the results obtained by the various methods is shown in the following summary:

Method	T (gpd/ft.)	S	Comments on application of method to data for this test.
Thiem profile	65,000	---	Only two points available on profile and these points are at nearly the same distance from pumping well. Hence small errors in drawdown measurement greatly affect the value of T.
Theis graphical			Yields maximum return for limited data available. Some error introduced because pumping well declined in yield progressively during test.
drawdown	79,800	9.1×10^{-4}	
recovery	87,400	7.2×10^{-4}	
Average	83,600	8.2×10^{-4}	
Recovery	90,400	---	Only later measurements applicable because observation well is at appreciable distance from pumped well whereas derivation assumes that distance is negligible.
Permeameter	92,700	---	Satisfactory as check method, but frequently yields erratic results because of difficulties in repacking sample in the permeameter to approximate the packing of the undisturbed material.

The average values for the coefficients of transmissibility and storage determined by the Theis graphical method are used in the following computations of the interference effects of the proposed well.

Interference Computations.

When a well is pumped the cone of depression on the water-table surface, or, in this case, the piezometric or pressure surface, progresses as pumping continues. When the cones of depression of two or more wells overlap interference occurs with a resultant loss of yield or increase of drawdown in each well. In practice, if the pump bowls are set at sufficient depth and if the pump can maintain the increased lift, the operator will maintain the well discharge at a constant rate and permit the drawdown to increase when interference occurs. However, if the drawdown is maintained constant because of limited pump capacity or if the pumping level is limited by the bowl setting then the well discharge declines when interference occurs. In the following discussion both cases are considered in the evaluation of the estimated interference effects of the proposed well for the Gas City Water Works and well 3 of the Owens-Illinois Glass Company. Inasmuch as the precipitation or recharge to the aquifer cannot be predicted, it is assumed for the basis of comparison that the recharge is zero and both wells pump continuously from storage for a period of 6 months. Although this condition might appear to be a severe restriction, at first consideration, it is not uncommon for drought periods to exceed 6 months or for water levels to decline progressively for periods of more than 6 months.

Case I

Assumptions:
(1) Gas City well discharge = Owens-Illinois well discharge.
(2) Continuous operation for 6 months = 183 days.
(3) All withdrawals are from storage, i.e., no recharge.
(4) Total drawdown for each well is limited to the drawdown that would occur in one well operating alone under the conditions assumed in (2) and (3).
(5) "Effective" radius of well = nominal radius of screen.

The drawdown of water level in the Owens-Illinois well operating alone at 500 GPM with continuous withdrawal from storage for 6 months is computed as follows:

T = 83,600 gpd/ft.	Well diameter = 18"	Q = 500 GPM
$S = 8.2 \times 10^{-4}$	Well radius = 9" = r = 0.75'	
t = 183 days	$r^2 = 0.563$	

$$u = \frac{1.87 \times r S}{Tt} = \frac{1.87 \times 0.563 \times 8.2}{83{,}600 \times 183 \times 10^4} = 5.7 \times 10^{-11}$$

from table 3, W(u) = 23.0

$$s = \frac{114.6 \times Q \times W(u)}{T} = \frac{114.6 \times 500 \times 23.0}{83{,}600} = 15.7 \text{ feet}$$

It should be noted that the computed drawdown for the pumping well is less than the actual drawdown by the amount of head-loss required to pass the given discharge through the well screen. An approximation of the screen-loss can be made by comparing the observed drawdown for the present test with the computed drawdown for the aquifer without a screen. All elements in the above example remain as noted except

$$Q = 750 \text{ GPM and } t = 8^h\ 05^m = 1/3 \text{ day}$$

$$\text{then} \quad u = \frac{183}{1/3} \times 5.7 \times 10^{-11} = 3.1 \times 10^{-8}$$

$$W(u) = 16.71$$

$$s = \frac{114.6 \times 750 \times 16.71}{83,600} = 17.2 \text{ feet}$$

As shown by table 3, the observed drawdown declined from a maximum of 23.7 feet to 20.0 feet because the well discharge declined as the total lift increased with the filling of the elevated storage tank. Inasmuch as metered records of the fluctuations in the well output are not available the discharge rate was approximated at 750 GPM as reported by the owner and therefore the drawdown is approximated as the arithmetic average of the drawdowns at nearly equal intervals of time during the test period. Using the observed average drawdown of 21.8 feet the head loss through the well screen at the 750 GPM rate is 21.8 - 17.2 = 4.6 feet. For a given well the screen loss varies as the square of the discharge. Then the screen loss for the 500 GPM example is $\frac{500^2}{750^2} \times 4.6 = 2$ feet.

Adding the screen loss to the computed drawdown in the aquifer at the well face, the total drawdown at the end of the 6-month period of withdrawal from storage, at 500 GPM, is 15.7 feet + 2 feet = 17.7 feet.

Limiting the drawdown in each well to the drawdown of the single well, i.e., 17.7 feet, the equation is set up as follows:

For Owens-Illinois Co.

$$s_o = 17.7 = \frac{114.6 \times Q_o W(u_o)}{T} + \frac{114.6 \times Q_g W(u_{og})}{T} + BQ_o^2 \qquad (10)$$

For Gas City Water Works

$$s_g = 17.7 = \frac{114.6 \times Q_g W(u_g)}{T} + \frac{114.6 \times Q_o W(u_{og})}{T} + BQ_g^2 \qquad (11)$$

In each equation the first drawdown factor is the evaluation of the effect of the well on itself, the second term represents the interference effect of the other well and the third term indicates the head loss through the well screen. It has been assumed that each well is identical in construction. The $W(u)$ for the well operating alone was computed above as $W(u) = 23.0$.

The $W(u)$ factor for the effect on the companion well is computed as follows:

T, S, t as before $\qquad\qquad$ r = 804 feet

$$\text{then} \quad u = \frac{1.87 \times 804^2 \times 8.2}{83,660 \times 183 \times 10^4} = 6.6 \times 10^{-5}$$

from table 3 , $W(u) = 9.05$

Substituting the appropriate values in equation (10) there follows:

$$17.7 = \frac{114.6 \times Q_o \times 23.0}{83,600} + \frac{114.6 \times Q_g \times 9.05}{83,600} + 2$$

$$15.7 = \frac{3.2}{10^2} Q_o + \frac{1.2}{10^2} Q_g$$

$$\text{or} \quad 1570 = 3.2\, Q_o + 1.2\, Q_g$$

$$\text{and similarly} \quad 1570 = 1.2\, Q_o + 3.2\, Q_g$$

$$\text{by symmetry} \quad Q_o = Q_g$$

$$\text{then } 1.2\, Q_o + 3.2\, Q_o = 1570 = 4.4\, Q_o = 4.4\, Q_g$$

$$Q_o = Q_g = \frac{1570}{4.4} = 357 \text{ GPM}$$

<u>Case II</u>

Assumptions: Same as Case I except

s_o = 15.7 ft. = drawdown at the well-face produced by Owens-Illinois well if pumped alone, at 500 GPM, for six months, from storage only.

s_g = 12.6 ft. = drawdown at the well-face produced by Gas City Water Works well if pumped alone, at 400 GPM, for six months, from storage only.

Then equations (10) and (11) are modified as follows:

$$3.2\, Q_o + 1.2\, Q_g = 1570 \qquad (12)$$

$$1.2\, Q_o + 3.2\, Q_g = 1260 \qquad (13)$$

Multiply (12) by 3.2/1.2 and subtract (13) as follows:

$$8.5\ Q_o + 3.2\ Q_g = 4190$$
$$1.2\ Q_o + 3.2\ Q_g = 1260$$
$$7.3\ Q_o = 2930$$
$$Q_o = \frac{2930}{7.3} = 401 \text{ GPM}$$

Then from (12) $3.2 \times 401 + 1.2\ Q_g = 1570$

$$Q_g = \frac{290}{1.2} = 242 \text{ GPM}$$

Case III

Assumptions: Same as Case I except

s_o = 20.4 ft. = drawdown at the well-face produced by Owens-Illinois well if pumped alone, at 650 GPM, for six months, from storage only.

s_g = 12.6 ft. = drawdown at the well-face produced by Gas City Water Works well if pumped alone, at 400 GPM, for six months, from storage only.

Then equations (10) and (11) are modified as follows:

$$3.2\ Q_o + 1.2\ Q_g = 2040 \quad (14)$$
$$1.2\ Q_o + 3.2\ Q_g = 1260 \quad (15)$$

Multiply (14) by 3.2/1.2 and subtract (15) as follows

$$8.5\ Q_o + 3.2\ Q_g = 5440$$
$$1.2\ Q_o + 3.2\ Q_g = 1260$$
$$7.3\ Q_o = 4180$$
$$Q_o = \frac{4180}{7.3} = 573 \text{ GPM}$$

From (14) $3.2 \times 573 + 1.2\ Q_g = 2040$

$$Q_g = \frac{210}{1.2} = 175 \text{ GPM}$$

The three cases computed above on the basis of a fixed pumping level are recomputed on the basis of fixed pumping rates.

Case IV

Assumptions: Same as Case I except $Q_o = Q_g = 500$ GPM and pumping level does not remain constant

$s_g = s_o$ = drawdown in Owens-Illinois well and Gas City Water Works well

s_o = (drawdown by its own pumping) + (drawdown by Gas City pumping)

$$= \frac{114.6 \times Q_o \times W(u_o)}{83,600} + \frac{114.6 \times Q_g \times W(u_{og})}{83,600}$$

$$= \frac{114.6 \times 500 \times 23.0}{83,600} + \frac{114.6 \times 500 \times 9.05}{83,600}$$

$$s_g = s_o = 15.8 + 6.2$$

$s_g = s_o$ = 22.0 feet = drawdown in formation
2.0 = screen loss, estimated
24.0 feet total drawdown
73.0 assumed static level depth to water at Glass Co.
97.0 pumping level, in feet below land surface

bottom of pump bowls = 94'

Case V

Assumptions: Same as Case IV except $Q_o = 500$ GPM, $Q_g = 400$ GPM

$$\text{then } s_o = \frac{114.6 \times 500 \times 23.0}{83,600} + \frac{114.6 \times 400 \times 9.05}{83,600}$$

$$= 15.8 + 5.0$$

Owens-Illinois Glass Co. = 20.8 feet = drawdown in formation
2.0 = screen loss, estimated
22.8 feet total drawdown
73.0 assumed static level depth to water at Glass Co.
96 pumping level, in feet below land surface

bottom of pump bowls = 94'

$$s_g = \frac{114.6 \times 400 \times 23.0}{83,600} + \frac{114.6 \times 500 \times 9.05}{83,600}$$

Gas City Water Works $= 12.6 + 6.2$

= 18.8 feet = drawdown in formation, at well face
$(\frac{400}{500})^2 \times 2 =$ 1. = screen loss, estimated
19.8 feet total drawdown
67 assumed static level depth to water at Water Works
87 pumping level, in feet below land surface

Case VI

Assumptions: Same as Case IV except Q_o = 650 GPM and Q_g = 400 GPM

then $s_o = \dfrac{114.6 \times 650 \times 23.0}{83{,}600} + \dfrac{114.6 \times 400 \times 9.05}{83{,}600}$

Owens-Illinois Glass Co. $= 20.5 + 5.0 = 25.5$

	=	25.5 feet	= drawdown in formation
$\left(\frac{650}{500}\right)^2 \times 2$	=	3.4	= screen loss, estimated
		28.9 feet	total drawdown
		73	assumed static level depth to water at Glass Co.
		102	pumping level in feet below land surface

bottom of pump bowls = 94'

$s_g = 12.6 + \dfrac{114.6 \times 650 \times 9.05}{83{,}600}$

$= 12.6 + 8.1$

Gas City Water Works	=	20.7 feet	= drawdown in formation, at well face
		1	= screen loss, estimated
		21.7 feet	total drawdown
		67	assumed static level depth to water at Water Works
		89	pumping level, in feet below land surface

A recapitulation of the interference computations is presented in the following summary:

Estimated interference effects between wells of Owens-Illinois Glass Co. and Gas City Water Works for different operating conditions.

Drawdown Constant

Case	Drawdown Ratio	Discharge in GPM Owens-Illinois Co.	Discharge in GPM Gas City Water Works
1	$s_o:s_g$ = 15.7:15.7	357	357
2	$s_o:s_g$ = 15.7:12.6	401	242
3	$s_o:s_g$ = 20.4:12.6	573	175

Discharge Constant	Drawdown in feet and pumping level in feet below land surface					
	Owens-Illinois			Gas City		
Case No.	IV	V	VI	IV	V	VI
Well discharge in GPM	500	500	650	500	400	400
Drawdown-caused by own pumping	17.8	17.8	23.9	17.8	13.6	13.6
" " " other well pumping	6.2	5.0	5.0	6.2	6.2	8.1
" total	24.0	22.8	28.9	24.0	19.8	21.7
Static level - feet below land surface	73	73	73	67	67	67
Pumping level - feet below land surface	97	96	102	91	87	89

Although the estimated pumping level for the Owens-Illinois Glass Co. well 3 ranges from 2 to 8 feet below the bottom of the present pump-bowl setting, N. E. Gunderson of the Layne-Northern Company indicated that pumps of this type will operate satisfactorily at levels as much as 10 feet below the bottom of the pump bowls.

Discussion of Results and Conclusions.

The primary consideration of the well-operator is the maintenance of a constant discharge from each well, with little importance attached to small increases in drawdown or pumping level, until a level is reached that will result in a reduction of pump capacity. If the wells are of sufficient depth, the pump column can be lengthened to compensate for the lowered water level. If the increased withdrawal of ground water by the new wells does not raise the total withdrawal from the aquifer beyond the total available recharge, then the pumping levels will eventually stabilize at a level commensurate with this rate of recharge. The net effect of the new wells will be a slight increase in pumping costs because of the lowered pumping levels. However, the continued addition of new wells in a given aquifer will result in overdevelopment when the total discharge exceeds the total available recharge and there follows a progressive decline of water levels within the zone of influence of this overdevelopment. Well owners keep pace with the water level recession by progressive lowering of the pump-bowl settings until the bottom of the well or aquifer prevents any additional lowering of the pumps. Then the condition of fixed drawdown or pumping level applies and further declines result in reductions of the well yields as shown by Cases I to III.

The "safe yield" of an aquifer depends on the area of the formation at its outcrop, the average rate of recharge by precipitation or other sources, whether natural or induced, and on the number, diameter and distribution of wells which fixes the head distribution and hence the "induced" drawdown. There are not sufficient data available to determine the location or areal extent of the outcrop of the aquifer or the average annual recharge rates for this area. The collection of these data would require an intensive inventory of wells, pumpage and well logs in the Gas City area, and the continuing measurement of ground-water levels in selected observation wells over a period of at least several years to determine the relationship between precipitation and recharge. However, from the experience of the Owens-Illinois Glass Company it is known that no large decline in water level has occurred in well 3 which has been in operation since 1937. This in itself is, of course, no guarantee that water levels will not decline if the total pumpage from the aquifer is about doubled as will be the case with the addition of the Gas City Water Works well. As pointed out in the discussion of the geology of the area, there is some evidence to indicate that this aquifer may be a part of a buried valley of considerable extent and if true, relatively large quantities of water could be pumped without serious declines in water level. In addition, the rock wells undoubtedly can be depended on to yield some water if such need arises in the future. Although the immediate effect of the new well on the existing wells will be only a small increase in the drawdown or pumping level, it would be advantageous for both the Gas City Water Department and the Owens-Illinois Glass Company to keep accurate records of the pumpage from their individual wells, and records of the static and pumping levels in these wells and make periodic observations of the fluctuations of water level in unused wells at these plants. These data will indicate the trends in the water levels, will serve as the basis for forecasting the effects of the new development, and may provide the means for estimating the safe yield of the aquifer.

Acknowledgement -- The writer wishes to express his appreciation for the advice and assistance given by C. E. Williams, consulting engineer for the City of Gas City, Indiana; T. S. McKee, supt. of the Gas City Water Works, N. E. Gunderson and O. O. Schwier of the Layne-Northern Company of Mishawaka, Indiana, R. G. Garland, supt. of the Owens-Illinois Glass Company, and F. H. Klaer, Jr., geologist in charge of ground-water investigations in Indiana, of the U. S. Geological Survey.

Indianapolis, Indiana.

FIGURE 1.

Map showing location of wells of the Gas City Water Works and the Owens-Illinois Glass CO. at Gas City, Indiana.

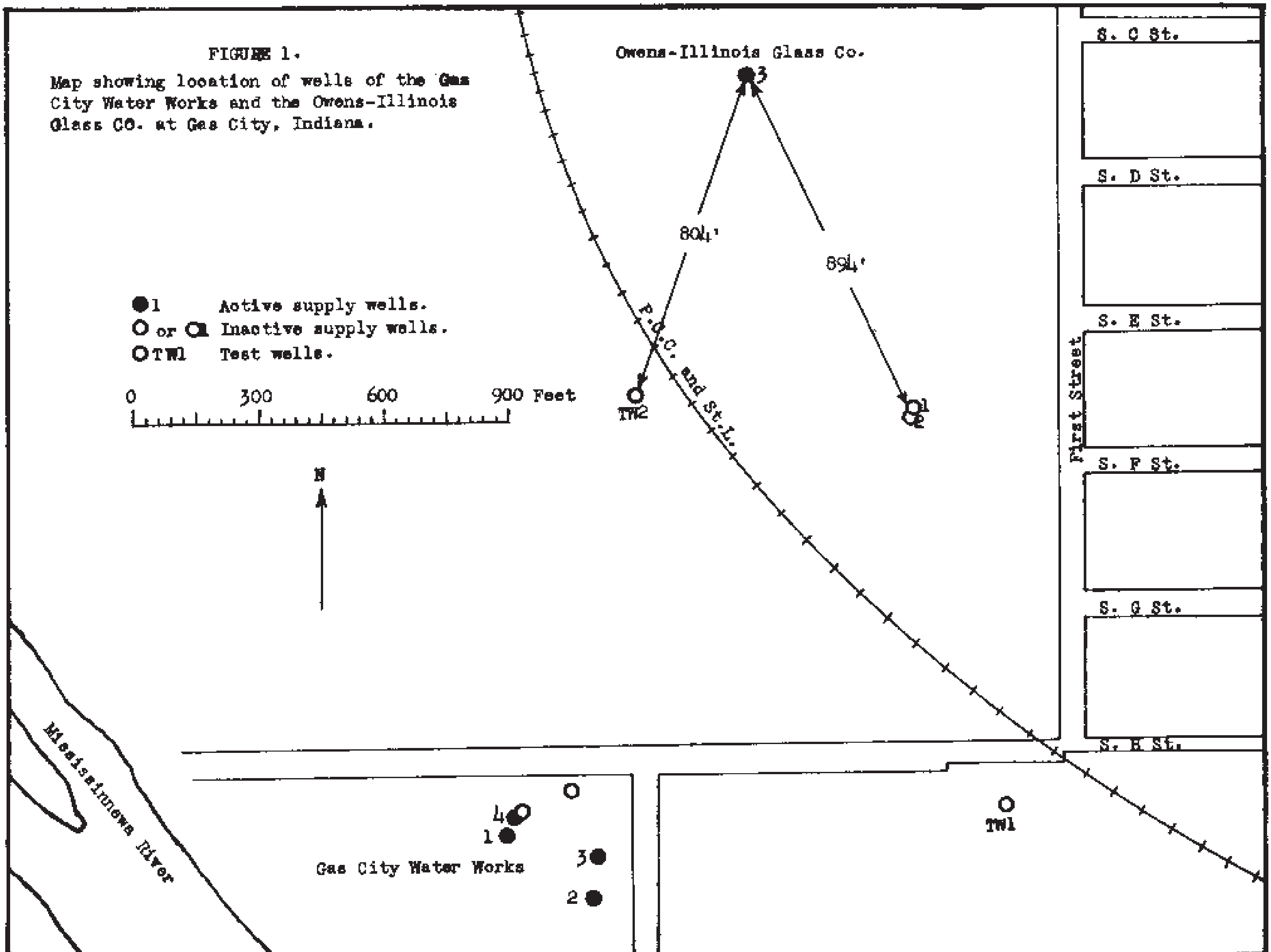
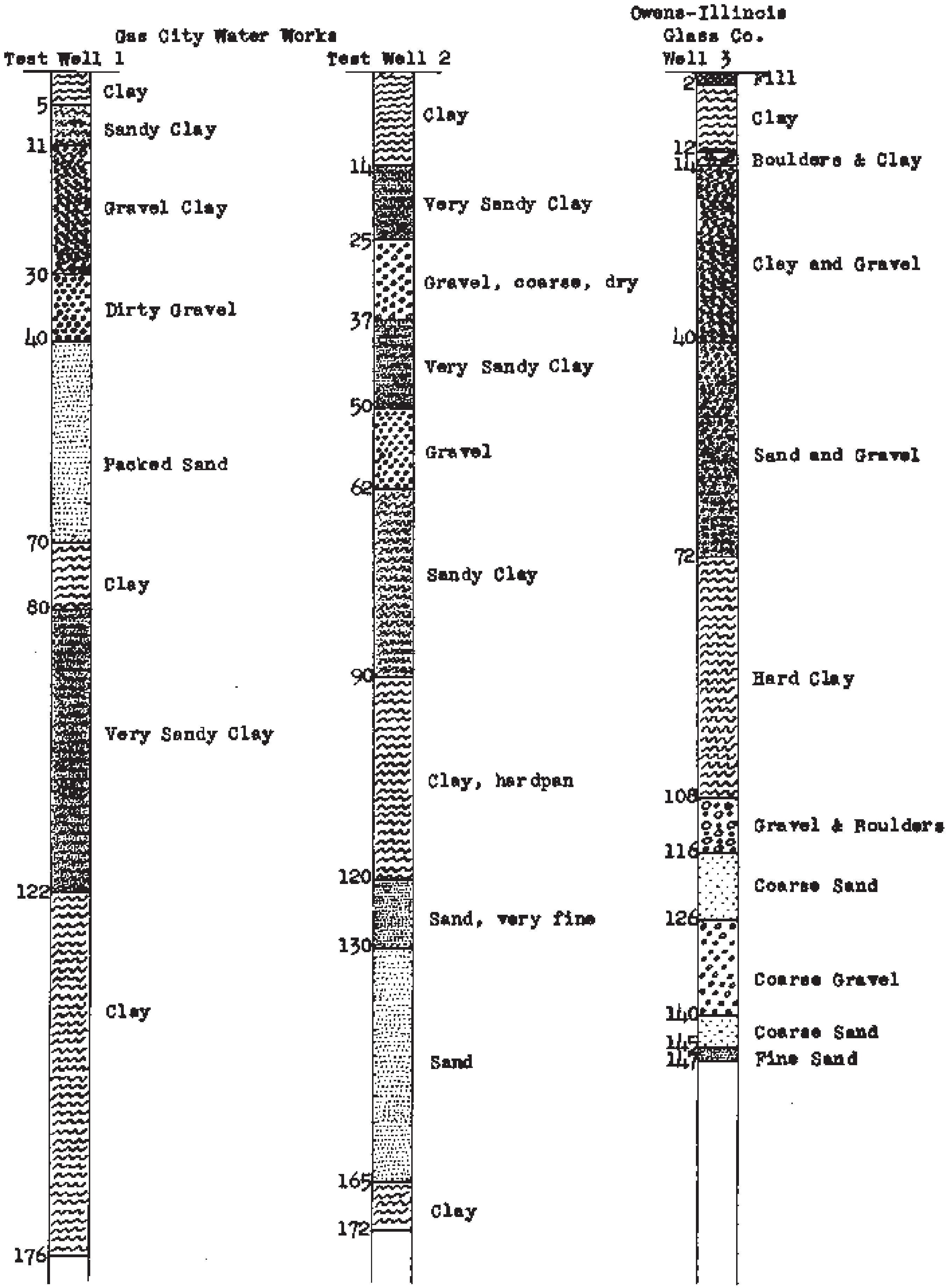


Fig. 2 - Logs of wells for Gas City Water Works and Owens-Illinois Glass Co., Gas City, Indiana.



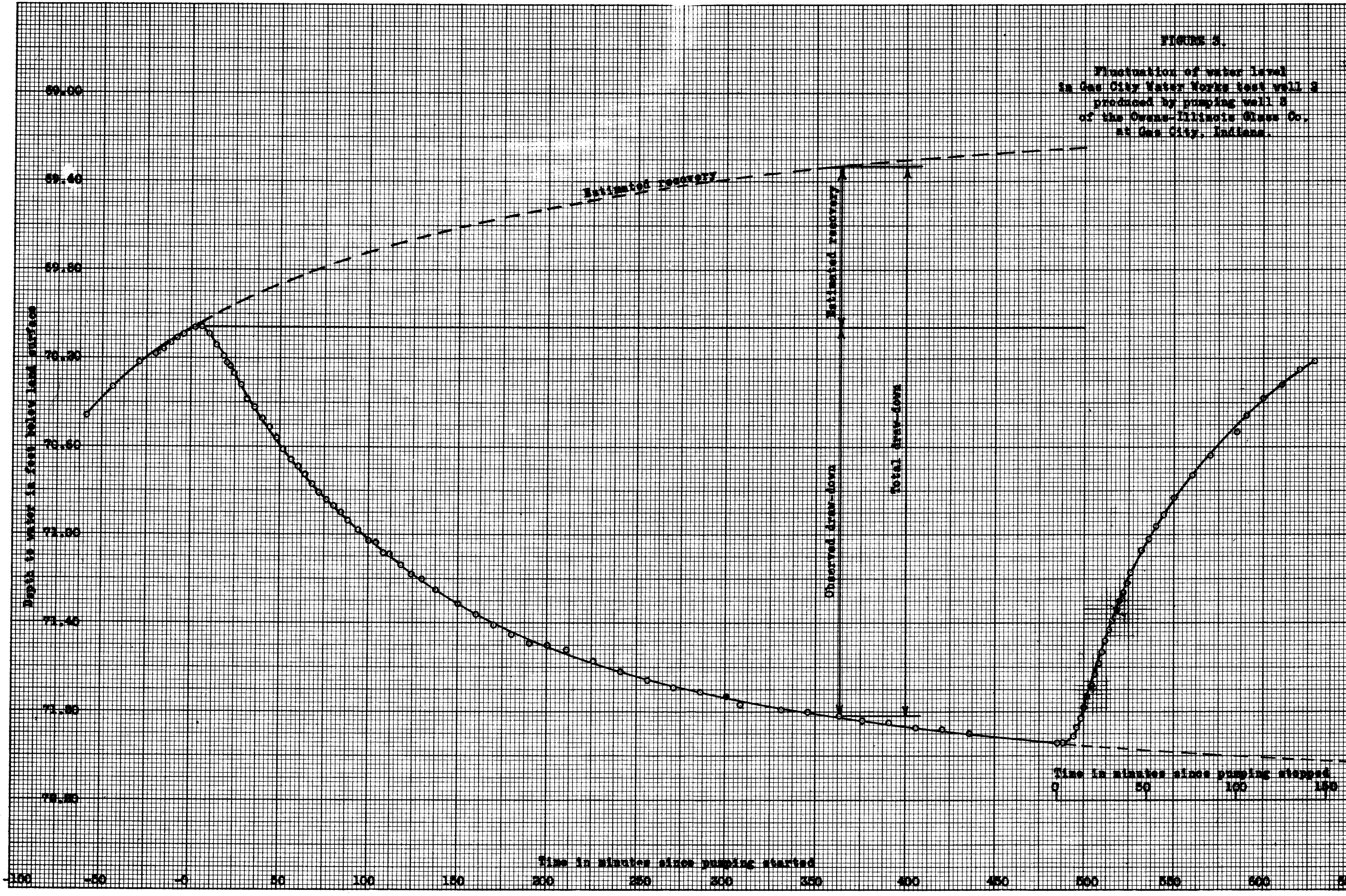


FIGURE 3.

Fluctuation of water level in Gas City Water Works test well 2 produced by pumping well 3 of the Owens-Illinois Glass Co. at Gas City, Indiana.

Fig. 4 - Logarithmic graph of the drawdown of water level in test well 2 of the Gas City Water Works at Gas City, Indiana.

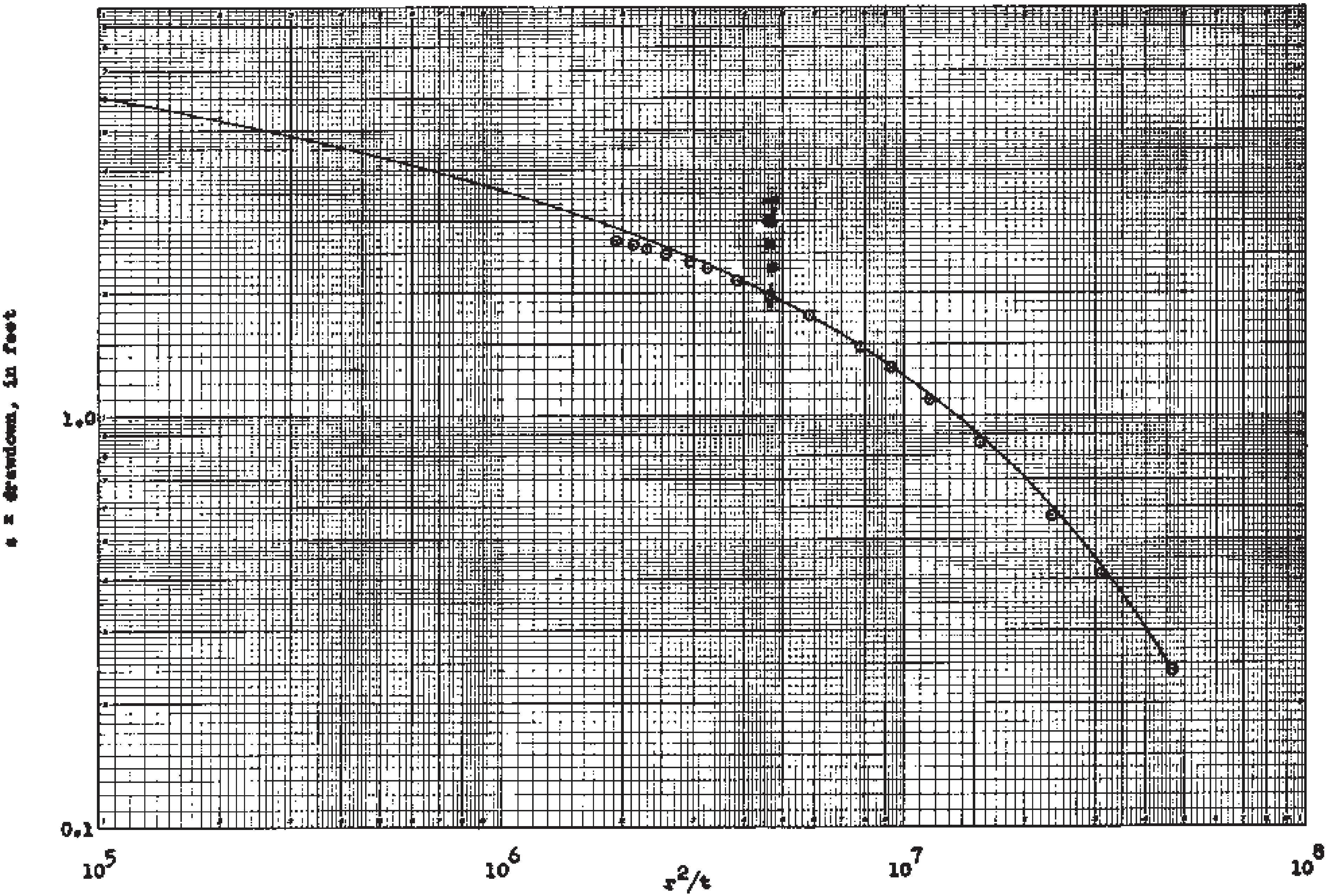


Fig. 5 - Logarithmic graph of the recovery of water level in test well 2 of the Gas City Water Works at Gas City, Indiana.

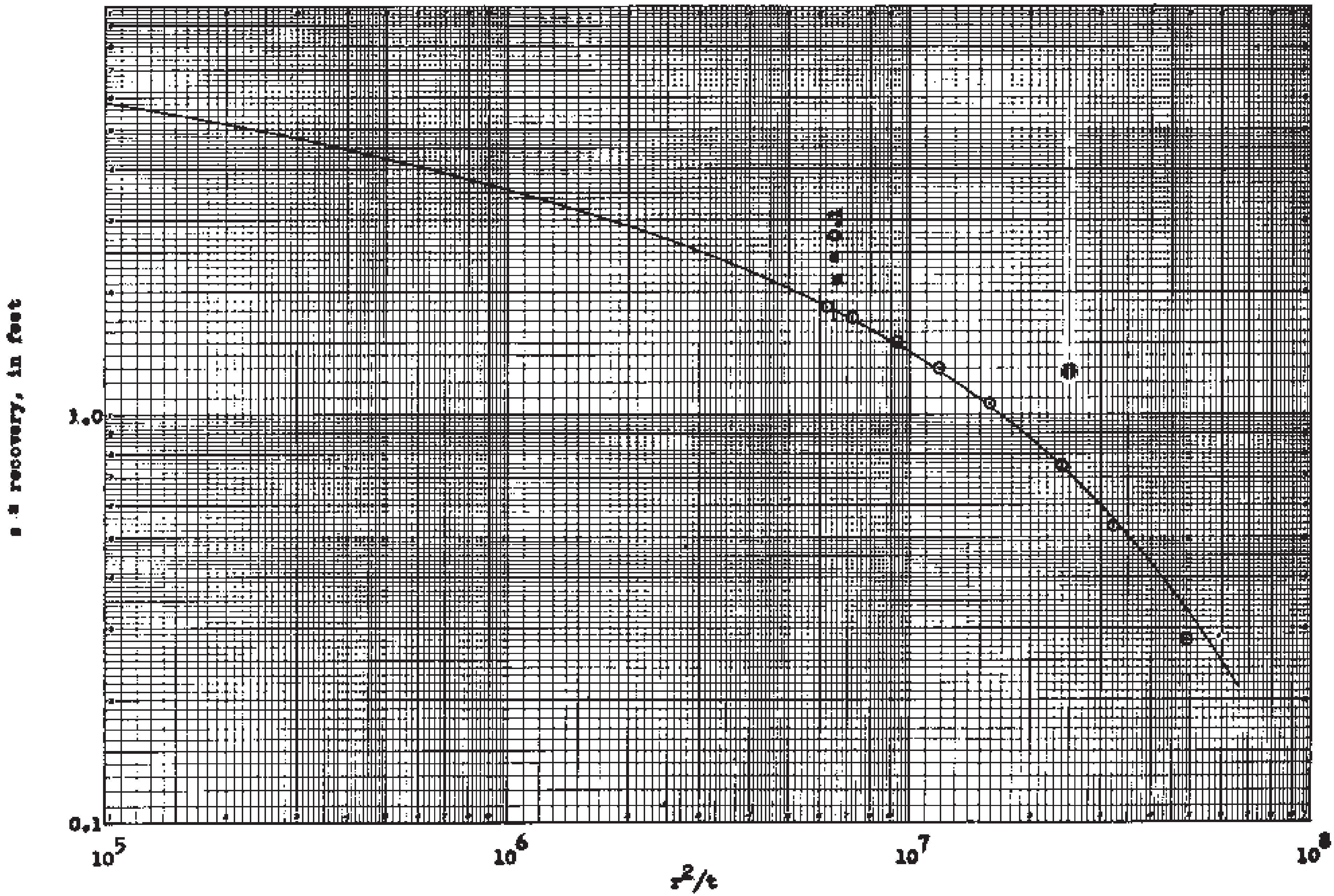
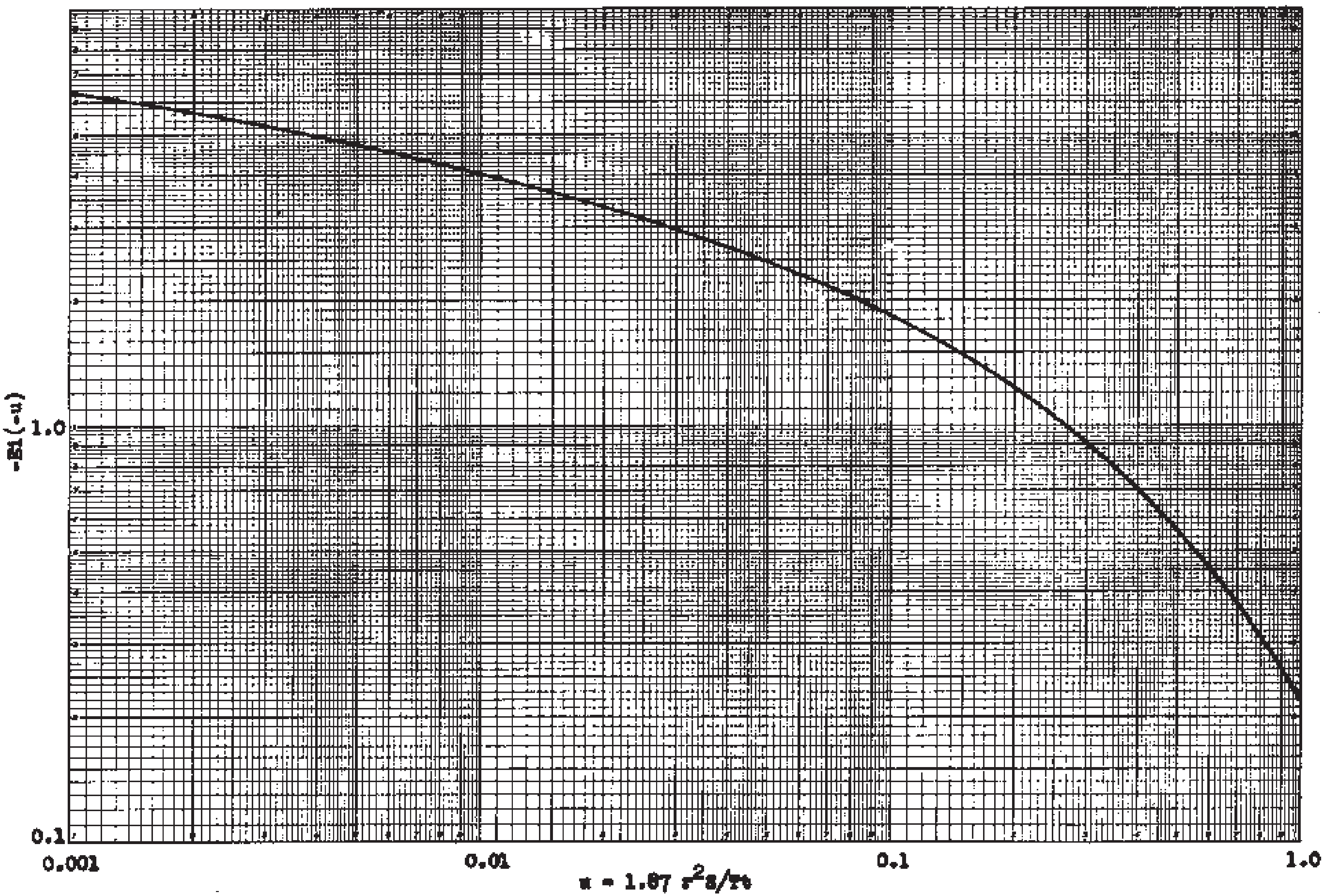


Fig. 6 -- Logarithmic graph of the exponential-integral "type curve"



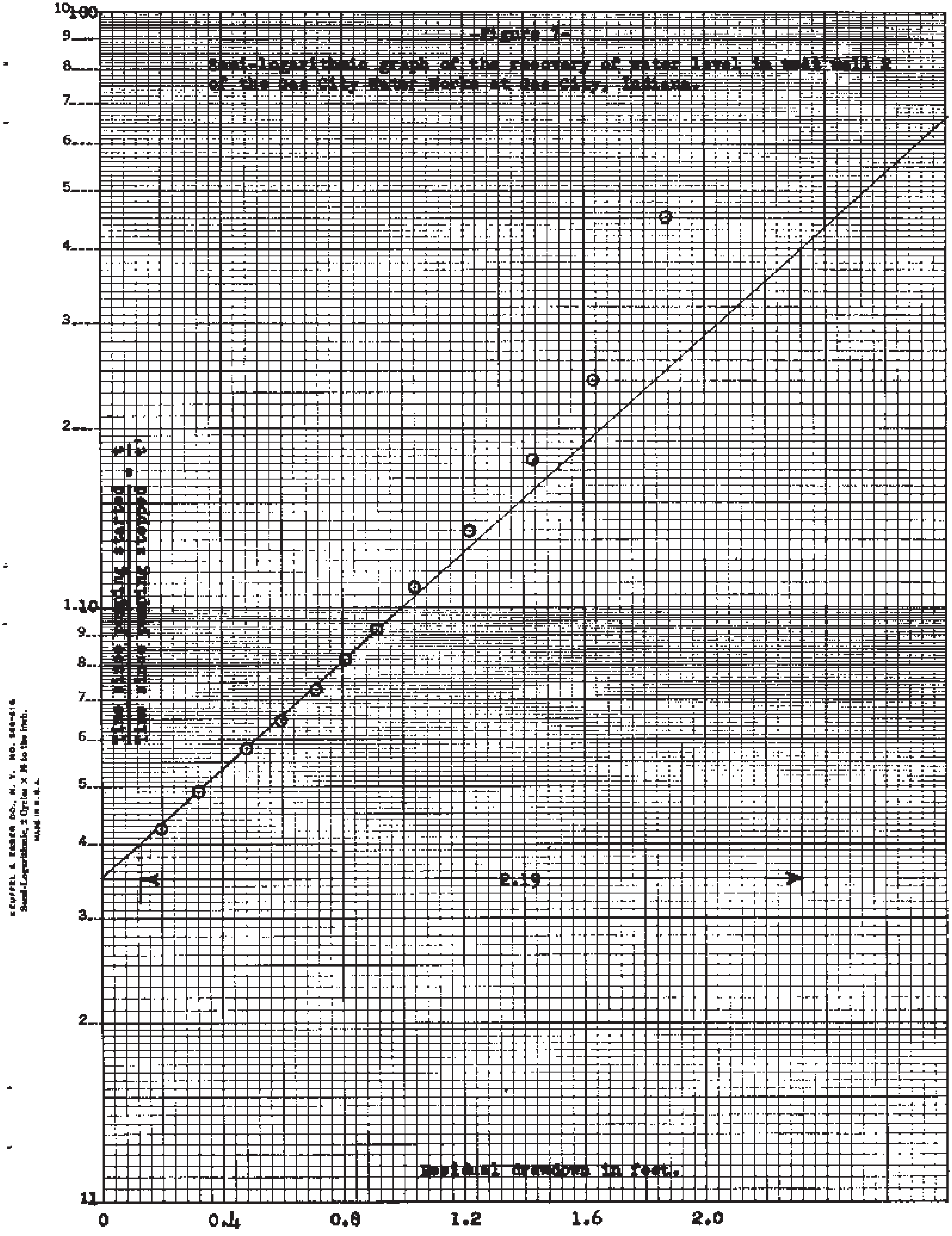
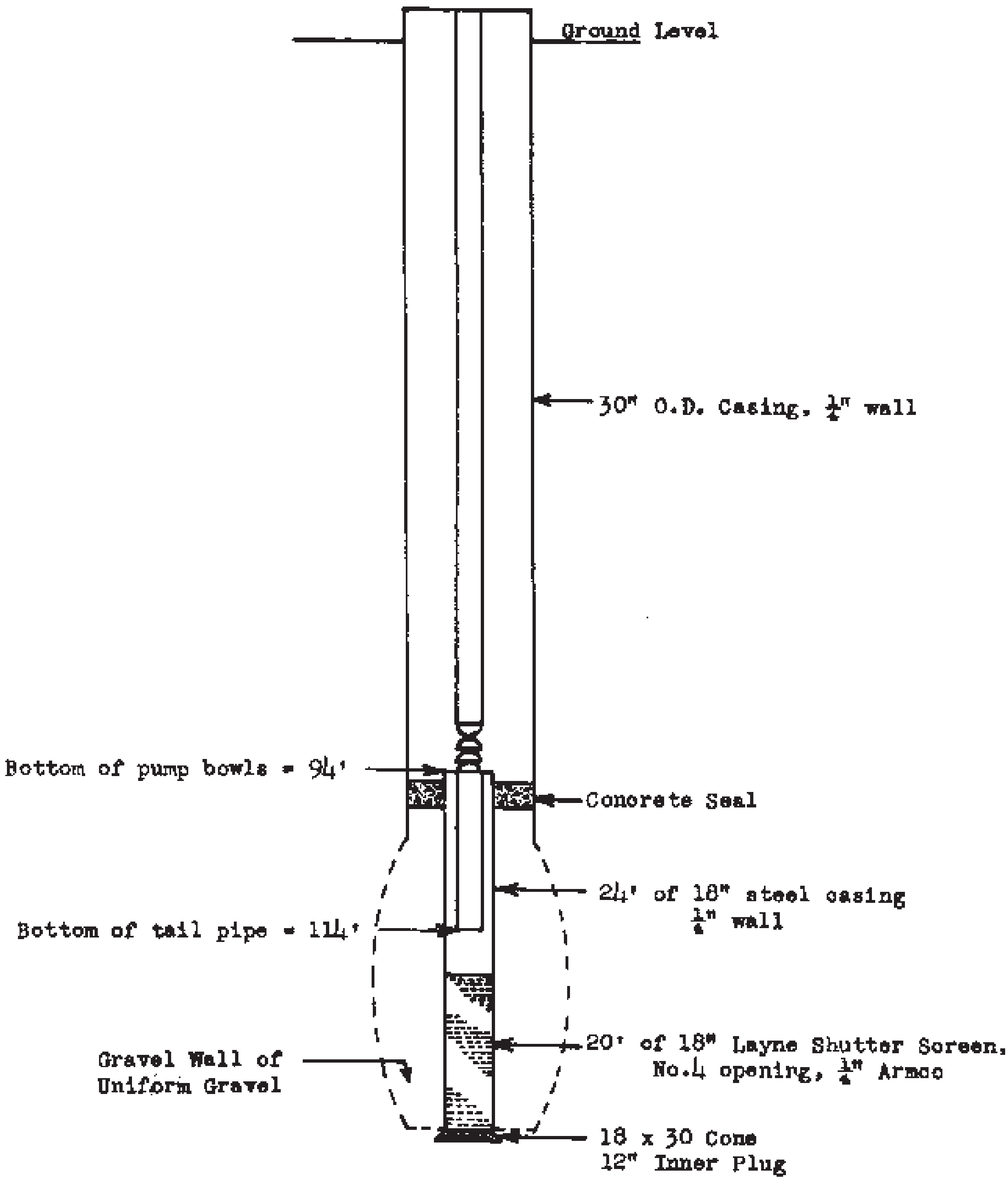

-Figure 7-
Semi-logarithmic graph of the recovery of water level in test well 2 of the Gas City Water Works at Gas City, Indiana.
2.19
Residual drawdown in feet.
0
0.4
0.8
1.2
1.6
2.0
KEUFFEL & ESSER CO., N. Y. NO. 359-61G
Semi-Logarithmic, 2 Cycles X 70 to the inch.
MADE IN U.S.A.

Figure 8. Diagram showing construction of Well No. 3 of the Owens-Illinois Glass Company at Gas City, Indiana.



Driller -- Layne Northern Co. Inc.
Mishawaka, Indiana
Date Started -- Feb. 22, 1937
Date Finished -- March 26, 1937

Static Level = 67'
Pumped 820 GPM
at 80' Pumping Level

Table No. 1. Altitude gage measurements of fluctuation of water level in Well No. 1 of the Owens-Illinois Glass Co. at Gas City, Ind.

Watch time	Pump time in minutes since pump started or stopped	Altitude gage (feet)	Observed drawdown (-) or recovery (+) (feet)
June 19, 1944			
	Drawdown		
1:21 PM	--	30	----
1:46	17	29.6	-0.4
2:24	55	29.5	-0.5
4:06	157	28.7	-1.3
6:53	324	28.4	-1.6
8:24	415	28.4	-1.6
9:24	475	28.4	-1.6
	Recovery		
9:53:30	19.5	30	+1.6
11:13	99	30	+1.6

Table No. 2. Altitude gage measurements of fluctuation of water level in Well No. 2 of the Owens-Illinois Glass Co. at Gas City, Ind.

Watch time	Pump time in minutes since pump started or stopped	Altitude gage (feet)	Observed drawdown (-) or recovery (+) (feet)
June 19, 1944			
	Drawdown		
1:22 PM	--	24.0	----
1:50	21	23.3	-0.7
2:28	59	23.0	-1.0
4:09	160	22.6	-1.4
6:55	326	22.4	-1.6
8:26	417	22.4	-1.6
9:26	477	22.4	-1.6
	Recovery		
9:55:30	21.5	23.1	+0.7
11:15	101	23.8	+1.4

Table No. 3. Altitude gage measurements of drawdown of water level in Well No. 3 of the Owens-Illinois Glass Co. at Gas City, Indiana.

Watch time	Pump time in minutes since pump started or stopped	Altitude gage (feet)	Observed drawdown (feet)
June 19, 1944			
1:28 PM	----	55	----
1:29:22	0.37	45	10
1:29:43	0.72	40.5	14.5
1:30	1.00	37.5	17.5
1:30:15	1.25	36	19.0
1:30:38	1.63	35	20.0
1:31:08	2.13	32.5	22.5
1:31:22	2.37	32	23.0
1:32	3.0	31.5	23.5
1:34:30	5.5	31.3	23.7 1/
1:56	27	31.5	23.5
2:11	42	31.6	23.4
2:36	67	31.6	23.4 1/
3:16	107	32.2	22.8
3:38	129	32.3	22.7 1/
3:57	148	32.6	22.4
4:25	176	33.3	21.7 1/
6:47	318	34.0	21.0 1/
8:18	409	34.7	20.3 1/
9:17	468	35.0	20.0
9:32	483	35.0	20.0 1/
			7/152.8
		average=	21.8

1/ - Used in determining average drawdown.

Table No. 4. Drawdown of water level in Gas City Water Works Test Well 2 produced by pumping Well 3 of the Owens-Illinois Glass Company at Gas City, Indiana.

Watch time	Pump time in mins.	Depth to water in ft. below measuring point	Total drawdown in feet	r^2/t	Watch time	Pump time in mins.	Depth to water in ft. below measuring point	Total drawdown in feet	r^2/t
12:30p	-59	70.46			2:31p	62	70.71		
12:45	-44	70.33			2:33	64	70.73		
1:00	-29	70.22			2:35	66	70.74		
1:09	-20	70.18			2:37	68	70.77		
1:11	-18	70.17			2:39	70	70.79		
1:13	-16	70.16			2:41	72	70.81		
1:15	-14	70.15			2:43	74	70.82		
1:17	-12	70.13			2:45	76	70.84		
1:19	-10	70.12			2:47	78	70.85		
1:21	- 8	70.11			2:49	80	70.87	1.10	$1.16x10^7$
1:23	- 6	70.10			2:51	82	70.88		
1:25	- 4	70.09			2.53	84	70.90		
1:27	- 2	70.08			2:55	86	70.91		
1:29	0				2:57	88	70.94		
1:31	2	70.06			2:59	90	70.95		
1:33	4	70.05			3:01	92	70.97		
1:35	6	70.06			3:03	94	70.98		
1:37	8	70.07			3:05	96	70.99		
1:39	10	70.09	0.07	$9.30x10^7$	3:07	98	71.02		
1:41	12	70.11			3:09	100	71.03	1.31	$9.30x10^6$
1:43	14	70.14			3:11	102	71.03		
1:45	16	70.17			3:13	104	71.04		
1:47	18	70.19			3:15	106	71.06		
1:49	20	70.22	0.24	$4.65x10^7$	3:17	108	71.08		
1:51	22	70.24			3:19	110	71.09		
1:53	24	70.27			3:21	112	71.09		
1:55	26	70.29			3:23	114	71.11		
1:57	28	70.32			3:25	116	71.13		
1:59	30	70.35	0.41	$3.10x10^7$	3:27	118	71.14		
2:01	32	70.38			3:29	120	71.15	1.48	$7.75x10^6$
2:03	34	70.40			3:31	122	71.16		
2:05	36	70.42			3:33	124	71.18		
2:07	38	70.44			3:35	126	71.18		
2:09	40	70.47	0.57	$2.33x10^7$	3:37	128	71.20		
2:11	42	70.49			3:39	130	71.20		
2:13	44	70.51			3:41	132	71.21		
2:15	46	70.54			3:43	134	71.22		
2:17	48	70.56			3:45	136	71.23		
2:19	50	70.58			3:47	138	71.24		
2:21	52	70.61			3:49	140	71.25		
2:23	54	70.63			3:51	142	71.26		
2:25	56	70.66			3:53	144	71.28		
2:27	58	70.67			3:55	146	71.29		
2:29	60	70.69	0.85	$1.55x10^7$	3:57	148	71.30		

Table No. 4. -- Continued

Watch time	Pump time in mins.	Depth to water in ft. below measuring point	Total drawdown in feet	r^2/t	Watch time	Pump time in mins.	Depth to water in ft. below measuring point	Total drawdown in feet	r^2/t
3:59p	150	71.31							
4:01	152	71.33							
4:03	154	71.34							
4:05	156	71.34							
4:07	158	71.35							
4:09	160	71.36	1.77	$5.81x10^6$					
4:11	162	71.38							
4:13	164	71.39							
4:15	166	71.39							
4:17	168	71.40							
4:19	170	71.41							
4:21	172	71.42							
4:23	174	71.43							
4:25	176	71.44							
4:27	178	71.44							
4:29	180	71.45							
4:31	182	71.46							
4:33	184	71.47							
4:35	186	71.47							
4:37	188	71.48							
4:39	190	71.49							
4:49	200	71.50	1.98	$4.65x10^6$					
5:00	211	71.52							
5:15	226	71.57							
5:30	241	71.62	2.16	$3.86x10^6$					
5:45	256	71.66							
6:00	271	71.69							
6:15	286	71.71	2.30	$3.25x10^6$					
6:30	301	71.73							
6:45	316	71.77	2.39	$2.94x10^6$					
7:00	331	71.79							
7:15	346	71.80							
7:32	363	71.82	2.49	$2.56x10^6$					
7:45	376	71.84							
8:00	391	71.85							
8:15	406	71.87	2.57	$2.29x10^6$					
8:30	421	71.88							
8:45	436	71.90	2.62	$2.13x10^6$					
9:34	485	71.94	2.68	$1.92x10^6$					

Table No. 5. Recovery of water level in Gas City Water Works Test Well 2 produced by shutdown of Well 3 of the Owens-Illinois Glass Co. at Gas City, Indiana.

Watch time	Pump time in mins.	Depth to water in ft. below measuring point	Total recovery in feet	r^2/t	Watch time	Pump time in mins.	Depth to water in ft. below measuring point	Total recovery in feet	r^2/t
6/19/44									
9:34p	0	71.94			10:53	79	70.69	1.30	$1.18x10^7$
9:37	3	71.94			10:55	81	70.66		
9:39	5	71.94			10:57	83	70.65		
9:41	7	71.93			10:59	85	70.62		
9:43	9	71.91	0.03	$1.03x10^8$	11:01	87	70.61		
9:45	11	71.87			11:03	89	70.59		
9:47	13	71.83			11:05	91	70.57		
9:49	15	71.78			11:07	93	70.55		
9:51	17	71.73			11:09	95	70.53		
9:53	19	71.68	0.28	$4.90x10^7$	11:11	97	70.52		
9:55	21	71.63			11:13	99	70.50	1.50	$9.39x10^6$
9:57	23	71.58			11:15	101	70.48		
9:59	25	71.53			11:17	103	70.47		
10:01	27	71.48			11:19	105	70.46		
10:03	29	71.43	0.53	$3.21x10^7$	11:21	107	70.44		
10:05	31	71.39			11:23	109	70.42		
10:07	33	71.34			11:25	111	70.41		
10:09	35	71.30			11:27	113	70.40		
10:11	37	71.26			11:29	115	70.38		
10:13	39	71.22	0.75	$2.38x10^7$	11:31	117	70.37		
10:15	41	71.17			11:35	119	70.35		
10:17	43	71.14			11:37	121	70.34		
10:19	45	71.11			11:39	123	70.33		
10:21	47	71.07			11:41	125	70.32		
10:23	49	71.04			11:43	127	70.31		
10:25	51	71.02			11:45	129	70.29	1.72	$7.21x10^6$
10:27	53	70.99			11:47	131	70.28		
10:29	55	70.96			11:49	133	70.27		
10:31	57	70.93			11:51	135	70.25		
10:33	59	70.91	1.07	$1.58x10^7$	11:53	137	70.24		
10:35	61	70.88			11:55	139	70.23		
10:37	63	70.86			11:57	141	70.22		
10:39	65	70.83			11:59	143	70.21		
10:41	67	70.81							
10:43	69	70.79			6/20/44				
10:45	71	70.77							
10:47	73	70.75			12:01a	145	70.20		
10:49	75	70.73			12:03	147	70.19		
10:51	77	70.71			12:05	149	70.19	1.83	$6.24x10^6$

Table No. 6. Sieve analysis and permeameter results 1/ for sand samples from Test Well 2 of the Gas City Water Works at Gas City, Indiana.

	DEPTH AT WHICH SAMPLE WAS TAKEN								
SCREEN OPENING	120 to 125	125 to 130	130 to 135	135 to 140	140 to 145	145 to 150	150 to 155	155 to 160	160 to 165
	Percentage of total sample by volume retained on screen opening specified in left hand column when that screen alone is used.								
.131"	0	0	0	4	2	0	0	0	4
.065"	0	3	4	28	11	2	3	7	13
.0328"	0	11	48	53	38	7	11	14	37
.0164"	55	73	85	88	80	67	70	64	76
.0082"	93	95	98	98	98	95	82	93	96
Time in Seconds Thru Permeameter using 64°F water	269	123	98	91	197	196	176	180	134
Permeability in Meinzers Units at 55°F	1130	2470	3110	3240	1540	1510	1730	1640	2210 Total 18,580
									Avge. P = 2060

1/ Data furnished by Layne-Northern Company at Mishawaka, Indiana.

Table No. 7. Residual drawdown of water level in test well 2 of the Gas City Water Works at Gas City, Indiana.

Time in minutes since pumping stopped t'	Time in minutes since pumping started t	t/t'	Residual drawdown (feet) s
11	496	45.1	1.87
21	506	24.1	1.63
29	514	17.7	1.43
39	521	13.4	1.22
49	531	10.8	1.04
59	541	9.17	0.91
67	552	8.24	0.81
77	562	7.30	0.71
89	574	6.45	0.59
101	586	5.80	0.48
125	610	4.88	0.32
149	634	4.25	0.19