50-103

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Memorandum on Pumping Test at Ambridge, Pennsylvania

November 10, 1949

By D. W. Van Tuyl

approved by Dean 7/25/50 for open file.

Pa. 49

Text

Illustrations

Appendix

Open-file reps 1950

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MEMORANDUM ON PUMPING TEST AT AMBRIDGE, PA.

By D. W. Van Tuyl

Introduction

By arrangement with Mr. J. Z. Columbia, Superintendent of the Ambridge Water Works, the United States Geological Survey conducted a "pumping test" in the Ambridge well field on November 10, 1949. As used in this report, "pumping test" means pumping a well at a fixed rate to determine the hydrologic properties of the water-bearing formation. By measuring the decline and recovery of water level in the pumped well and in other observation wells the necessary information is obtained for computing these properties.

Such procedures are part of the field activities of the ground-water program in Pennsylvania being sponsored jointly by the Pennsylvania Topographic and Geologic Survey and the United States Geological Survey.

The amount of water that can be pumped from an underground formation depends upon its ability to transmit water to a well and upon the amount of water that is released from storage when the water table or pressure head is lowered. The first is measured by the coefficient of transmissibility and the second by the coefficient of storage. These two characteristics are then used to determine the effect on water levels caused by changes in the location and rate of pumping from the aquifer.

Description of Wells

The Borough of Ambridge obtains its water supply from 8 drilled wells, located in a line along the east bank of the Ohio River at Ambridge, Beaver County, Pa. The wells are spaced about 200 feet apart and are from 17 to 40 feet from the river at normal pool stage. They are numbered from 1 to 8, starting from the north end. The wells are 12 inches in diameter and range in depth from 42.6 to 58 feet. The lower 12 - 14 feet of each well is screened. The wells are equipped with electrically driven turbine pumps and can be operated individually.

Geology

The aquifer consists of sand and gravel of Pleistocene age overlain by Recent clay and river mud. The sand and gravel is believed to be the outwash from a Wisconsin ice sheet which invaded the Allegheny watershed in northwestern Pennsylvania. .though these valley-fill deposits are relatively shallow - not exceeding 60 feet in this locality, they generally extend over the entire width of the present valley. The sand and gravel aquifer underlies Ambridge to the east wall of the valley, and probably extends under the Ohio River to the west side of the valley, a total width of about 4,200 feet. The rock floor of the valley is composed for the most part of shales and fine sandstones of the Conemaugh formation of Pennsylvanian age. The water-bearing properties of the bedrock are poor as compared to the valley sediments and few rock wells have been drilled.

Test Procedure

For at least 24 hours prior to the test, Borough wells 1-3 were idle, while wells 4-8 were in continuous operation. Beginning at 9:30 AM Nov. 10, 1949, well 2 was pumped at the rate of 300 gpm and wells 1 and 3 were used as observation wells. Pumping of well 2 was continued for 5 hours and 10 minutes. The rate of discharge was measured through a 6" by 4" freely-discharging pipe orifice and was constant during the period of the test. Discharge was into the Ohio River opposite the well. Static water levels in wells 1, 2, and 3 were measured by steel tape before the pump was started. Periodic measurements were made in wells 1 and 3 during the period of pumping and for 40 minutes after pumping stopped.

Measurements in well 2 could not be made with a tape while the pump was running, but two measurements were obtained by means of an electric cable and test set. Recovery of the water level after pumping stopped was measured by steel tape. Fig. 1 shows graphs of the measured water levels in wells 1 and 2. The temperature of the well water and the Ohio River were recorded periodically and were found to be about 68° F and 54° F, respectively. A temporary staff gage installed in the River was read occasionally to determine any changes in pool stage.

Analysis of Data

Figure 2 contains curves of the drawdown in wells 1 and 3 caused by pumping well 2. Drawdown is plotted against time on the logarithmic scale. The slope of the line through the first few points determines the value of the coefficient of transmissibility, T, computed by the

Theis non-equilibrium formula. According to this formula the time-drawdown relation is a straight line on semi-log paper for a uniform aquifer of unlimited areal extent.

The aquifer pumped at Ambridge acts as a uniform infinite body only for a short time, until other effects are introduced. The first of these - the presence of recharge - is indicated by the sharp change of slope in the drawdown curve. The second factor - a boundary of the aquifer - is observed in the next change of slope. The slope of this last limb of the drawdown curve is double the slope of the recharge limb. The effect of the boundary, in this case probably the eastern limit of the aquifer, is an increase in the drawdown which may be considered to be caused by a hypothetical "image" well beyond the boundary.

From the test data the following have been computed:

Coefficient of Transmissibility T = 180,000 gpd/ft

Coefficient of Storage S = 2.4×10^{-4} (0.00024)

Distance to line of recharge = 400 feet

Distance to boundary = 2700 feet

The drilling records indicate an average thickness of formation in this area of about 28 feet. The coefficient of permeability thus is about 6,400 gpd/ft^2.

The magnitude of the coefficient of storage S indicates that the ground water occurs in the aquifer under artesian head. Further evidences of this condition are in the position of the static water level (pressure surface) and in the effect on the water level of passing railroad trains.

Drawdown and Interference

Using the values of coefficients of transmissibility and storage computed from the test data, the curves in fig. 3-a were plotted to show the drawdown or interference effect of an adjacent well for various rates of pumping. Based on a well spacing of 200 feet, the interference includes the effects of the recharge and the boundary conditions found at the site.

Similarly, the curves in fig. 3-b show the expected drawdown in well 2 for continuous pumping at these rates, with no other wells operating. The total drawdown in this well after any period of pumping would be the sum of the amount shown in fig. 3-b for the given rate and the amounts produced by any other wells being pumped at the time. The drawdown caused by wells 1 and 3 can be obtained from the curves in fig. 3-a, whereas the effects of wells 4-8 on well 2 have not been determined. Wells 4-8 were in operation during the test, but the combined rate of pumping was not recorded. Assuming they had each been pumped at 300 gpm for 24 hours, their combined effect on the water level in well 2 is estimated to be about 1.5 feet.

Theoretically, the amount of drawdown is directly proportional to the rate of withdrawal. This relation holds for all practical considerations in observation wells at any distance from the point of withdrawal. For example, at the end of any period of pumping, the drawdown caused by pumping 200 gpm is half the drawdown caused by pumping 400 gpm., as shown in fig. 3-a. Likewise, the drawdown for 300 gpm is three-fourths the amount for 400 gpm. In a well which is being pumped, however, this relationship does not apply, and conversions of the drawdowns in fig. 3-b to the other rates of pumping follow a different law, which could be determined by a special test on the well. An approximation of this law was used in computing the time-drawdown curves in fig. 3-b.

Conclusion

The hydrologic properties of the aquifer tapped by the municipal wells at Ambridge have been computed from the drawdown curves in fig. 2. With a fixed transmissibility the amount of water that can be withdrawn through a well is governed in this case by the amount of drawdown produced. That recharge to the aquifer is derived from the Ohio River is shown by the first abrupt change in the slope of the curve. The contribution of water from the direction of the river was less than the rate of pumping during the test, and the curve continued to decline (second limb) but at a lesser slope. Eventually the pumping effect reached a boundary of the aquifer and the curve steepened (third limb) to a slope twice that of the second limb.

Equilibrium would be reached only when all the water comes from recharge. The test data indicates that for the period of the test the Ohio River was not supplying all the water to the pumping well. Apparently the hydraulic gradient from the area of recharge to the well must be made steeper by increasing the drawdown. Then the river will be contributing the entire amount and none will be taken from storage with the aquifer.

The interference between wells in this group is small, being less than 1.0 foot of drawdown after one day of pumping at 300 gpm. For example, the total drawdown in well 2 after one day of pumping wells 1-3 all at 300 gpm would be, from fig. 3-b, 14.95 + 0.90 + 0.90 = 16.75 feet.

The drawdown curves computed for well 2 probably are typical of the performance of the other wells in the group, except that the initial drawdowns may vary in a range of a few feet. The time-drawdown curves for other wells should have approximately the same slopes as those for well 2 in fig. 3-b.

Appendix

Ambridge, Pa.
Nov. 10, 1949

Water Levels in Well 1

Time	Water level(a)	Time	Water level	Time	Water level
8:46 am	2.76	10:04 am	3.315	2:00 pm	3.49
9:28	2.74	10:06	3.315	2:15	3.49
9:30		10:08	3.34	2:30	3.50
9:31	3.03	10:10	3.34	2:40	3.50
9:32	3.17	10:15	3.34	2:41	3.34
9:33	3.22	10:20	3.34	2:42	3.10
9:34	3.24	10:25	3.36	2:43	3.06
9:35	3.25	10:30	3.36	2:44	3.02
9:36	3.26	10:35	3.37	2:45	3.01
9:37	3.26	10:40	3.37	2:46	3.00
9:38	3.27	10:45	3.39	2:48	2.985
9:40	3.27	10:50	3.38	2:50	2.98
9:42	3.28	10:55	3.40	2:52	2.96
9:44	3.28	11:00	3.40	2:54	2.95
9:46	3.29	11:10	3.40	2:56	2.95
9:48	3.29	11:20	3.41	3:00	2.95
9:50	3.29	11:30	3.42	3:05	2.96
9:52	3.295	11:45	3.44	3:10	2.92
9:54	3.30	12:00 n	3.43	3:15	2.94
9:56	3.30	12:30 pm	3.45	3:20	2.93
9:58	3.31	12:45	3.45		
10:00	3.31	1:00	3.48		
10:02	3.32	1:15	3.47		
		1:30	3.48		
		1:45	3.485		

(a) Water level in feet below measuring point; measuring point = edge of air-line hole in pump base.

Appendix

Ambridge, Pa.
Nov. 10, 1949

Well No. 2

Water Levels(a)

Time	W. L.	
9:08 am	7.23	
9:28	7.26	
9:50	23.3	(c)
11:45	23.3	(c)
1:45 pm	22.10	(d)
2:28	22.10	(d)
2:41	7.90	
2:42	7.67	
2:43	7.59	
2:44	7.57	
2:45	7.54	
2:46	7.54	
2:48	7.51	
2:50	7.51	
2:52	7.50	
2:55	7.48	
3:00	7.49	
3:05	7.48	
3:10	7.43	
3:12	7.50	
3:13	7.47	

Rate of Discharge

Time	Ht. of water(b)
9:30 am	0
9:32	22¼
9:40	22¼
9:55	22¼
10:25	22¼
11:05	22¼
11:30	22¼
12:10 pm	22 1/8
12:38	22 1/8
1:50	22 1/8
2:30	22 1/8
2:40	0

Temperature

Time	°F
9:35 am	68
9:55	67
10:25	67
11:05	67.5
12:10 pm	68
1:50	67.5
2:30	68

(a) Water level in feet below measuring point by steel tape, except as otherwise indicated; measuring point = edge of air-line hole in pump base.
(b) Inches of water above center of discharge pipe orifice.
(c) By air gage, in feet below center of gage which was 1.00 foot above M. P.
(d) By electric tape, in feet below M. P.

Ohio River

Time	Staff Gage	Temp.
9:03 am	0.30 ft.	
9:35	.30	
10:00	.30	
10:30	.30	52.5° F.
11:25	.25	54
12:10 pm	.25	
1:50	.30	55
2:30	.23	

Appendix

Ambridge, Pa.
Nov. 10, 1949

Water Levels in Well 3

Time	Water Level(a)	Time	Water Level	Time	Water Level
9:15 am	3.90	10:35 am	4.62	2:44 pm	4.15
9:28	3.93	10:40	4.625	2:45	4.15
9:31	4.32	10:43	4.59	2:46	4.14
9:32	4.32	10:45	4.625	2:47	4.13
9:33	4.46	10:50	4.63	2:48	4.13
9:34	4.51	10:56	4.65	2:49	4.13
9:35	4.51	10:58	4.64	2:50	4.13
9:36	4.54	11:00	4.665	2:51	4.13
9:37	4.58	11:10	4.66	2:52	4.11
9:38	4.57	11:20	4.69	2:53	4.11
9:39	4.53	11:30	4.665	2:54	4.07
9:40	4.59	11:40	4.64	2:55	4.065
9:41	4.55	11:50	4.675	2:56	4.065
9:42	4.59	12:00 n	4.695	2:57	4.10
9:43	4.57	12:15 pm	4.66	2:58	4.11
9:44	4.61	12:30	4.70	2:59	4.13
9:45	4.57	12:45	4.65	3:00	4.12
9:46	4.56	1:00	4.66	3:02	4.14
9:47	4.58	1:15	4.65	3:04	4.145
9:48	4.59	1:30	4.66	3:06	4.17
9:49	4.62	1:45	4.66	3:08	4.07
9:50	4.60	2:00	4.67	3:10	4.08
9:55	4.59	2:15	4.66	3:12	4.13
10:00	4.57	2:30	4.69	3:14	4.05
10:05	4.59	2:35	4.75	3:16	4.075
10:10	4.60	2:38	4.75	3:18	4.11
10:15	4.60	2:39	4.75	3:20	4.05
10:20	4.60	2:40	4.67		
10:30	4.65	2:41	4.44		
10:32	4.60	2:42	4.31		
		2:43	4.21		

(a) Water level in feet below measuring point; measuring point = edge of air-line hole in pump base.

Appendix

Ambridge, Pa.
Nov. 10, 1949

Water Levels in Well 3

Time	Water Level(a)	Time	Water Level	Time	Water Level
9:15 am	3.90	10:35 am	4.62	2:44 pm	4.15
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9:31	4.32	10:43	4.59	2:46	4.14
9:32	4.32	10:45	4.625	2:47	4.13
9:33	4.46	10:50	4.63	2:48	4.13
9:34	4.51	10:56	4.65	2:49	4.13
9:35	4.51	10:58	4.64	2:50	4.13
9:36	4.54	11:00	4.665	2:51	4.13
9:37	4.58	11:10	4.66	2:52	4.11
9:38	4.57	11:20	4.69	2:53	4.11
9:39	4.53	11:30	4.665	2:54	4.07
9:40	4.59	11:40	4.64	2:55	4.065
9:41	4.55	11:50	4.675	2:56	4.065
9:42	4.59	12:00 n	4.695	2:57	4.10
9:43	4.57	12:15 pm	4.66	2:58	4.11
9:44	4.61	12:30	4.70	2:59	4.13
9:45	4.57	12:45	4.65	3:00	4.12
9:46	4.56	1:00	4.66	3:02	4.14
9:47	4.58	1:15	4.65	3:04	4.145
9:48	4.59	1:30	4.66	3:06	4.17
9:49	4.62	1:45	4.66	3:08	4.07
9:50	4.60	2:00	4.67	3:10	4.08
9:55	4.59	2:15	4.66	3:12	4.13
10:00	4.57	2:30	4.69	3:14	4.05
10:05	4.59	2:35	4.75	3:16	4.075
10:10	4.60	2:38	4.75	3:18	4.11
10:15	4.60	2:39	4.75	3:20	4.05
10:20	4.60	2:40	4.67		
10:30	4.65	2:41	4.44		
10:32	4.60	2:42	4.31		
		2:43	4.21		

(a) Water level in feet below measuring point; measuring point = edge of air-line hole in pump base.

Appendix

Ambridge, Pa.
Nov. 10, 1949

Log of Well No. 2

Description	From	To
Clay.	0	21 feet
River mud	21	25
Sand and gravel	25	31
Fine gravel	31	35
Fine sand	35	38
Fine sand and gravel.	38	44
Coarse sand and gravel. . . .	44	48
Clay and gravel	48	50.67

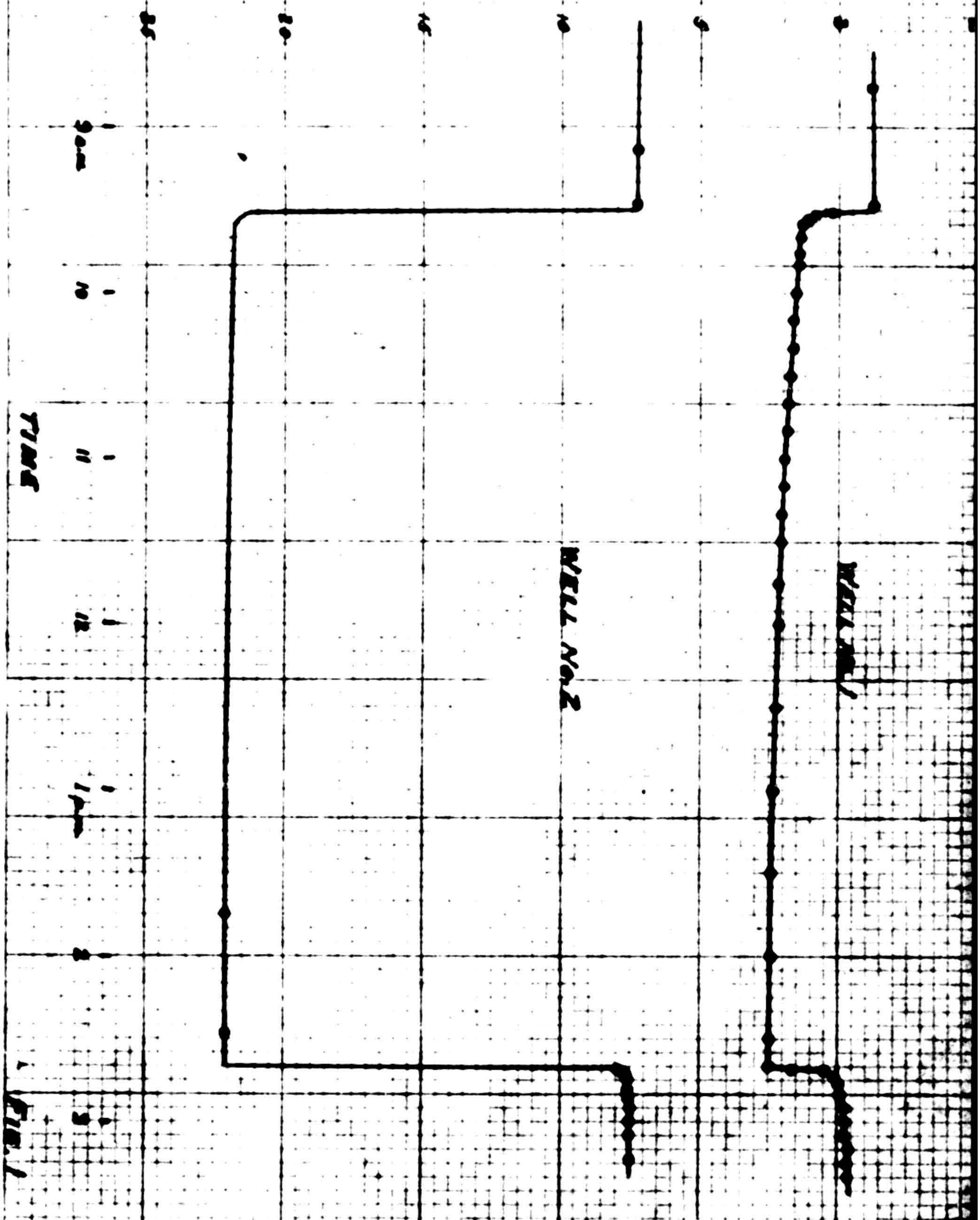
9—212-A
(November 1939)

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES BRANCH

File Number | Washington District

AMBRIDGE PUMPING TEST - Nov 10, 1949

Water Level, in Feet



(DO NOT USE THIS SPACE EXCEPT FOR BINDING PURPOSES)

Sheet No. .... of .... sheets. Prepared by .... Date .... Checked by .... Date ....

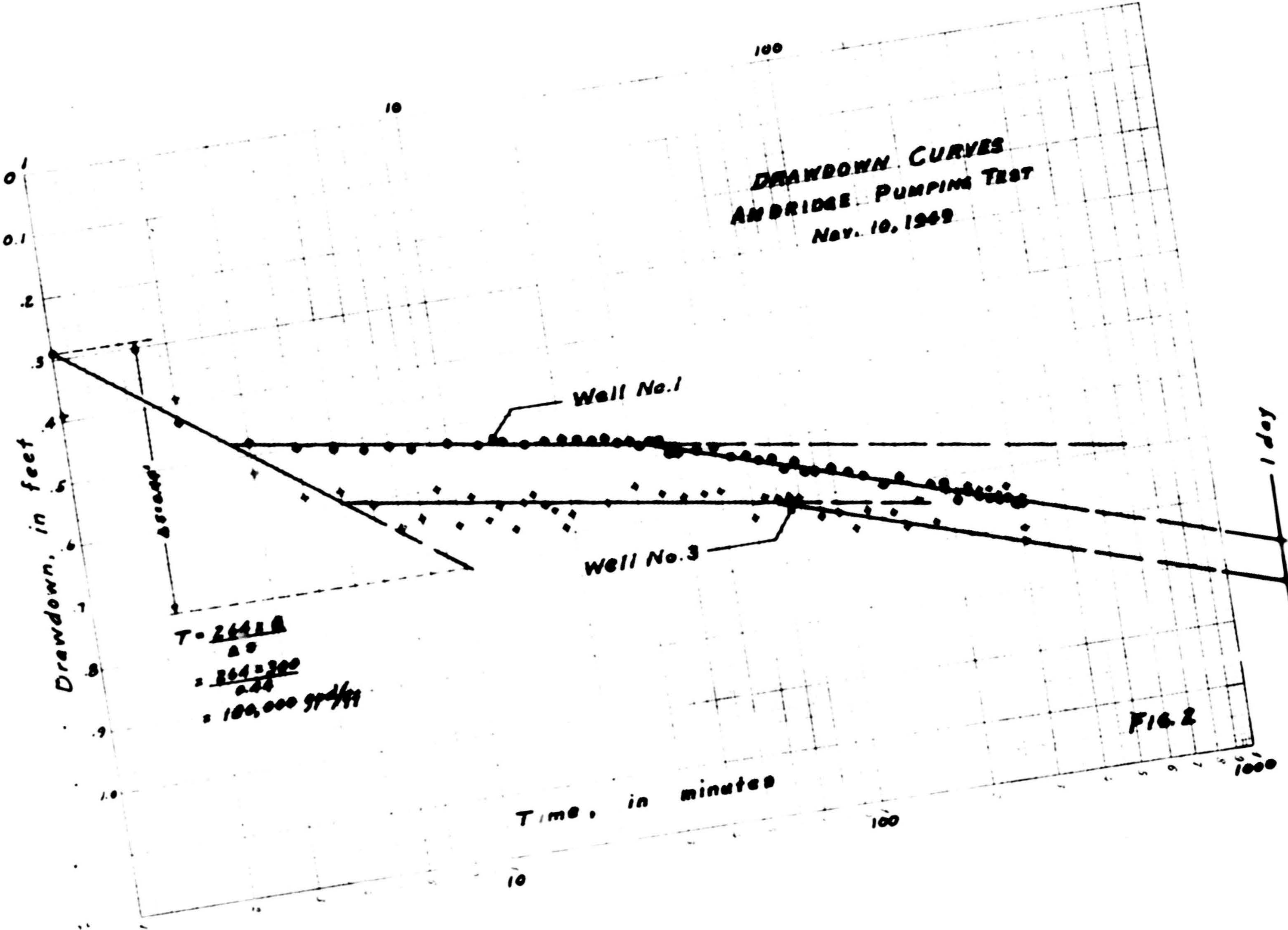

DRAWDOWN CURVES
ANDRIDGE PUMPING TEST
Nov. 10, 1949
Well No.1
Well No.3
1 day
Drawdown, in feet
Time, in minutes
10
100
1000
0.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0

FIG. 2

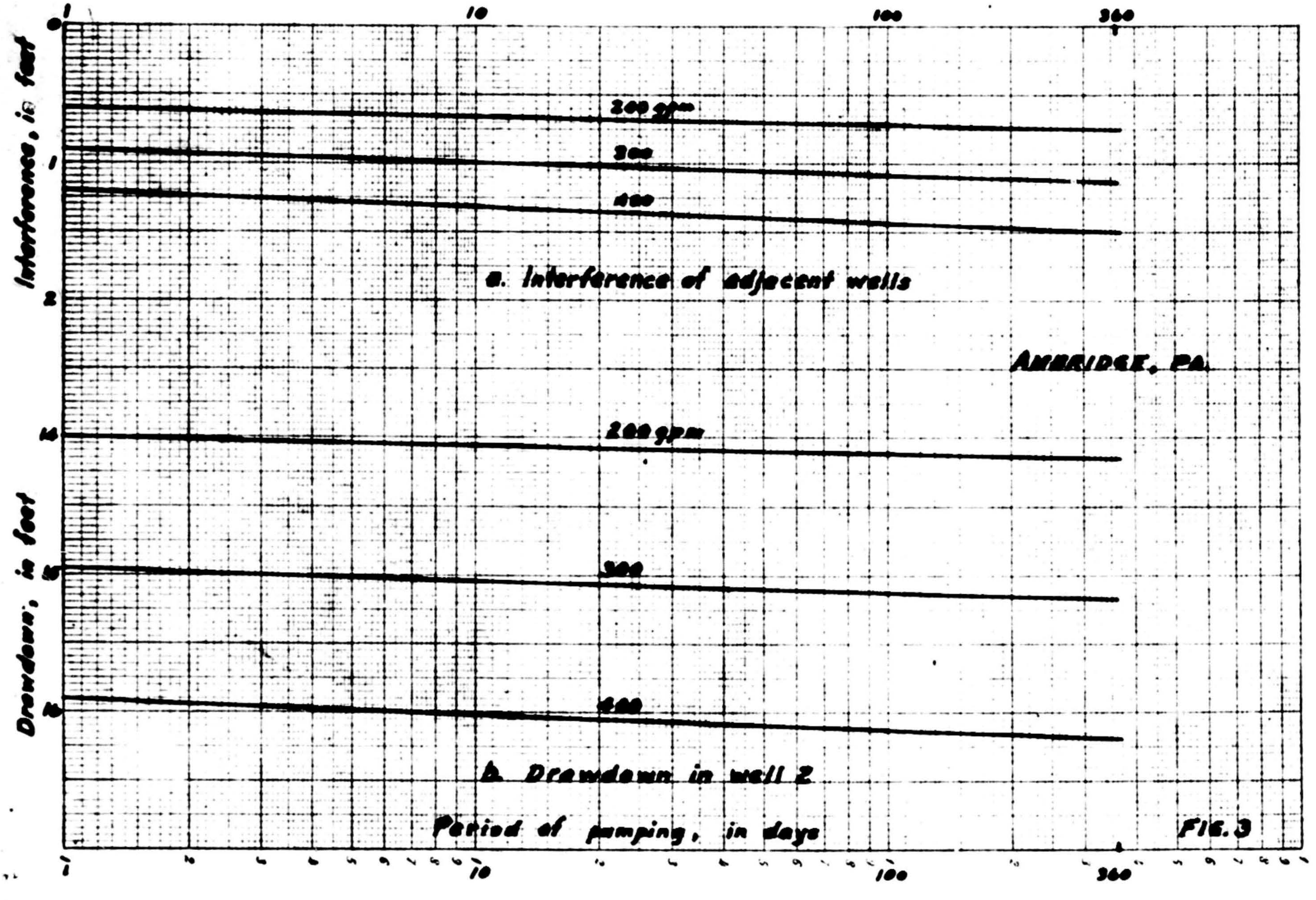

Interference, in feet
200 gpm
300
400
a. Interference of adjacent wells
AMBRIDGE, PA.
200 gpm
300
400
Drawdown, in feet
b. Drawdown in well 2
Period of pumping, in days
1
10
100
360

FIG. 3

STANDARD FORM NO. 64

Pa 49

Office Memorandum • UNITED STATES GOVERNMENT

TO : A. N. Sayre, Washington, D.C.

DATE: June 22, 1950

R.H.B.

FROM : John G. Ferris, Lansing, Michigan

File: 45040

SUBJECT: Ambridge, Pa. report

Returned herewith is the report titled "Memorandum on Pumping Test at Ambridge, Pa." by D. W. Van Tuyl, which has been reviewed in accord with your request of May 24. It is regretted that practically a month has elapsed since your original transmittal of this report for review, but the pressure of work in Michigan during this past month imposed numerous delays.

Inasmuch as this represents my first attempt as a reviewer I would greatly appreciate your appraisal of my enclosed memo of criticism prior to its transmittal to the author. If your selection of this particular report was made with the point of appraising my qualifications as a reviewer you are to be complimented on your choice. Having no previous experience in the review of Survey reports I am uncertain as to your policy in this regard. It may be that I have criticized this report too severely and perhaps you may wish to temper some of my remarks. In view of the prospect that I might review additional reports I would greatly appreciate your opinion on the nature and extent of my enclosed memo of revision and correction to the Ambridge report.

John G. Ferris

John G. Ferris

Suggested revisions and corrections to report by D. W. Van Tuyl

Titled Pumping Tests at Ambridge, Pa.

Item 1 Page 1, Introduction

The introductory section puts the cart before the horse by mentioning the name of the local water works superintendent in the opening paragraph and relegating the name of the cooperating agency to the brief second paragraph. While proper acknowledgement is due the local water works superintendent such recognition is of secondary importance.

In the second paragraph of the Introduction the statement is made that;

> "Such procedures (meaning pumping tests) are part
> of the field activities of the ground-water program
> in Pennsylvania - - - - -."

While it is recognized that considerable attention has been focused on pumping tests and the hydraulics of ground water within recent years we should never lose sight of our principle objective. Pumping tests are only a tool which we have found useful in our studies of the hydrology of an area. In effect then, the sentence in question tells nothing more than the following statement;

> Water-stage recorders and tapes are part of the
> field equipment of the ground water program in
> Pennsylvania - - - - -.

While my substitute sentence is perhaps extreme it serves to demonstrate the point in question.

It is suggested that the Introduction be rewritten in a manner which will convey to the reader of your report the overall objectives of the cooperative ground-water program in Pennsylvania. Indicate how and to what extent the Ambridge pumping test fits into the regional program. Include pertinent comments on the nature and extent of past and present water problems in the Ambridge area. Demonstrate how this particular test will assist in the appraisal of local water problems.

Item 2, Page 1 and 2, Description of Wells

The monotonous recitation in arithmetic to describe the well system owned by the borough of Ambridge is apt to leave the reader cold. The old adage that a picture is worth a thousand words certainly applies forcefully to your well-description paragraph. At least a map of the well field area should be furnished to show the reader the relation of the wells to the adjacent Ohio River and the orientation of the pumping wells and observation wells used in the test. It would be helpful to show on that map a section of the well construction, the position of screens and pump-bowl settings, and ground-water levels in relation to land surface and river level.

It is recognized that you are probably pressed for time, but it seems reasonable that even a brief report warrants the one or two days work necessary to prepare the suggested illustrations.

Item 3 Page 2, Geology

When we recognize that it is the geology which determines the occurence of ground water in an area and establishes the controls on the hydrology of the area it would appear impossible to do justice to this phase of the investigation in only a single paragraph. Here again the lack of illustration greatly impairs your presentation of the subject. Pertinent description should be provided of the lithology, structural geology, geomorphology, and glacial geology of the area with special reference to their bearing on the occurence of ground water. If logs of the existing wells are available furnish them and show a geologic section through the test area. In this regard, note that Leggette's Southern Pennsylvania Report, W3 on page 94 indicates that 38 driven wells were owned by the borough of Ambridge at the time of his field work during 1928 and 1929. If logs of these wells are available, add same to the geologic sections and to the well-log appendix. If logs of the wells are not available records of well depth and screen setting could be used to construct a generalized geologic section.

Your last sentence of the geology paragraph indicates that the bed rock in the Ambridge area is a poor aquifer. The question arises as to whether you mean poor from the standpoint of large capacity wells for industrial or municipal use or do you mean poor without qualification? Leggette implies that the Conemaugh formation may yield "good supplies of moderately mineralized water" in parts of Beaver County. While it is true that your pumping test applies to the alluvial deposits, your report should include comments on the availability of water from all aquifers in the Ambridge area.

<u>Item 4</u> Pages 2 and 3, Test Procedure

In this section, just as in the above section titled Description of Wells, it would be desirable to present the pertinent data in graphic form. Your figure 1 could be drafted to a somewhat different scale in order to provide space for an underlying graph that would show the rate of discharge by the pumping well with reference to time. In this manner the start and stop times and the duration of pumping could all be shown by the pumpage graph. If available it would be desirable to show a similar graph for the pumpage from the group of wells 4 to 8 inclusive.

If water levels were measured during the 24 hour rest period, prior to the start of pumping, then show same on your water level graphs. The two isolated measurements made in well number 2, near the close of the pumping period, do not provide sufficient basis for drawing the complete hydrograph given by your figure 1. If the hydrograph shown was drawn by inference or guesstimate then show same as a dashed or dotted line rather than a solid line. Generally when a solid line is used it implies that you have sufficient coverage of data to be reasonably certain of the trend at all times, throughout the range of observation. Certainly two points prior to the start of pumping and two points at the close of pumping do not justify the liberties you have taken in showing a hydrograph for well number 2.

In view of the limited number of water-level measurements for well number 2, in contrast to the data shown by figure 2 for well number 3, it might be better to record the measurements for well 2 in tabular form and show the measurements for well number 3 in graphic form. Your choice of Survey form 9-213A for plotting the hydrographs of figure 1 results in a makeshift scale for the time variable. Any saving in cost that might be made by the use of this form as contrasted to commercial 12 x 10 or 12 x 20 cross-section paper is offset many times by the convenience you impose on reviewers and readers of your report. Further, makeshift graph paper such as figure 1 leaves a poor impression on the public who consult and use your report.

Item 5 Pages 3 to 7 inclusive, Analysis of Data, Draw-down and Interference, and Conclusion

Errors in your interpretation of the pumping test data void these sections and thereby invalidate the entire report. After your recovery from the shock of this bald statement and the subsidence of the burning sensation in my ears let's look at the data for clues that point to the correct answer to your problem.

First, test your answer versus the observed drawdown or recovery for the pumped well. A 12-inch diameter well with 10 feet of screen should deliver the 300 gpm with a screen loss of 1 foot or less if properly screened and developed. Within 15 minutes after shutdown, well 2 recovered 14.6 feet. Let's assume that most of this recovery represents formation recovery and only a small part was screen loss. Using your values for T, S, and the distance to the recharge source we can compute the recovery of the formation at the end of 15 minutes. We need not consider the effect of the distant impervious boundary for this short period.

Given:

$r = 6$ inches $\quad T = 180{,}000$ gpd/ft

$t = 15$ minutes $\quad S = 2.4 \times 10^{-4}$

$Q = 300$ gpm

$$u = \frac{1.87r^2S}{Tt} = \frac{1.87 \times (\frac{1}{2})^2 \times 2.4 \times 1440}{1.8 \times 10^5 \times 10^4 \times 15} = 5.8 \times 10^{-8}$$

$W(u) = 16.1$

$$s = \frac{114.6\,Q\,W(u)}{T} = \frac{114.6 \times 300 \times 16.1}{180{,}000} = 3.1 \text{ ft.}$$

Compute the effect of the recharge well

$r_i = 2 \times 400 = 800$ ft

$$u = \frac{800^2}{\frac{1}{4}} \times 5.8 \times 10^{-8} = 1.5 \times 10^{-1}$$

$W(u) = 1.5$

$$s = \frac{1.5}{16.1} \times 3.1 = 0.3 \text{ ft}$$

Then the drawdown in the real well = 3.1 - 0.3 = 2.8 ft.

If this computed value of drawdown or recovery is accepted, you imply that the balance of the observed drawdown, which is 14.6 - 2.8 = 11.8 ft. must be largely screen loss. For the moderate pumping rate involved, a screen loss of this magnitude is out of line unless the well was poorly developed or the screen incrusted. Thus, the performance of well 2 suggests that your computed T value is too large.

Our next step is to inspect the original data to determine whether it presents evidence of smaller T values. In analyzing the results of a pumping test, the use of Jacob's semi-log method must be restricted to regions where the values of u are small.

As explained by Jacob in his original presentation and by others in subsequent reports, the semi-log method is an approximation that only becomes valid after u is quite small (less than 0.01 generally). Using your values of T, S, and the distances to the real well, to the recharging image well and to the discharging image well, we find that u values for both image wells are many times greater than the upper limit for use of the semi-log method. If the T value is revised downward to where we suspect it may be, the u values for the first few measurements are also beyond the acceptable limit for use of the semi-log method.

In the second paragraph of your page 4 you refer to changes in slope of the time drawdown curves in a manner that indicates you are somewhat confused on this matter. If as you imply, the slope of the last limb of the drawdown curve results from the entrance of an imperviours boundary then the slope of that line for this problem must be exactly equal to the slope of the initial limb, caused by the drawdown of the real well. The second or intermediate limb which shows the effect of the recharging image well should have been essentially horizontal. If the test begins with a discharge Q that is caused by the real discharging well, then the introduction of a recharging image well would occur at the same rate Q and would thereby cancel the initial slope or cause the water-level observations to trend essentially horizontal. This statement obtains only if the use of the semi-log plot is justified for the example, that is if and providing u is quite small. Inasmuch as the observed data does not reach horizontality before the entrance of the recharging image you are reasonably assured that you are not dealing with a region of small u values.

From your figure 2 it appears that the effect of the recharging image well reached the observation wells shortly after the second minute of pumping. In the case of well 3 the effect of the recharging-image well may have arrived after the third minute of pumping. Unfortunately the data is insufficient to be positive of these inferences. Further, the data for wells 1 and 3 during the first 3 minutes are so erratic, both with regard to water-level measurement and to timing, that any fit of these three points to the type curve is largely a matter of speculation.

Since both wells 1 and 3 are about the same distance from the pumping well, the drawdown effect in each well should have been essentially the same for those observations made prior to the arrival of any effect from recharging-image well. It seems probable that at least the observations at 1 minute and 2 minutes for wells 1 and 3 should show essentially the same drawdown. Note that your observations report the following drawdowns.

Time of pumping in minutes	Drawdown of water level in feet	
	Well No. 1	Well No. 3
1	0.29	0.39
2	0.43	0.39

In confirmation of the above premise your reported observations at the 2 minute interval do approach eachother. Note however, the wide spread between the drawdown values for wells 1 and 3 at the 1-minute interval and that for well 3 the same drawdown is recorded at the 2-minute interval as was reported for the 1-minute interval. It is physically impossible for the drawdown at well 3 to be the same at both the 1 and 3-minute inverval unless extraneous sources disturbed well 3 without producing any comparable effect on well number 1. While the hydrograph of well 3 does show interference throughout most of its extent, for the most part this interference effect is too small in magnitude to entirely account for the erratic observations in well 3 at the 1-minute and 2-minute intervals.

When a pumping test is run in an artesian aquifer that is of limited areal extent it is imperative that the measurements of water level in each observation well be made at very frequent intervals during the first few minutes of the test. This is particularly true if you suspect that a boundary lies within a distance comparable to the distance from the observation well to the pumped well. In this test it would have been helpful to obtain water-level measurements in both wells 1 and 3 at half minute intervals or less during the first 5 minutes of the pumping period. In order to make observations at this frequency it may be necessary to assign both a water-level observer and a time observer to each observation well during the first 5 minutes of the test.

It is imperative in a test of the Ambridge type that all observers synchronize their watches and this statement includes the operator who is responsible for starting the pump on the discharging well. Time errors as small as 20 seconds can greatly distort the observational data and will defeat your purpose in fitting the type curve through this early time region. Many investigators who have conducted pumping tests in areally-limited aquifers with moderate to poor success have "missed the boat" by being slip-shod or careless in synchronizing observation time with pumping time. Notwithstanding the many idealized assumptions necessary to the derivation of the Theis non-equilibrium formula, you will generally find for an artesian aquifer, that if water-level measurements are accurately made and if timing of observations are precise a match to the type curve can usually be obtained with observational data measured during the first 5 minutes of pumping. It must be recognized however, that this early time region requires far greater precision in the measurement of both water level and time than any other part of the test. It should also be recognized that in this region of small t values the sampling of the aquifer obtained is most limited and thereby most largely effected by local inhomogeneities.

As a guide for your re-interpretation of the pumping test data collected during the Ambridge test we have enclosed log-log plots for several possibilities that may point toward the answer. Examine first our figure A for well number 1 which assumes that the observations at 1 minute and at 2 minutes are correct as reported and that the effect of the recharging-image well did not reach well 1 until sometime later than the second observation. Using only the first 2 observations, a match is made to the type curve as indicated on the log-log plot by M.P. 1. This match indicates a T value of 179,000 or about the same value which you obtained by the semi-log method using the same 2 points. Now, with the observational data superimposed on the type curve at M. P. 1 trace the path of the type curve onto the observation plot. Next, measure the departure of the observed data from the trace of the type curve and replot these departures using the right-hand scale for drawdown. These departures are shown point by point as the inscribed squares. The departure data represents the effect on well 1 from the recharging-image well only. Inasmuch as the image well pumps at exactly the same rate as the real well, the plotted squares should fit the type curve at an s-intercept value equal to the s-intercept value for the real well. This is not the case and thus you are left with the conclusion that if all observed data shown are correct then the choice of 179,000 for T must be in error.

From examination of your figure 2 we note there is a leveling-off trend shown by well 1 from 12 to about 20 minutes after the start of pumping. Let's assume that this trend would have continued if the second boundary had not entered the picture.

Draw a horizontal line through the noted points at s=0.55. Measure the departures below this line of all subsequent data and compute therefrom the log-log plot, our figure B. If our assumptions are correct, these departures represent the separate effect of the discharging-image well that reflects the valley-wall boundary. By construction, that image pumps at the same rate as the real well and the departure data should fit the type curve at an s-intercept value equal to the value for the real well. The match used gives T = 34,000.

As a check, we return to the data for wells 1 and 3 and arbitrarily trace the type curve through the 1-minute observation for well 1 and the 2-minute observation for well 2 and maintaining the T value, of 34,000 determined above. The decisions as to which observations on wells 1 and 3 were made prior to the entry of the first image and the accuracy of these measurements in relation to stage and time leaves considerable latitude for individual interpretation as to where to fit the type curve. Our selection resulted after several trial fits, but is by no means the best possible fit and is used here only for demonstration. For figures A and C, a u value of 1.0 was used and the type curve was translated along the u = 1.0, and s = 0.22 axes until it passed through the desired observation point. The trace of the type curve was drawn on the data plot and departures of the observed data measured therefrom. The plotted departures were then matched to the type curve and found to agree roughly with the original fit of T = 34,000. You can follow the same process and make numerous other trials to estimate the probable T value. It is probably not T = 34,000 but this value is more nearly correct than the T = 179,000 value given by your semi-log plot.

You will find that the law of diminishing returns operates severely on this trial and error matching because of the uncertainties of the original data. It would be quicker and perhaps cheaper to rerun the pumping test rather than pursue the cut and try approach.

For the purpose of demonstration we may determine the image distances from the trial match points at the T = 34,000 value. Let s_r represent the drawdown in any observation well due to the real well pumping and s_i, the effect of the image well.

Then when $s_r = s_i$

$$\frac{114.6QW(u_r)}{T} = \frac{114.6QW(u_i)}{T}$$

or $W(u_r) = W(u_i)$

therefore $u_r = u_i$

$$\frac{1.87r_r^2 S}{Tt_r} = \frac{1.87r_i^2 S}{Tt_i}$$

and $\dfrac{r_r^2}{t_r} = \dfrac{r_i^2}{t_i}$

$$r_i = r_r\sqrt{t_i/t_r} \quad \text{when } s_r = s_i$$

or for our convenience $r_i = r_r\sqrt{\dfrac{r_r^2/t_r}{r_r^2/t_i}}$

Since all of our match points were taken at the same s-intercept we can use the r^2/t relation to determine the images. For the recharging image well we obtain:

from Fig. A, $r_i = 200 \sqrt{\frac{6.8}{3.5}}$ = 280 ft. to image

from Fig. C, $r_i = 200 \sqrt{\frac{4.2}{2.1}}$ = 290 ft. to image

Similarly for the discharging-image well,

from Fig. A and B, $r_i = 200 \sqrt{\frac{68}{2.5}}$ = 1040 ft.

Using the above estimates, let's check again the observed data for the performance of well 2.

Given:

r = 6 inches T = 34,000 gpd/ft

t = 15 minutes $S = 2.6 \times 10^{-4}$ (curve A, MP2)

Q = 300 gpm

Whence

$$u = \frac{1.87 \times (\frac{1}{2})^2 \times 2.6 \times 1440}{3.4 \times 10^3 \times 10^4 \times 15} = 3.4 \times 10^{-6}$$

W(u) = 12.0

$$s = \frac{114.6 \times 300 \times 12.0}{34,000} = 12 \text{ feet}$$

Subtract the effect of the recharging image well

$$u = \frac{\overline{280}^2}{(\frac{1}{2})^2} \times \frac{3.4}{10^6} = 1.1 \qquad W(u) = 0.19$$

$$s = \frac{0.19}{12} \times 12 = 0.2 \text{ ft.}$$

The computed drawdown in well 2 is 12 - 0.2 = 11.8 ft. This value appears reasonable when compared to the observed drawdown of 14.6 feet which includes screen loss.

While the above examples and trial computations leave your Ambridge problem unanswered, it is hoped that they serve their purpose in illustrating the procedure for further analysis.

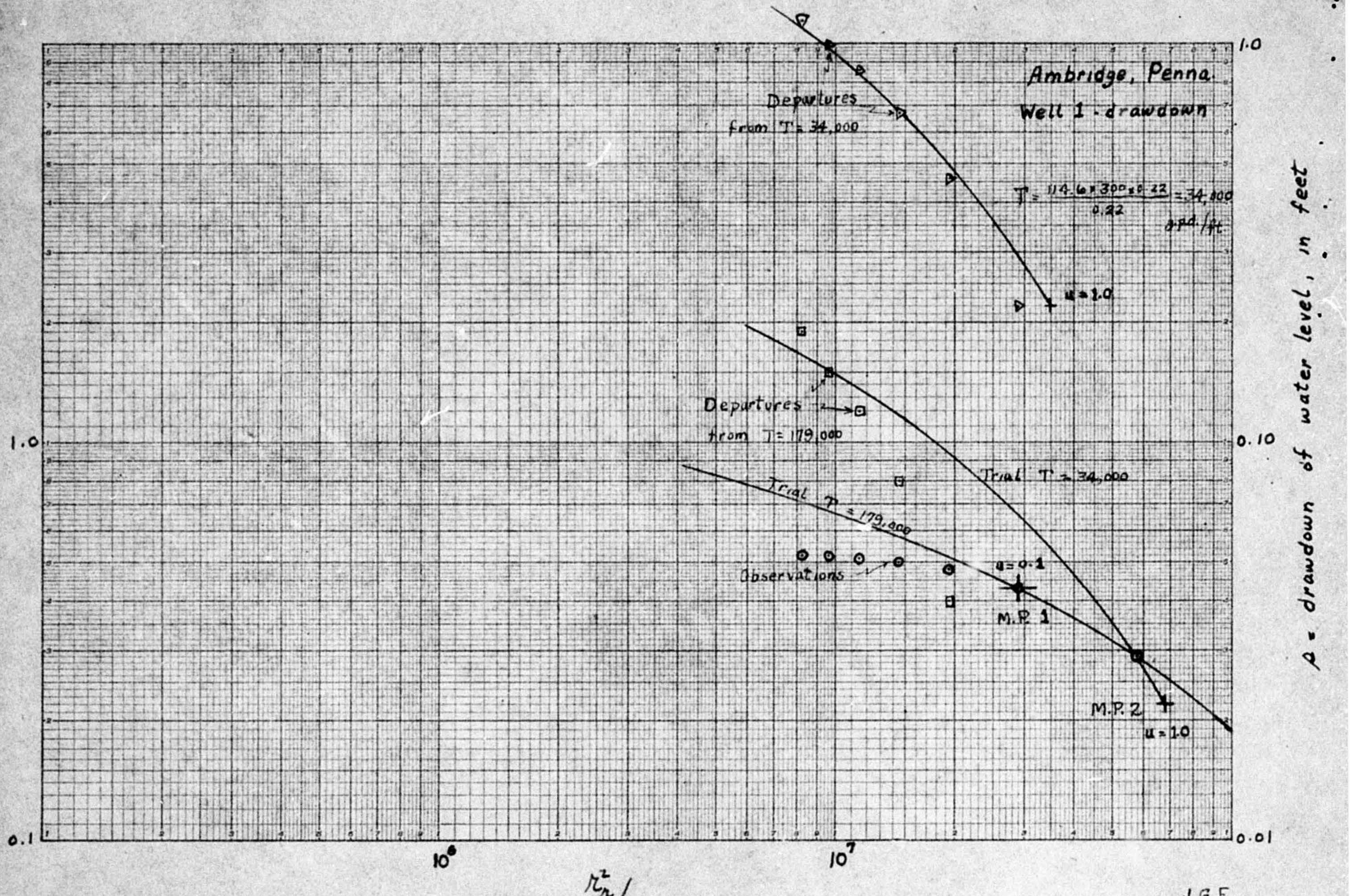
If another test can be run at this site it would be well to carefully consider the choice of other wells in the group as pumping sources or observation sites. If there is any latitude in this regard it would be advisable to select a pumped well and observation wells farther removed from the river. In this manner you prolong the real-well portion of the data curve for each observation well and verify the T value for the formation. We shall be glad to review any plan or layout of the well field to assist you in selecting the optimum test pattern.

You may wish to consider also our system of the engineer-geologist team for pumping tests. As standard practice we use both an engineer and a geologist on each pumping test, for not only the field work but also the office analysis. The geologist's interpretation of the well-log data and the regional geology assists the engineer's analysis of the hydraulic data and vice versa. The two specialists jointly prepare the resultant report from their mutual interpretation of all data.

Reviewer,

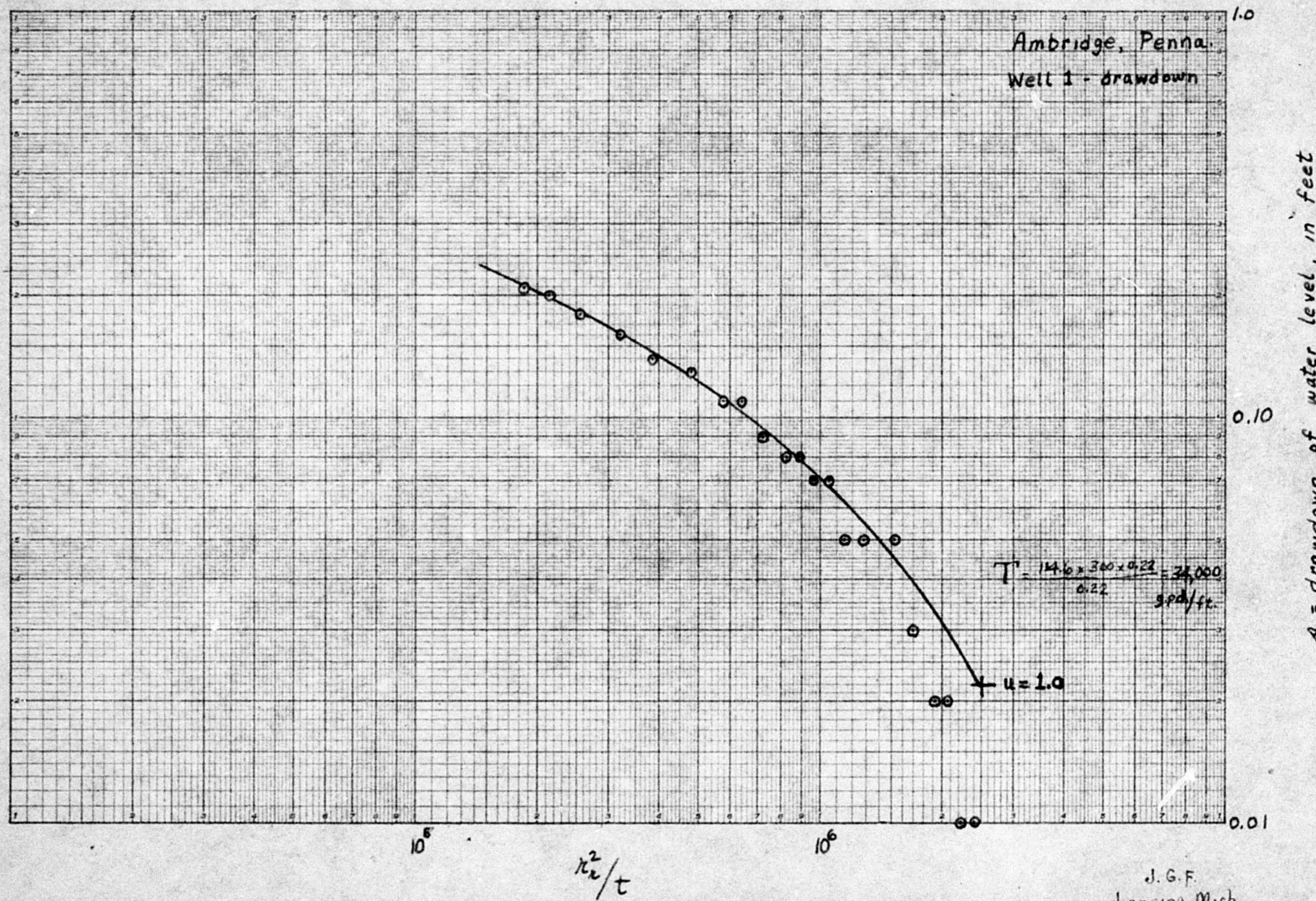
John G. Ferris
District Engineer, GW
Lansing, Michigan
June 22, 1950

Fig. A



J. G. F.
Lansing, Mich.
6-21-50

Fig. B



J. G. F.
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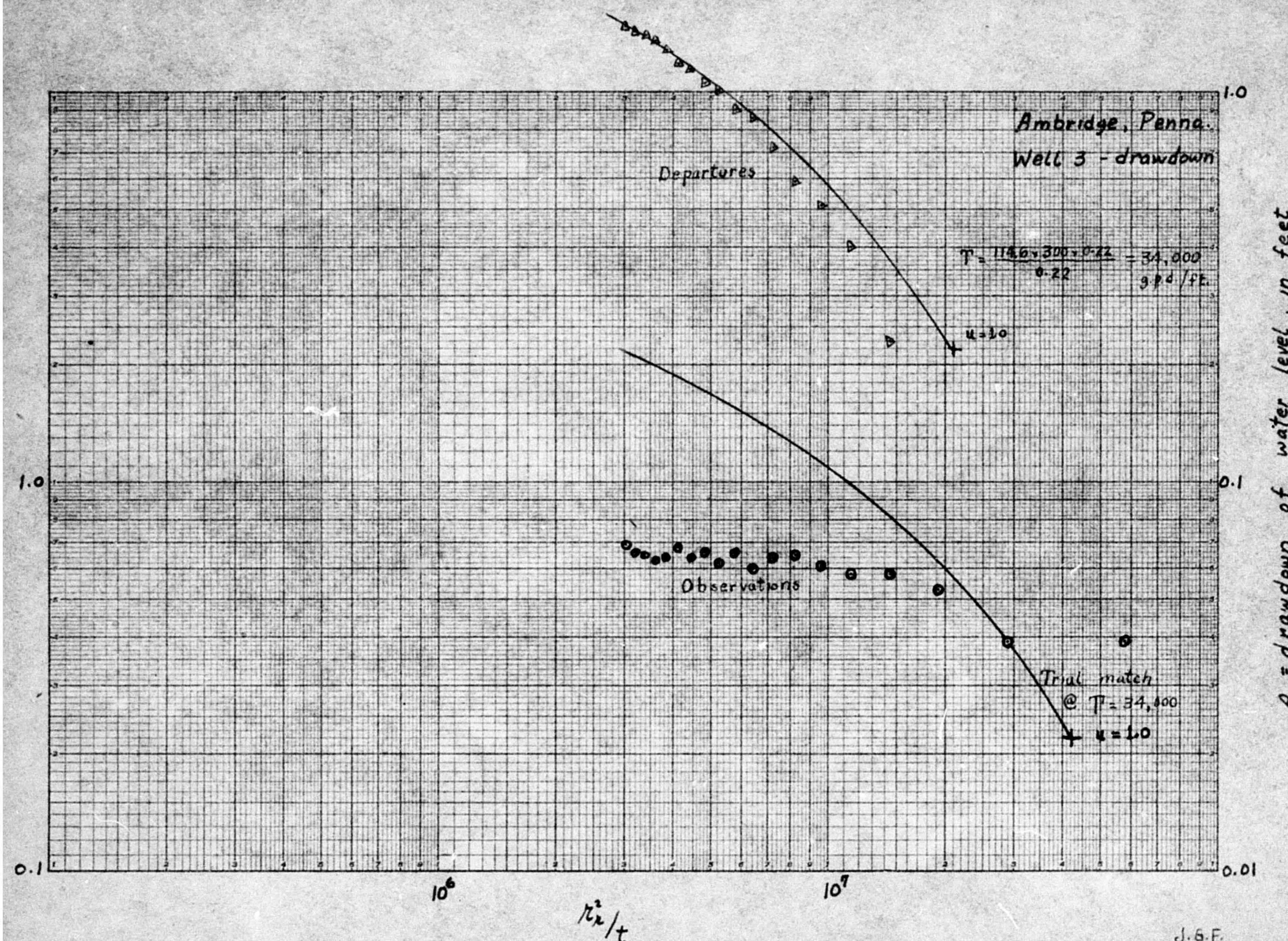
Fig. C



J. G. F.
Lansing, Mich.
6-21-50

Mr. D. W. Van Tuyl, Pittsburgh, Penn. GW July 20, 1950

Robert W. Stallman, Washington, D. C. GW

Your paper entitled "Memorandum on pumping test at Ambridge, Penn."

From the data given in your report, it does not seem likely that a clear solution of the image problem can be obtained. Perhaps you will recall a discussion in which we participated, held at Columbus, Ohio, in early March 1949. At that time we discussed test data obtained by the Ohio office at Toledo, using a set of type curves entitled "Theis non-equilibrium curve for water level changes due to two-well systems." Using Ferris' value of r_i at about 300 feet and a value of r_p of 200 feet, the value of K or $\left(\frac{r_p}{r_i}\right)^2$ is equal to about 0.45. For this value of K at $u_p = 1.0$, the drawdown at the observation well would be only about 75 percent of that which occurs as a result of pumping in the real well. For a clearcut solution of the image problem ratios of $\left(\frac{r_p}{r_i}\right)^2$ should not exceed 0.25. However, as Ferris has pointed out, a series of trial computations can be used to obtain a rough estimate of r_i. This estimate may, however, be in error because of the inadequacy of data during the early part of the pumping test. These data are definitely required for detailed analysis of the hydraulic characteristics of the system containing image wells. Copies of the type curves for image well solutions can be obtained from Mr. R. H. Brown, Hydraulics Section, at the Washington office.

/s/ Bob

Hydraulic Engineer
Ground Water Branch

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