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CANADA

DEPARTMENT OF MINES AND TECHNICAL SURVEYS

GEOLOGICAL SURVEY OF CANADA

TOPICAL REPORT NO. 53

GROUNDWATER INVESTIGATIONS GREATER WINNIPEG FLOODWAY

BY

J. S. SCOTT

OTTAWA

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Table of Contents

	Page
Introduction.	1
Part I.	2
Conclusions from Analysis of Piezometer Readings and Water Well data	2
Preliminary design of pump test.	4
Part II	5
1. Assessment of water well inventory	5
2. Location of pump test areas.	6
3. Permanent observation wells in vicinity of the Floodway	10
4. Recommendation for geophysical work along Floodway right of way.	11
5. General data	12
Appendix A. Items to be included in pump test contract	13

List of Figures

Fig. 1. Piezometric levels in test excavation, Aug 12, 1961.

Fig. 2. Piezometric levels in test excavation, Aug. 20, 1961.

Fig. 3. Piezometric levels in test excavation, Sept. 5, 1961.

Fig. 4. Piezometric levels in test excavation, Oct. 5, 1961.

Fig. 5. Jacob straight line method applied to recovery data for Workman Well.

Fig. 6. Recovery of water levels in wells adjacent to G.W.F. test pit.

Fig. 7. Predicted drawdown with time in observation wells at various distances from pumped well.

Fig. 8. Location plan of wells for pump test.

Fig. 9. Plan of Floodway right of way showing location of pump test sites and permanent observation wells.

Table 1. Trial calculations for location of observation wells.

Introduction

During excavation of the test pit within the right of way of the Greater Winnipeg Floodway springs began to flow from fractures in the glacial lake deposits at the sides and base of the pit to an extent that pumping of water from the pit was necessary to permit continuance of excavation.

The unexpected occurrence of these springs in an area underlain mainly by relatively impervious lake clay, suggested the possibility that dewatering may be a pertinent factor during construction of the Floodway and that dewatering would probably have an effect on water levels in wells adjacent to the Floodway.

A request was made by the Director, Water Control and Conservation Branch, Manitoba Department of Agriculture to the Director, Geological Survey of Canada for assistance in assessing the magnitude of the groundwater problems presented by the springs and by the occurrence of groundwater in gravels in the Birds Hill area approximately 4 miles north of Transcona.

The author examined the above areas in the field during the period Nov. 15-17, 1961 and recommended that an inventory of water wells in the vicinity of the Floodway be undertaken to determine, if possible, the regional hydraulic gradient as well as to provide a record of water levels in the adjacent areas prior to construction.

Records of piezometer readings obtained during construction of the pit, staff gauge readings of recovery of the water level in the test pit after pumping ceased and the recovery data from observations on on water levels in wells near the test pit were requested by the author in order that a preliminary assessment of the groundwater problems could be made.

The piezometer readings and the recovery data (for the period Nov. 12, 1961 to Jan. 16, 1962) were forwarded to the author on Jan. 25, 1962. The analysis of these data and the conclusions drawn therefrom are recorded in Part I of this report.

The results of discussions by the author with members of the Floodway Division, Water Control and Conservation Branch in Winnipeg from Feb. 21 to Feb. 23, 1962 are summarized in Part II of this report.

PART I

Conclusions from Analysis of Piezometer Readings and Water Well Data

1. The piezometric surfaces (Figs: 1-4)drawn from piezometer readings obtained from the Floodway test pit indicate the following:

   a) Water is moving upward toward the surface probably from the limestone or from an aquifer near the bedrock surface. Groundwater, therefore, flowed into the test pit by upward leakage from an artesian aquifer.

   b) Zones of concentrated flow (Fig. 1) are indicated by concentrations of flow direction arrows. These zones probably correspond to fractures in the cemented till or to zones of higher permeability such as sand lenses within the till.

   c) Piezometer plots subsequent to Aug. 12 (Figs.2-4) after excavation to various depths indicate the preferred zones of flow are still active because of the increased head loss across these zones.

d) No data relative to the quantity of seepage into the pit can be determined from the piezometer plots.

Mr. L. Gray has estimated the rate of inflow to the pit at 50 gallons/minute. This rate corresponds to an average seepage of 0.156 gal/min. per foot of test pit. The actual seepage, however, was concentrated along several fracture zones.

2. A value for the transmissibility of the aquifer(limestone) penetrated by the Workman well has been computed by the straight line recovery method (Fig. 5) to be 3,000 gpd/ft. This value of T may vary considerably particularly if the limestone contains numerous solution channels.

3. The bedrock aquifer is probably continuous over a large area.

4. The data available are not sufficient to determine the value of the storage coefficient which is required if the Theis non-equilibrium formula, or some modification thereof, is used to determine the drawdown of water levels in nearby wells caused by drainage through the Floodway.

A series of plots of recovery data (Fig. 6) from the test pit and adjacent wells, however, indicates the probable limit of influence of drainage by the Floodway will not exceed a distance of 6 miles from the Floodway and at 1,500 feet from the centre line of the Floodway the probable drawdown will be in the order of 6 feet.

5. A series of field pump tests is recommended to determine more accurately the hydraulic parameters of the aquifer which will be affected by the Floodway.

Preliminary design of Field Pump Test.

A series of curves showing drawdown in wells with time at various distances from a pumped well are shown in Fig. 7. These curves have been computed from a transmissibility value (T) = 3,000 gpd/ft. (as determined from the recovery data, see Fig. 5), an assigned value of the storage coefficient (S) of $1x10^{-3}$ and an assumed pumping rate of 100 gpm.

If the pumped well only partly penetrates the aquifer then the first observation wells should be located at a distance from the pumped well equal to twice the thickness of the aquifer, i.e. if the aquifer is 100 feet thick the first observation wells should be placed 200 feet from the pumped well.

Additional observation wells may be placed at greater distances as desired provided that readings could be obtained from these wells within the duration of the test, e.g. (See Fig. 7) a well at 800 ft. from the pumped well should show no drawdown during the first 6-7 hours under the aquifer conditions stated. Thus a 12 hour minimum pump test would be required to obtain useable data from this observation well.

A suggested plan for the location of observation wells relative to the pumped well is shown in Figure 8.

The first observation wells are spaced radially about and equidistant from the pumped well in order to detect lateral boundary effects. Two additional observation wells are shown at a distance 3 r feet east and west of the pumped well thus placing four observation wells in the presumed direction of the hydraulic gradient.

The location plan as shown should provide adequate data from a pump test to determine transmissibility, storage coefficient and any boundary effects the aquifer may have.

Part II

1. Assessment of Water Well Inventory

   a) The results of the inventory to date show that little data are available about the depth and construction of wells and because of the presence of sealed pressure systems or heavy coatings of ice at the bases of pumps many wells are not accessible for water level readings during the winter.

   b) The main purpose of the inventory will be to obtain a record of water levels in wells adjacent to the Floodway prior to construction. It is desirable to obtain water level measurements in as many wells as possible. Thus re-visits to wells which cannot be measured during the winter or at which the owner was absent during the first visit are strongly recommended.

      The records of water level measurements and other pertinent well data duly signed by the two observers are valuable information and should be accorded the same safeguards as given to field notebooks.

   c) An attempt should be made during analysis of the inventory data to distinguish between wells completed in bedrock and those completed in the overlying deposits. These data are required in order to obtain a proper understanding of piezometric surfaces related to aquifers in bedrock and aquifers above bedrock.

d) Piezometric maps or cross-sections showing piezometric surfaces drawn on the basis of the well inventory will not be completely accurate because of uncertainty of well depth and well construction. Because an approximation of well depth will probably be used in constructing piezometric surfaces it is suggested that elevations for points of measuring for these wells be estimated from the topographic map and not by stadia and level measurements. Elevations of particularly useful wells, however, could be determined by aneroid barometer (altimeter).

2. Location of Pump Test Areas.

Five areas along the Floodway right of way are recommended as sites for pump tests (see Fig. 9). These areas have been chosen because they represent variation in geological conditions and/or are representative of areas in which groundwater problems may be encountered during excavation of the Floodway or construction of its control structures.

All pump test sites are located away from the centre line of the Floodway in order that the wells used during the test will not create seepage problems during excavation.

Each of the pump test sites is located near a drainage ditch or natural drain which may be used to convey water discharged from the pumped well away from the test site.

The areas designated for pump testing are not rigidly defined, thus the actual location of the test wells in the field should be made at the discretion of the supervising engineer after consideration of existing field conditions.

The purpose of the pump tests is to determine the hydrologic parameters (transmissibility and storage coefficient) of aquifers underlying the test areas. Upon determination of these parameters it will then be possible to predict the pumping rate necessary to maintain water levels below the level of the excavation and the effect of the removal of water on levels in nearby wells. The long term effect of groundwater discharge along the Floodway on the level of water in nearby wells can also be predicted from the parameters determined by the pump tests if the amount of groundwater discharge along the Floodway is known.

In order to obtain maximum benefit from the pump tests it is recommended that a qualified contractor be engaged and an engineer familiar with pump test techniques supervise the field testing, compare the results of the tests and duly submit a report of the test results to the Floodway Division.

A location plan of wells for a pump test in areas underlain by lake clays/till/bedrock is shown in Figure 8. The plan is designed to yield maximum information from the test and to facilitate interpretation of test results.

A pumping rate of 50-80 gpm, based on the estimated pumping rate from the test pit and a preliminary knowledge of the probable yield of the aquifer, is suggested.

Items to be included in a contract for a pump test, suggested by Mr. L. V. Brandon, Geological Survey of Canada, are included as an appendix to this report in order to assist the Floodway Division in drawing up their contract for pump tests.

Area I - Intake structure site

Details of the geology of the site can be obtained from logs of borings which have been made for foundation investigations. The area is one of groundwater discharge to Red River thus groundwater flow will probably be encountered during excavation of the structure foundation and uplift pressures will probably occur on the completed structure.

Design of a pump test for this area should be made in consultation with engineers responsible for the design of the structure thus no pump test design is suggested here.

Area II - 5.26,35, T.10, Rge. 4 E.

A pump test location is suggested approximately 2 1/2 miles north of the Floodway test pit in order to limit the recharge effect of water in the test pit on pump test results.

Area II is representative of those parts of the Floodway underlain by lake clay, non cemented till, hard pan and bedrock. On the basis of existing information the main aquifer in this area is within fractured limestone bedrock. The bedrock aquifer is probably in the order of 100 feet thick.

A 6" diameter well cased to bedrock and penetrating 20 feet into bedrock pumped for 24 hours at a rate of 50-80 gpm surrounded by observation wells as shown in Figure 8 in which r = 200 ft. should be entirely satisfactory for a pump test in this location.

One of the observation wells at a distance greater than r from the pumped well should be completed in noncemented till in order to determine the effect of lowering the piezometric surface of the bedrock aquifer on wells completed above bedrock.

Area III. Birds Hill, 5.33, T.11, R. 4E.

Before a design of a pump test is made for this area it would be desirable to have information on the following:

1) The extent of gravel in the Floodway area and elevations of water levels in these gravels. These data should be shown on a large scale plan and cross-sections of the area.

2) The direction of groundwater movement in the area. It is possible that upward leakage of water from bedrock into the gravel occurs in addition to water table conditions imposed by local topography and geology.

3) The depth to bedrock beneath the gravels would be helpful in determining the possible effects of upward leakage.

A pump test could be done in the gravel area before the above data are known but the interpretation of the test results would be more valuable with the background of geologic and hydrologic data.

Wells for pump testing in this area will probably require screens, thus the specifications for well construction for aquifers in limestone are not applicable here.

Recommendations for a pump test in the Birds Hill area will be made upon receipt of the data listed above.

Area IV. North of Birds Hill.

Bore hole data from Area IV indicates the geology to be similar to that for Area II, thus groundwater problems will probably be related to aquifers in bedrock.

A pump test similar to that for Area ~~I~~ II is therefore recommended for Area IV.

Area V. Outlet Structure Site

The outlet structure is to be founded on bedrock thus pump testing of the bedrock aquifer in this area, as in Area I should be done after consultation with the design engineers.

3. Permanent Observation Wells in Vicinity of Floodway.

Figure 9 shows the location of 23 permanent observation wells both along the limits of the Floodway right of way and, in some places,beyond the limits of the right of way.

Two inch diameter wells 20 feet into bedrock and cased to bedrock are recommended for these observation wells.

The locations as shown on Figure 9 will provide adequate data on the long term fluctuation of water levels adjacent to the Floodway and the effect of the Floodway on water levels. The precise location of these wells in the field can be made by the Floodway Division geologist after examination of the proposed sites in the field.

It would be desirable to install these wells prior to construction and to make weekly readings on these wells from the time they are installed, during construction and for at least one year after construction. At the end of this period it will then be possible to delete some of the wells and to reduce the frequency of readings of others.

Hydrographs obtained from the observation wells along with the pump test data should be sufficient to calculate drawdown of water levels at any distance from the Floodway at any time.

Consideration could be given to the installation of observation wells in areas beyond the Floodway, other than those shown on Figure 9, in which no water well data are available from the inventory or in which local concern about the effect of the

Floodway is expressed.

The Groundwater Section, Geological Survey of Canada would be interested to receive copies of records from the observation wells to augment their program of observation wells throughout Canada.

4. Recommendation for geophysical work along Floodway right of way.

It would be desirable to obtain a profile of the bedrock surface along the centre line of the Floodway because it is felt the areas in which groundwater problems will probably be encountered are a function of the proximity of the base of the Floodway to bedrock.

The present bore holes to bedrock along the Floodway centre line are too widely spaced to permit drawing an accurate centre line cross-section. It is suggested therefore that seismic equipment be used to extend the bore hole data.

The Geophysics Section, Geological Survey of Canada are willing to undertake this work during the coming field season by using their FS-2 hammer seismic instrument. The field work would be done during the period July 15 - Aug. 31, 1962 and a report of the results of the work submitted to the Floodway Division by Dec. 31, 1962. All costs for this work would be under-written by the Geological Survey, thus the Geophysics Section would retain the right to use these data at their discretion.

The Geophysics Section will require the following data in order to facilitate their work:

a) One copy of the Floodway right of way plan (scale 1" = 3,000 ft.) showing the location and elevation of Floodway bench marks.

b) Two blank copies of the plan of the Floodway right of way.

c) A centre line cross-section of the Floodway showing location and logs of bore holes both to bedrock and above bedrock. The location of these bore holes could also be shown on the right of way plan showing location of bench marks.

5. General Data

The author discussed with Mr. E.B. Owen, (who was seconded from the Geological Survey by the St. Lawrence Seaway Authority) the policy adopted by the Seaway Authority with respect to water wells disturbed by Seaway construction. No accurate records of well levels in the area were obtained by the Seaway Authority prior to construction, thus the Seaway Authority endeavoured to settle all claims for damage to wells by dewatering as promptly as possible to prevent organized protests by well owners. In some instances, particularly during construction, settlements consisted of installing 200 gallon tanks on the owners' property and making daily delivery of water to these tanks. In other cases wells were either deepened or new ones drilled. In most cases where claims did arise the construction of the Seaway (dewatering of canal excavations) was within 1/4 mile of the wells affected and the large quantities of water pumped during the dewatering phase were very likely responsible for the drawdown of the water levels. When pumping ceased, however, recovery of water levels in the wells was accompanied by a decrease in chemical quality of the water, possibly the result of deeper water of low chemical quality being drawn into the wells. The quantities of water pumped which produced this effect were in the order of 22 million gallons per day in some excavations which are greater by a factor of at least 200 times the anticipated pumping rates for excavations along most of the Floodway.

Mr. Owen is not aware of any written policy practiced by the Seaway Authority with respect to damage to water wells.

If seepages are encountered during construction of the Floodway these may affect the stability of Floodway slopes. It is suggested that consideration be given to the planting of a phreatophytic forage crop such as alfalfa along the Floodway to reduce seepages and to serve as an additional source of feed for the numerous feed-lots in the Winnipeg area. The most suitable cover crop for the Floodway can, no doubt, re recommended by either the Provincial or Federal Department of Agriculture.

Appendix A.

Items to be included in a contract for a pump test as suggested by Mr. L. V. Brandon, Geological Survey of Canada are as follows:

	Item	Basis for Payment
1.	Mobilization of drill rig	lump sum
2.	Drilling test well for pumping including 6" casing to bedrock	per foot of drilling
3.	Drilling observation wells 2" diam. cased to bedrock	per foot of drilling
4.	Installation and withdrawal of pump used for test	lump sum
5.	Pumping test well and making observations in all other wells including four hours of recovery measurements	per hour
6.	Chemical analysis of water from pump test	lump sum
7.	Professional report of test results	fee

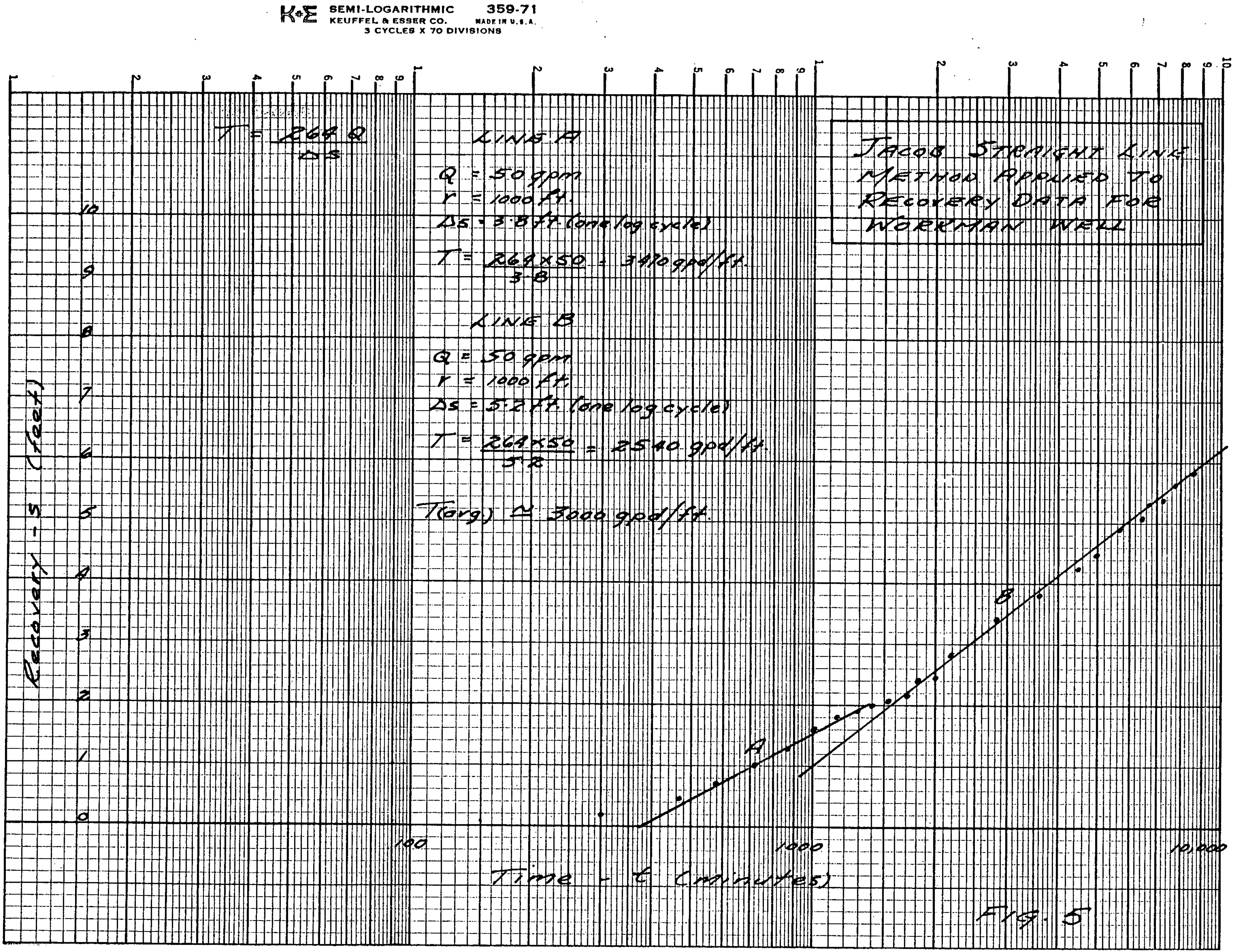

K+E SEMI-LOGARITHMIC 359-71
KEUFFEL & ESSER CO. MADE IN U.S.A.
3 CYCLES X 70 DIVISIONS
JACOB STRAIGHT LINE METHOD APPLIED TO RECOVERY DATA FOR WORKMAN WELL
T = 264 Q / ΔS
LINE A
Q = 50 gpm
r = 1000 ft.
ΔS = 3.8 ft. (one log cycle)
T = 264 x 50 / 3.8 = 3470 gpd/ft.
LINE B
Q = 50 gpm
r = 1000 ft.
ΔS = 5.2 ft. (one log cycle)
T = 264 x 50 / 5.2 = 2540 gpd/ft.
T(avg.) ≃ 3000 gpd/ft.
A
B
Recovery - s (feet)
Time - t (minutes)
100
1000
10,000

FIG. 5

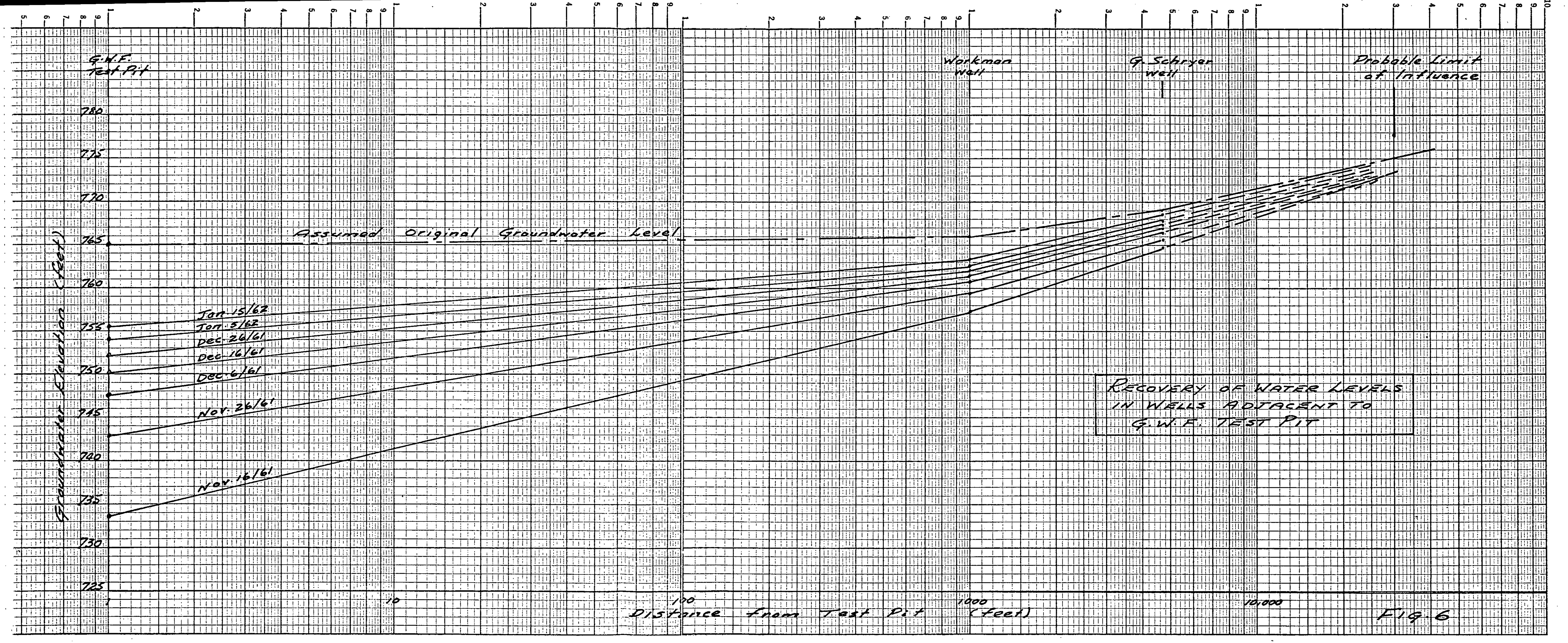

G.W.F. Test Pit
Workman Well
G. Schryer well
Probable Limit of Influence
Assumed Original Groundwater Level
Jan. 15/62
Jan. 5/62
Dec. 26/61
Dec. 16/61
Dec. 6/61
Nov. 26/61
Nov. 16/61
Groundwater Elevation (feet)
780
775
770
765
760
755
750
745
740
735
730
725
1
10
100
1000
10,000
Distance from Test Pit (feet)
RECOVERY OF WATER LEVELS IN WELLS ADJACENT TO G.W.F. TEST PIT

Fig. 6

[redacted]

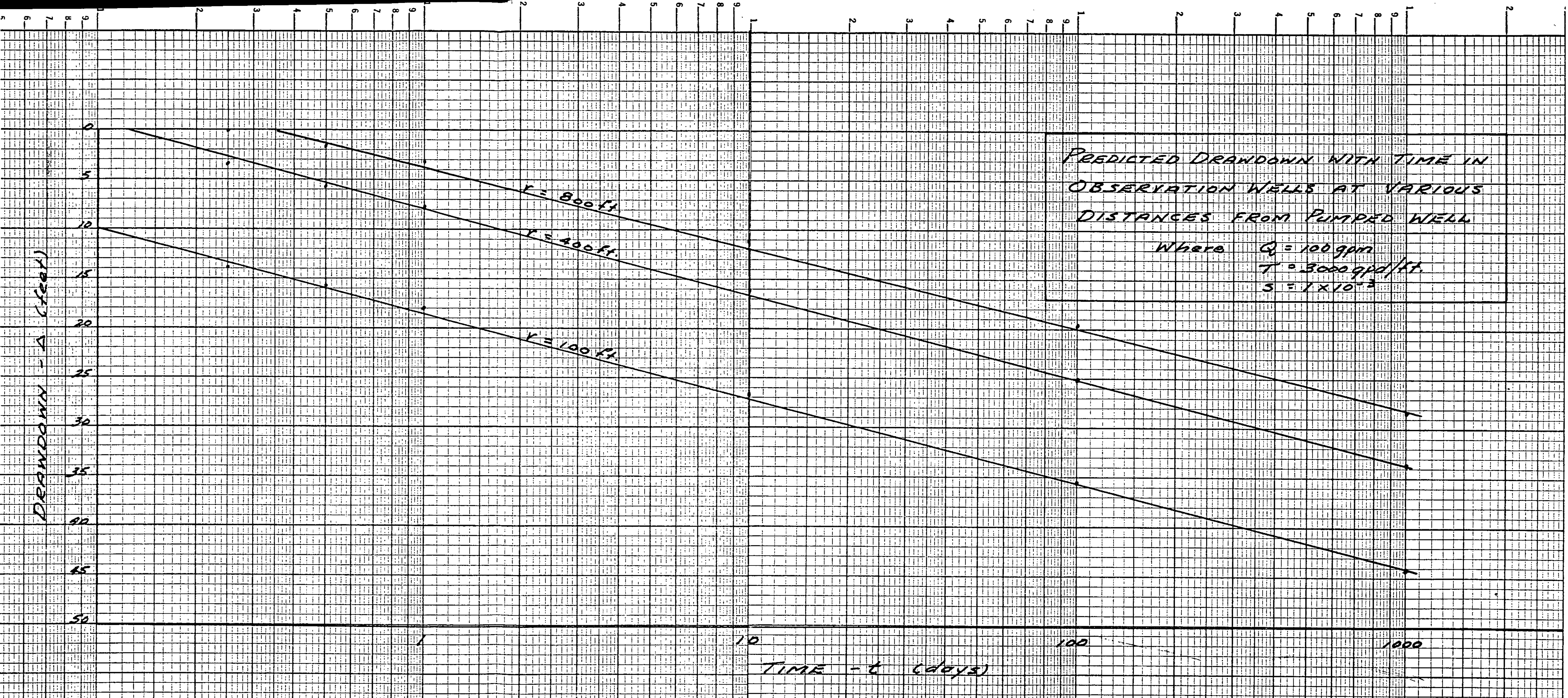
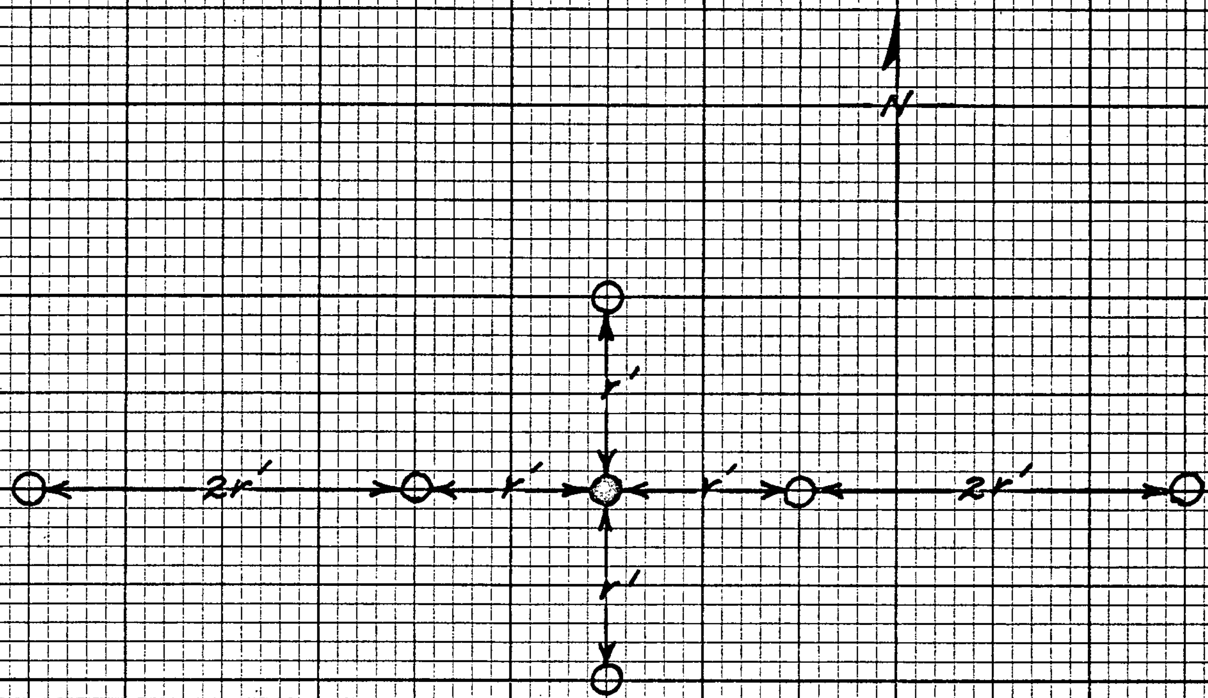


FIG. 7



LOCATION PLAN OF WELLS FOR PUMP TEST

● - Pumped Well - 6" diam., 20ft. into bedrock, cased to bedrock

○ - Observation Well - 2" diam. 20ft. into bedrock, Cased to bedrock.

r' - Distance = 2x thickness of aquifer

Fig. 8

K+E 10 X 10 TO THE CM. 359-14L KEUFFEL & ESSER CO. MADE IN U.S.A.

TRIAL CALCULATIONS FOR LOCATION OF OBSERVATION WELLS

Δ - Drawdown of water level (feet)
r - Distance from pumped well (feet)
t - Time since pumping started (feet)
Q - Rate of discharge pumped well (gpm)
T - Coefficient of transmissibility (gpd/ft)
S - Coefficient of storage

The above variables are related by the Theis non-equilibrium formula as follows:

$$\Delta = \frac{114.6\,Q \cdot W(u)}{T} \qquad \text{where} \quad W(u) = \int_u^\infty \frac{e^{-u}}{u}\,du = -0.577 - \log_e u + u - \frac{u^2}{2.2!} + \frac{u^3}{3.3!} - \frac{u^4}{4.4!} + \cdots$$

$$u = \frac{1.56\,r^2 S}{Tt}$$

Values of $W(u)$, "the well function of u" corresponding to values of u can be determined from prepared tables.
For the Floodway area a value of $T = 3000$ gpd/ft has been determined from recovery data and a value of $S = 1 \times 10^{-3}$ is assumed to be reasonable for this area.

Calculation for drawdown with time and distance

$T = 3000$ gpd/ft
$S = 1 \times 10^{-3}$
$Q = 100$ gpm (assumed)

$$u = \frac{1.56\,r^2 S}{Tt} = \frac{1.56 \times r^2 \times 1 \times 10^{-3}}{3 \times 10^3 \times t} = 5.2\,\frac{r^2}{t} \times 10^{-7}$$

If $r = 100$ ft $\quad u = \frac{5.2 \times 10^{-3}}{t}$

$r = 400$ ft $\quad u = \frac{8.3 \times 10^{-2}}{t}$

$r = 800$ ft $\quad u = \frac{3.4 \times 10^{-1}}{t}$

Variations of t for $r = 100$ ft.	$t = 0.25$ day	$u = \frac{5.2 \times 10^{-3}}{0.25} = 2.1 \times 10^{-2}$ $\quad W(u) = 3.3$
		$\therefore \Delta = \frac{114.6 \times 100 \times 3.3}{3000} = 13.6$ ft
	$t = 0.50$ day	$u = \frac{5.2 \times 10^{-3}}{0.5} = 1.0 \times 10^{-2}$ $\quad W(u) = 4.03$
		$\therefore \Delta = \frac{114.6 \times 100 \times 4.03}{3000} = 15.4$ ft
	$t = 1$ day	$u = 5.2 \times 10^{-3}$ $\quad W(u) = 4.68$
		$\therefore \Delta = 3.82\,(W(u)) = 3.82 \times 4.68 = 17.8$ ft.
	$t = 10$ days	$u = 5.2 \times 10^{-4}$ $\quad W(u) = 6.98$
		$\therefore \Delta = 3.82\,W(u) = 3.82 \times 6.98 = 26.8$ ft.
	$t = 100$ days	$u = 5.2 \times 10^{-5}$ $\quad W(u) = 9.28$
		$\therefore \Delta = 3.82\,W(u) = 3.82 \times 9.28 = 35.4$ ft
	$t = 1000$ days	$u = 5.2 \times 10^{-6}$ $\quad W(u) = 11.58$
		$\therefore \Delta = 3.82\,W(u) = 3.82 \times 11.58 = 44.4$ ft.
Variations of t for $r = 400$ ft.	$t = 0.25$ day	$u = \frac{8.3 \times 10^{-2}}{0.25} = 3.3 \times 10^{-1}$ $\quad W(u) = 0.83$
		$\therefore \Delta = 3.82\,W(u) = 3.82 \times 0.83 = 3.16$ ft.
	$t = 0.50$ day	$u = \frac{8.3 \times 10^{-2}}{0.50} = 1.65 \times 10^{-1}$ $\quad W(u) = 1.38$
		$\therefore \Delta = 3.82\,W(u) = 3.82 \times 1.38 = 5.3$ ft.
	$t = 1$ day	$u = 8.3 \times 10^{-2}$ $\quad W(u) = 1.99$
		$\therefore \Delta = 3.82\,W(u) = 3.82 \times 1.99 = 7.6$ ft.
	$t = 10$ days	$u = \frac{8.3 \times 10^{-2}}{10} = 8.3 \times 10^{-3}$ $\quad W(u) = 4.22$
		$\therefore \Delta = 3.82\,W(u) = 3.82 \times 4.22 = 16.1$ ft.
	$t = 100$ days	$u = \frac{8.3 \times 10^{-2}}{100} = 8.3 \times 10^{-4}$ $\quad W(u) = 6.51$
		$\therefore \Delta = 3.82\,W(u) = 3.82 \times 6.51 = 24.8$ ft.
	$t = 1000$ days	$u = \frac{8.3 \times 10^{-2}}{1000} = 8.3 \times 10^{-5}$ $\quad W(u) = 8.81$
		$\therefore \Delta = 3.82\,W(u) = 3.82 \times 8.81 = 33.6$ ft.
Variations of t for $r = 800$ ft.	$t = 0.25$ day	$u = \frac{3.4 \times 10^{-1}}{0.25} = 1.36$ $\quad W(u) = 0$
		$\therefore \Delta = 3.82\,W(u) = 0$
	$t = 0.50$ day	$u = \frac{3.4 \times 10^{-1}}{0.5} = 6.8 \times 10^{-1}$ $\quad W(u) = 0.38$
		$\therefore \Delta = 3.82\,W(u) = 3.82 \times 0.38 = 1.45$ ft.
	$t = 1$ day	$u = 3.4 \times 10^{-1}$ $\quad W(u) = 0.81$
		$\therefore \Delta = 3.82\,W(u) = 3.82 \times 0.81 = 3.1$ ft.
	$t = 10$ days	$u = 3.4 \times 10^{-2}$ $\quad W(u) = 2.83$
		$\therefore \Delta = 3.82\,W(u) = 3.82 \times 2.83 = 10.8$ ft.
	$t = 100$ days	$u = 3.4 \times 10^{-3}$ $\quad W(u) = 5.11$
		$\therefore \Delta = 3.82\,W(u) = 3.82 \times 5.11 = 19.5$ ft.
	$t = 1000$ days	$u = 3.4 \times 10^{-4}$ $\quad W(u) = 7.40$
		$\therefore \Delta = 3.82\,W(u) = 3.82 \times 7.40 = 28.2$ ft.

TABLE 1.


LEGEND
HIGHWAYS
MUNICIPAL ROADS
RAILWAYS
TRANSMISSION LINES
AQUEDUCTS & PIPE LINES
MUNICIPAL BOUNDARIES
TOWNS
GRAVEL PITS
FLOODWAY BRIDGES
Pump Test Area
Location of Permanent Observation Well
PROVINCE OF MANITOBA
DEPARTMENT OF AGRICULTURE AND CONSERVATION
WATER CONTROL AND CONSERVATION BRANCH
GREATER WINNIPEG FLOODWAY
LOCATION MAP SHOWING
Right of way, Pump Test Areas and
Location of Permanent Observation Wells
PLAN NO. 11-5-1015-A
SCALE IN MILES
1 INCH = 3000 FEET
WINNIPEG
RED RIVER
ST. NORBERT
MIDDLECHURCH
MANLIUS
BIRDS HILL
TRANSCONA
LOCKPORT
PRAIRIE GROVE
SPRINGFIELD
GRANDE POINTE
CANADIAN PACIFIC RAILWAY
PERIMETER HIGHWAY
METROPOLITAN
BYPASS
AREA

Figure 9

Piezometric Levels in Test Excavation
Greater Winnipeg Floodway

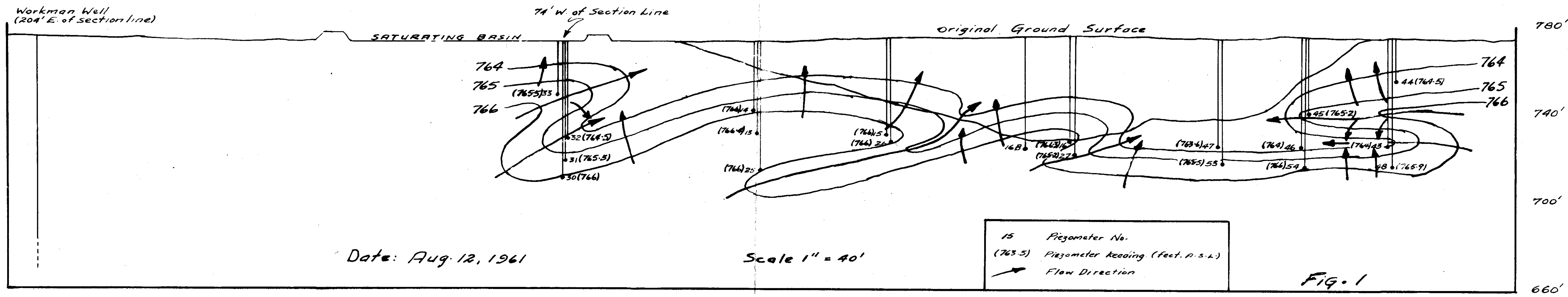


Fig. 1

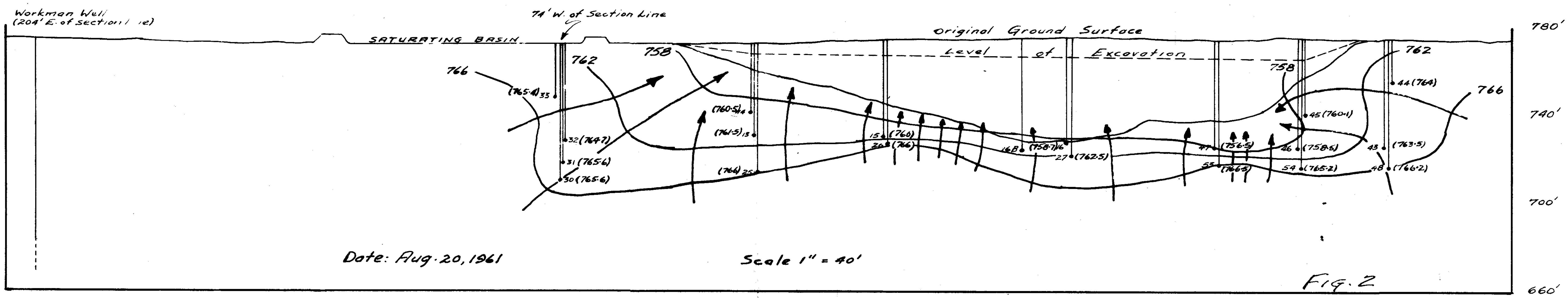


Fig. 2

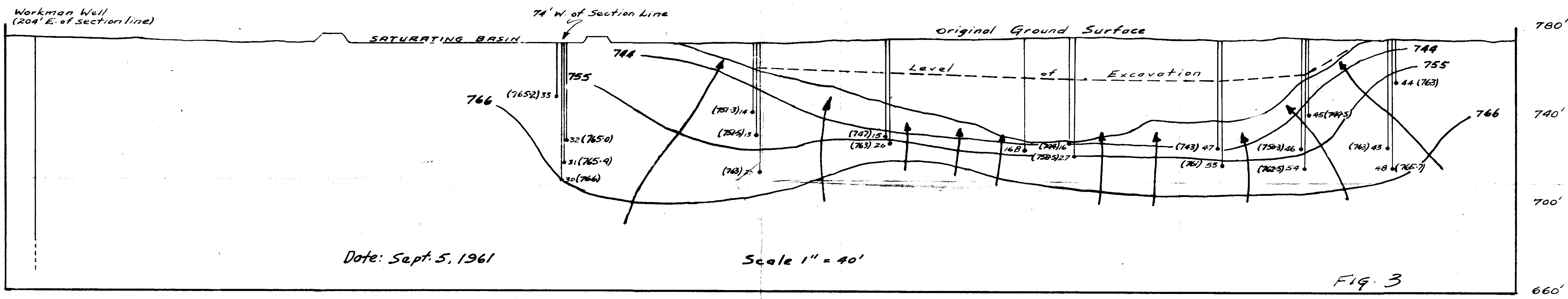


Fig. 3

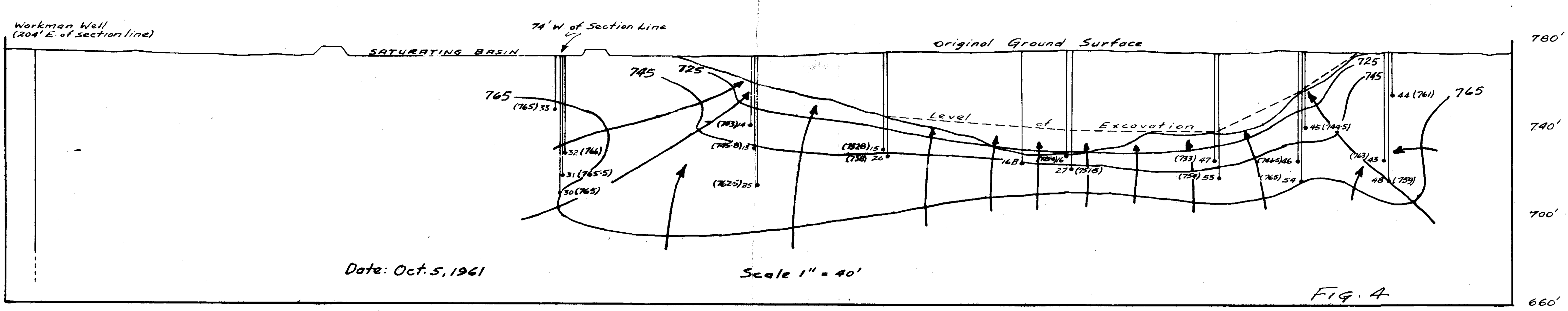


Fig. 4