Report on Exxon Crandon pump test: response to DNR memorandum. October 1984

Golder Associates

[Atlanta, Georgia]: Golder Associates, Inc., October 1984

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Golder Associates
CONSULTING GEOTECHNICAL AND MINING ENGINEERS

Report on

EXXON CRANDON
PUMP TEST
RESPONSE TO DNR MEMORANDUM

Submitted to:

Exxon Minerals Company
P. O. Box 813
Rhinelander, Wisconsin 54501

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October 1984

834-1389

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Golder Associates
CONSULTING GEOTECHNICAL AND MINING ENGINEERS

September 12, 1984 834-1389

William C. Walton
Rural Route 5
Box 131
Mahomet, Illinois 61853

Dear Bill:

Enclosed is a draft of Golder's response to the Wisconsin DNR letter concerning the Crandon Pump Test. We have analyzed the test by three different methods and found additional documentation supporting the analysis method used. As you can see from Table 1 of this response, we found no significant variation by using other analysis techniques, including the Neuman type curve method, and have concluded that the results presented in the Pump Test Report are valid.

Please review the analysis and provide us with your comment. If you agree with the analyses and the conclusion, we would appreciate a letter indicating such.

Very truly yours,

GOLDER ASSOCIATES

John F. Clerici, P.E.
Associate

JFC:das

Encl.

cc: Mr. Carlton Schroeder, Exxon
Mr. Charles R. Glore, Exxon

William C. Walton

CONSULTANT IN WATER RESOURCES
RR 5 BOX 131 • MAHOMET, ILLINOIS 61853
TELEPHONE 217-586-4285

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SEP [illegible] 1984
GOLDER ASSOC.

September 17, 1984

Mr. John F. Clerici
Golder Associates
Consulting Geotechnical and Mining Engineers
3772 Pleasantdale Road
Suite 165
Atlanta, Georgia 30341

Dear John:

In response to your letter dated September 12, 1984, I reviewed the report "Exxon Crandon Pump Test Response To DNR Memorandum." I agree with the analyses and I concur with the conclusions. The three methods used to reanalyze the test data are appropriate for existing groundwater conditions. The computed values for parameters seem reasonable in light of my past experiences. The values are in tune with drillers logs.

If I can be of further assistance in this mater please inform me.

Yours truly,

William C. Walton

William C. Walton

Golder Associates
CONSULTING GEOTECHNICAL AND MINING ENGINEERS

October 29, 1984 834-1389

Exxon Minerals Company
P.O. Box 813
Rhinelander, Wisconsin 54501

Attn: Mr. Carlton C. Schroeder

RE: SITE 41 PUMP TEST
CRANDON PROJECT

Gentlemen:

Mr. Carlton Schroeder requested in December, 1983, that Golder Associates respond to an internal memorandum from Mr. K. Bradbury to Mr. K. Wade with the State of Wisconsin. This memorandum, dated November 15, 1982, contained specific comments on the pump tests performed at the Exxon Crandon waste disposal Site No. 41 area during June, July and August, 1980. A copy of the State's Memorandum is attached in Appendix A for reference. The test results were presented in a report by Golder Associates dated September 30, 1981 and titled "Pump Test and Analyses, Crandon Project Waste Disposal System, Project Report 4", hereafter referred to as the Report.

The primary purpose of the pump tests was to obtain data for evaluation of hydraulic characteristics of the aquifer system in the Site 41 waste disposal area. This data was considered necessary for future evaluation of the impact of the proposed waste disposal system. Specific objectives of the tests were:

1. To estimate the horizontal hydraulic conductivity of the coarse grained stratified drift, hereafter referred to as drift,
2. To estimate storage coefficients for the aquifer system,
3. To estimate the vertical hydraulic conductivity of the confining till materials, and

4. To demonstrate the extent of groundwater gradient reversals which a pumping well could impose on the groundwater system beneath the Site 41 area.

Response to the specific comments in the letter from the Wisconsin DNR are listed below.

Item 1 VERTICAL HYDRAULIC CONDUCTIVITY OF CONFINING LAYER

Vertical hydraulic conductivities for the confining materials for the Crandon Site 41 pump test were calculated in the Report using a method similar to that developed by M. S. Hantush and C. E. Jacob, Reference 1. For this analysis the leakance factor, B, is given as:

$$B = (Tm'/k_v)^{0.5}$$

where: T = transmissivity of the aquifer (L^2/T)
m' = thickness of the confining layer (L)
k_v = vertical hydraulic conductivity of the confining layer (L/T)

This method was applied to the Boulton analysis to estimate the vertical hydraulic conductivity by rewriting the equation to get:

$$k_v = Tm'/B^2$$

The Boulton analysis, however, is concerned with storage coefficients and not the leakage of confining layers. The "B" parameter in Boultons' analysis is defined differently, References 2 and 3, as follows:

$$B = (T/aS')^{0.5}$$

where: a = reciprocal of the delayed index
S' = total delayed yield volume per unit area per unit drawdown

Detail review of the Boulton work was made by Richard Cooley and Clinton Case, Reference 4, indicating the analysis is the same as that developed by Hantush and that the vertical hydraulic conductivity of the confining layer can be calculated directly as described above. In addition, this work also showed that the problem analyzed by Boulton is for the hydrogeologic setting at Crandon, namely a low permeability material overlying an aquifer with a water table in the upper material.

The similarity of the Boulton and Hantush analyses can indirectly be shown by comparing type curves for the Hantush and Jacob leakage analyses developed by H. H. Cooper, Jr., to type curves developed by Boulton. Both sets of curves are presented in Reference 5 and are used with drawdown data plotted at the same scale. Overlay of the two type curves in Reference 5, Plates 3 and 8 respectively, shows that 2v (Cooper) = R/B (Boulton). Applicable portions of these curves are shown on Figure 1 for reference. Note that in the leaky aquifer range of these curves the drawdowns shown are identical. Cooper also indicates the following equation for estimating the vertical hydraulic conductivity:

$$v = (R/2)(k_v/m'T)^{0.5}$$

where: R is the distance from the pump well.

Rearranging the equation and substituting 2v = R/B we get:

$$k_v = (2v/R)^2(Tm')$$

$$k_v = Tm'/B^2$$

This is exactly the equation used in the Site 41 pump test analysis for estimating the vertical hydraulic conductivity of the confining materials, till.

Additional analyses were performed for different assumed hydrogeologic systems to indicate a reasonable range for the vertical hydraulic conductivity. These analyses were:

1. The Hantush and Jacob/Cooper type curve method: This analysis is for a leaky-confined aquifer system.

2. Neuman and Witherspoon Ratio method: This analysis is for a leaky-confined or leaky-unconfined aquifer system.

3. Neuman delayed yield type curve method: This analysis is for a unconfined anisotropic aquifer with delayed yield response.

These analyses were performed on selected wells to illustrate the range of parameter values that can be expected from each analyses method and for comparison to the results presented in the Report. The results of these analyses are shown in Table 1 and the calculations are attached in Appendix B to this Report. Review of the results in Table 1 indicate that the calculated aquifer transmissivities and confining layer vertical hydraulic conductivities for different assumed hydrogeologic scenarios generally vary by less than a factor of 3. Therefore, since the analyses used in the Report most closely approximate the hydrogeologic setting at the Crandon Site 41 area, the results presented in the Report are considered to be the most applicable hydraulic parameter estimates.

The leaky aquifer theory is based on large hydraulic conductivity contrasts and vertical flow through the confining layer. With a fully penetrating well some horizontal flow occurs. Close review has been made of the induced gradients to define the direction of flow. Vertical and horizontal gradients for wells in the upper till were estimated after a time period when leakage was affecting the well response, yet drainage of the upper till had not been initiated. This corresponds to the near horizontal, constant drawdown with time, portion of drawdown verses time curves used for the Boulton analyses. Therefore, for times near about 1,000 minutes the gradients were calculated using the following procedure, see Figure 2:

1. Drawdown versus distance was plotted for the upper till and the drift.

2. The horizontal gradient was estimated as the slope of the drawdown versus distance curve at the well location.

3. The saturated thickness of the upper till was estimated as the difference between the water level in the till and top of the drift.

4. The vertical gradient was estimated as the head difference between the upper till and the drift divided by saturated thickness of the upper till (Step 3).

This data indicates that near vertical gradients were occurring in the confining material, since the flow direction was between 2° and 22° off vertical. Neglecting the horizontal component of flow to estimate vertical hydraulic conductivity in the confining material was justified.

The aquifer was described as semi-confined to emphasize the degree of confinement. Yet, during periods of the test the system exhibited leaky behavior with near vertical flow. The Boulton method for analyzing pump test data is based on a hydrogeologic system similar to that found at the Crandon Site 41 area. The Boulton analysis considers drainage of the material, as observed, and allows estimates of specific yield. In addition, the Boulton analysis provides a method for estimating the vertical hydraulic conductivity of the confining materials.

Item 2 AQUIFER THICKNESS

An average aquifer thickness of 21.3 m (70 ft.) was used in the analysis of the pump test as was indicated in the Management Summary and in the Conclusions to the Report. This value was based on the saturated thickness of drift encountered in the pump test well and other wells in the area of the pump test, as shown on Figures 3.4, 3.5 and 3.6 of the Report. Table 2 (attached) lists each of these wells and the associates aquifer thickness. The calculated average aquifer thickness from Table 2 is 20.8 m (68 ft.) which substantiates the average value of 21.3 m (70 ft.) used in the pump test analysis.

Subsequent data collected at the site, and presented in Reference 7, substantiate the use of 21.3 m (70 ft.) as an average aquifer thickness. Figure 4.10 of the "Geohydrologic Characterization, Crandon Project" report (Reference 7), titled "Saturated Coarse Drift Isopach Contours Project Area" shows saturated drift thicknesses between 15 m (50 ft.) and 40 m (130 ft.) in the area of the pump test. For the area enveloped by the 0.03 m (0.1 ft.) drawdown circle on Figure 6.13 of the Report, the average drift thickness is about 23 m (75 ft.), see Figure 3 (attached). Therefore, the average thickness of 21.3 m (70 ft.) used in the pump test analysis is reasonable.

Item 3 RADIAL DRAWDOWN PATTERN

The circular drawdown pattern shown on Figure 6.13 of the Report was not based on analytical methods. It was developed from the drawdown versus radial distance plot for the drift shown on Figure 6.12 of the Report. The plot of drawdowns on Figure 6.12 shows a well defined curve regardless of the direction from the pumping well; sufficient to define an essentially radial drawdown pattern.

Limited geologic and groundwater data from the area north of well TW-41 was available at the time of the pump test. However, sufficient geologic data was available when the pump test was designed to reasonably assume that the drift was extensive throughout the Site 41 area. Subsequent data collected at the site supports this initial evaluation. Figure 4.10 of Reference 7 (and Figure 3 attached) shows relatively uniform saturated drift thicknesses within the area of influence of the pump test. Therefore, drawdown north of TW-41 could be expected to be similar to those south of TW-41 and the radial pattern presented on Figure 6.12 of the Report was a reasonable approximation.

Page iv, Para. 1 SCREENED INTERVAL

The test well was screened from about 5 feet above the top of rock to about 10 feet above the coarse grained stratified drift, except for a 43 foot blank section of casing at the location of a fine grained glacial drift. The filter material extended from below the screen to the groundwater table which was about 39 feet above the top of the upper screen section, see Figure 4.1 of the Report. The fine grained glacial till were therefore connected to the well screen intervals via the filter material. The well screen was not extended through these layers in order to reduce the potential for drawing fine grained soil particles directly into the well screen. Therefore, the entire saturated glacial deposit was open to the well with the screen sections only located within the coarse grained portion of the stratified drift. Although those portions of the glacial deposit with high fines content contributed little flow to the well, the filter material was sufficient to achieve pressure reduction in the materials. The entire saturated aquifer (coarse grained stratified drift) thickness was screened.

Page iv, Para. 4 WELL EFFICIENCY

Water levels measured in the well TW-41 were considered representative of the water levels adjacent to the well as shown on Figure 6.1 of the Report. Well efficiency calculations using drawdown data from the flow velocity test and the long term pump test indicate relatively small well losses for the rates used. This is not surprising since extreme care was taken to fully develop well TW-41 prior to testing. The well was surged with air extensively and subsequently jetted at about 350 psi. A significant amount of fines was removed from the formation during development which would maximize the wells efficiency.

Well efficiency can be calculated as described by W. C. Walton on p. 313 of Reference 8. Using pumping rates from the flow velocity test and the main pump test at times of about two hours the wells loss, C, can be calculated as:

$$C = \frac{\Delta s_i/\Delta Q_i - \Delta s_{i-1}/\Delta Q_{i-1}}{\Delta Q_i + \Delta Q_{i-1}}$$

where: Δs is the increment of drawdown for each corresponding Q rate of pumping.

with: $s_0 = 0$ ft. for $Q_0 = 0$ cfs
$s_1 = 24$ ft. for $Q_1 = 1.2$ cfs
$s_2 = 68$ ft. for $Q_2 = 3.1$ cfs

we get: $C = 1.0$ ft./(cfs)^2

At 3.1 cfs (1390 gpm) this corresponds to about 2.9 m (9.6 ft.) of well loss, which is a small well loss (14%) considering that these were not stable water levels. However, the water level shown on Figure 6.1 of the report applies to the well and not the formation.

Page 3, Para. 2 LAKE AND WETLAND INFLUENCE

The effects of the surrounding lakes and wetlands on the pump test was not considered significant, since flow contribution to the well and drawdowns at these sources were small. Duck Lake and the adjacent wetland are perched. As such, flow to the groundwater system is small and would not significantly affect the flow to well TW-41.

Hemlock Slough is considered to be a groundwater discharge area, and could have affected the pump test. Significant drawdowns in the drift, in excess of 0.1 m (0.3 ft.), were not observed beyond about 850 m (2800 ft.) (see Figure 6.12 of the Report) and Hemlock Slough is about 1100 m (3600 ft.) from the well. Therefore, although portions of Hemlock Slough are within the potential area of influence shown on Figure 6.12 of the Report, the very small drawdowns at Hemlock Slough would result in small flow contributions to the well.

Page 30, Para. 2 FLOW VELOCITY TEST

The flow velocity test analysis was based on "the approximate laminar flow equation" below:

$$k = \Delta Q/LH$$

where: k = hydraulic conductivity
ΔQ = flow for a given portion of the well
L = length of the well portion
H = head drop in the well

This procedure is presented on p. 161 of Reference 9, where the specific capacity of the well is used as an estimate of the transmissivity, T. The thickness of the aquifer used was the interval of the well receiving flow. The hydraulic conductivity for each portion was then calculated by dividing the transmissivity by the open interval. So, with $T=kL$ and $T=Q/H$ we get:

$$k = \Delta Q/LH$$

The analysis of the flow velocity test using the above equation indicated hydraulic conductivities at about $2.3\text{x}10^{-4}$ m/s ($7\text{x}10^{-3}$ ft./sec), which is in close agreement with the values on Table 7.6 of the Report of $1.3\text{x}10^{-4}$ m/s ($4.3\text{x}10^{-4}$ ft./sec). Therefore, for a short duration test such as the flow velocity test, the specific capacity calculation was a good method for estimating the hydraulic conductivity.

Page 41, Para. 4 OPEN WELL INTERVAL

The test well was screened from about 5 feet above the top of rock to about 10 feet above the coarse grained stratified drift, except for a 43 foot blank section of casing at the location of a fine grained glacial drift. The filter material extended from below the screen to the groundwater table which was about 39 feet above the top of the upper screen section, see Figure 4.1 of the Report. The fine grained glacial till were therefore connected to the well screen intervals via the filter material. The well screen was not extended through these layers in order to reduce the potential for drawing fine grained soil particles directly into the well screen. Therefore, the entire saturated glacial deposit was open to the well with the screen sections only located within the coarse grained portion of the stratified drift. Although those portions of the glacial deposit with high fines content contributed little flow to the well, the filter material was sufficient to achieve pressure reduction in the materials. The entire saturated aquifer (coarse grained stratified drift) thickness was screened.

Page 60 and 51 <u>ASSUMPTIONS</u>

The assumptions should be in quotations and the source referenced as noted by the Wisconsin DNR.

Page 60, Para. 2 <u>VERTICAL HYDRAULIC CONDUCTIVITY</u>

The use of the Boulton method for estimating the vertical hydraulic conductivity of the confining layer is discussed in Item 1 above.

Page 74, Para. 3 <u>HYDRAULIC CONDUCTIVITY ANISOTROPIC RATIOS</u>

Anisotropic ratios of hydraulic conductivity for the glacial materials were estimated to be between 3:1 and 10:1, horizontal to vertical. Both the coarse grained stratified drift and the outwash materials were very uniform; all the material was essentially the same size. Depositional sorting of these materials was small and large hydraulic conductivity contrasts could not occur. Large contrasts would have been expected if lenses of silt or clay had been encountered; but, since they were not, the range of 10 horizontal to 1 vertical was a reasonable estimate.

The till materials, on the other hand, were very well graded; the material has a large size range. Generally, till materials do not exhibit any depositional sorting or layering, as was observed in the samples obtained at the site. For most soils this would suggest isotropic soil conditions, 1:1 ratios. The ratio of 3 horizontal to 1 vertical was given to account for consolidation effects.

The reported ratios were given as guides, so some variation in these ratios is justified for modeling. Ratios on the order of 1000:1, however, did not seem reasonable for the coarse grained stratified drift or outwash, nor were ratios on the order of 100:1 considered reasonable for the till materials.

Page 78, Conc. 1 AQUIFER THICKNESS

The 21.3 m (70 ft.) aquifer thickness presented in Conclusion 1 is simplistic since the aquifer thickness varies areally. However, as stated in Items 1 and 3 above, this thickness is a reasonable average that applies north of the pumping well.

Golder Associates hopes that this addresses the concerns of Exxon and the State regarding the pump test and its analyses. Please contact us if you have any questions.

Very truly yours,

GOLDER ASSOCIATES

John F Clerici

John F. Clerici, P.E.
Associate

JFC:das

Encl.

REFERENCES

1. Hantush, M.S. and C.E. Jacob, "Non-Steady Radial Flow in an Infinite Leaky Aquifer", Transactions American Geophysical Union, Vol. 36, No. 1, February, 1955.

2. Boulton, N.S., "Unsteady Radial Flow to a Pumped Well Allowing for Delayed Yield from Storage", Publication No. 37 de l'Association Internationale d'Hydrologic, Assemblee generale de Rome, Tome II, 1955.

3. Boulton, N.W., "Analysis of Data from Non-Equilibrium Pumping Tests Allowing for Delayed Yield from Storage", Proceedings of the Institute of Civil Engineers, Vol 26., 1963.

4. Cooley, R.L. and C.M. Case, "Effects of a Water Table Aquitard on Drawdown in an Underlying Pumped Aquifer", Water Resources Research, Vol. 9, No. 2, April 1973.

5. Lohmen, S.W., "Groundwater Hydraulics", Geological Survey Professional Paper 708, U.S. Department of Interior Geologic Survey, 1979.

6. Jacob, C.E., "Radial Flow in a Leaky Artesian Aquifer", Transactions American Geophysical Union, Vol. 27, No. 11, 1946.

7. Golder Associates, "Geohydrologic Characterization Crandon Project", October 6, 1982.

8. Walton, W.C., Groundwater Resource Evaluation, McGraw Hill Book Co., New York, 1970.

9. Groundwater Manual, Water Resources Technical Publication, U.S. Department of Interior Bureau of Reclamation, 1977.

TABLE 1

SUMMARY OF SUPPLEMENTAL PUMP TEST ANALYSIS

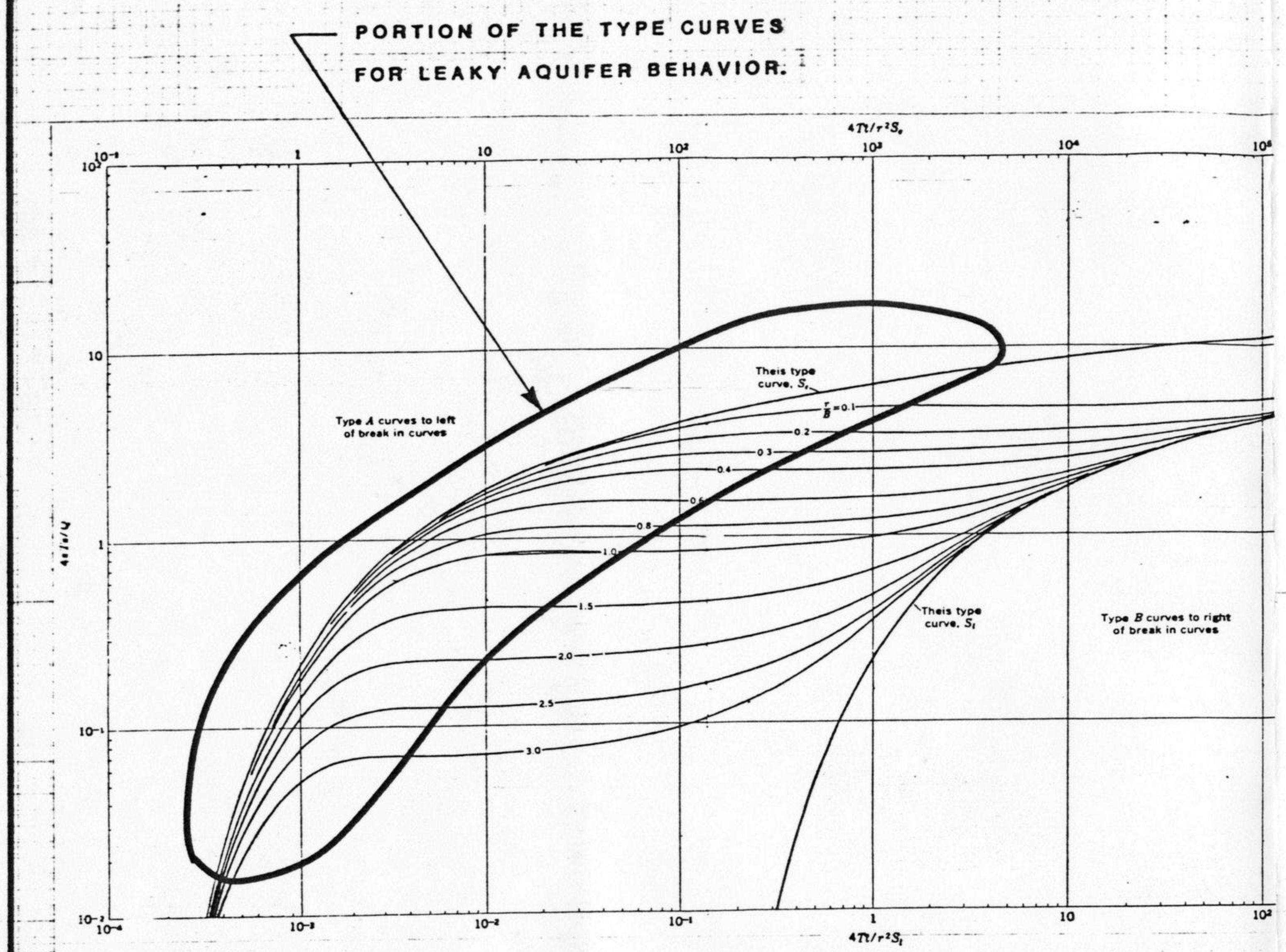
Well No.	BOULTON $T^{(1)}$ m^2/s (ft.^{2}/sec.)	 $K_v^{(2)}$ m/s (ft./sec.)	HANTUSH & JACOB/COOPER $T^{(1)}$ m^2/s (ft.^{2}/sec.)	 $K_v^{(2)}$ m/s (ft./sec.)	RATIO TEST $T^{(3)}$ m^2/s (ft.^{2}/sec.)	 $K_v^{(2)}$ m/s (ft./sec.)	NEUMAN TYPE CURVE $T^{(4)}$ m^2/s (ft.^{2}/sec.)	 $K_v^{(5)}$ m/s (ft./sec.)
G41-G14A	$4.6\text{x}10^{-3}$ ($5\text{x}10^{-2}$)	$1.2\text{x}10^{-6}$ ($4.0\text{x}10^{-6}$)	--	--	--	$2.0\text{x}10^{-7}$ ($6.5\text{x}10^{-7}$)	--	--
G41-G14B	$2.3\text{x}10^{-3}$ ($2.5\text{x}10^{-2}$)	$1.1\text{x}10^{-6}$ ($3.6\text{x}10^{-6}$)	--	--	--	--	--	--
G41-G14D	$2.1\text{x}10^{-3}$ ($2.3\text{x}10^{-2}$)	$2.1\text{x}10^{-6}$ ($6.9\text{x}10^{-6}$)	$2.1\text{x}10^{-3}$ ($2.3\text{x}10^{-2}$)	$2.7\text{x}10^{-6}$ ($8.8\text{x}10^{-6}$)	--	--	$2.9\text{x}10^{-3}$ ($3.1\text{x}10^{-2}$)	$2.8\text{x}10^{-6}$ ($9.3\text{x}10^{-6}$)
G41-G14F	$2.4\text{x}10^{-3}$ ($2.6\text{x}10^{-2}$)	$3.6\text{x}10^{-7}$ ($1.1\text{x}10^{-6}$)	--	--	--	--	--	--
G41-G15B	$2.6\text{x}10^{-3}$ ($2.8\text{x}10^{-2}$)	$9.2\text{x}10^{-7}$ ($3.0\text{x}10^{-6}$)	$2.6\text{x}10^{-3}$ ($2.8\text{x}10^{-2}$)	$9.0\text{x}10^{-7}$ ($3.0\text{x}10^{-6}$)	--	$3.6\text{x}10^{-7}$ ($1.2\text{x}10^{-6}$)	$8.6\text{x}10^{-4}$ ($9.3\text{x}10^{-3}$)	$8.2\text{x}10^{-7}$ ($2.7\text{x}10^{-6}$)
G41-G15	$3.5\text{x}10^{-3}$ ($3.8\text{x}10^{-2}$)	$6.4\text{x}10^{-7}$ ($2.1\text{x}10^{-6}$)	--	--	--	--	--	--
G41-E13	$6.9\text{x}10^{-3}$ ($7.4\text{x}10^{-3}$)	$1.9\text{x}10^{-6}$ ($6.3\text{x}10^{-6}$)	$6.5\text{x}10^{-3}$ ($7.0\text{x}10^{-2}$)	$2.1\text{x}10^{-6}$ ($6.8\text{x}10^{-6}$)	--	--	--	--
G41-K13	$3.1\text{x}10^{-3}$ ($3.3\text{x}10^{-2}$)	$5.8\text{x}10^{-7}$ ($1.9\text{x}10^{-6}$)	--	--	--	--	--	--

NOTES:
1. T is the transmissivity of the pumped aquifer.
2. K_v is the vertical hydraulic conductivity of confining layer.
3. T is transmissivity of pumped aquifer as calculated by other methods and was, therefore, not included in the table.
4. T is transmissivity of unconfined aquifer (entire saturated zone).
5. K_v is vertical hydraulic conductivity of unconfined aquifer (entire saturated zone).

TABLE 2

ESTIMATED AQUIFER THICKNESS FROM OBSERVATION WELL DATA

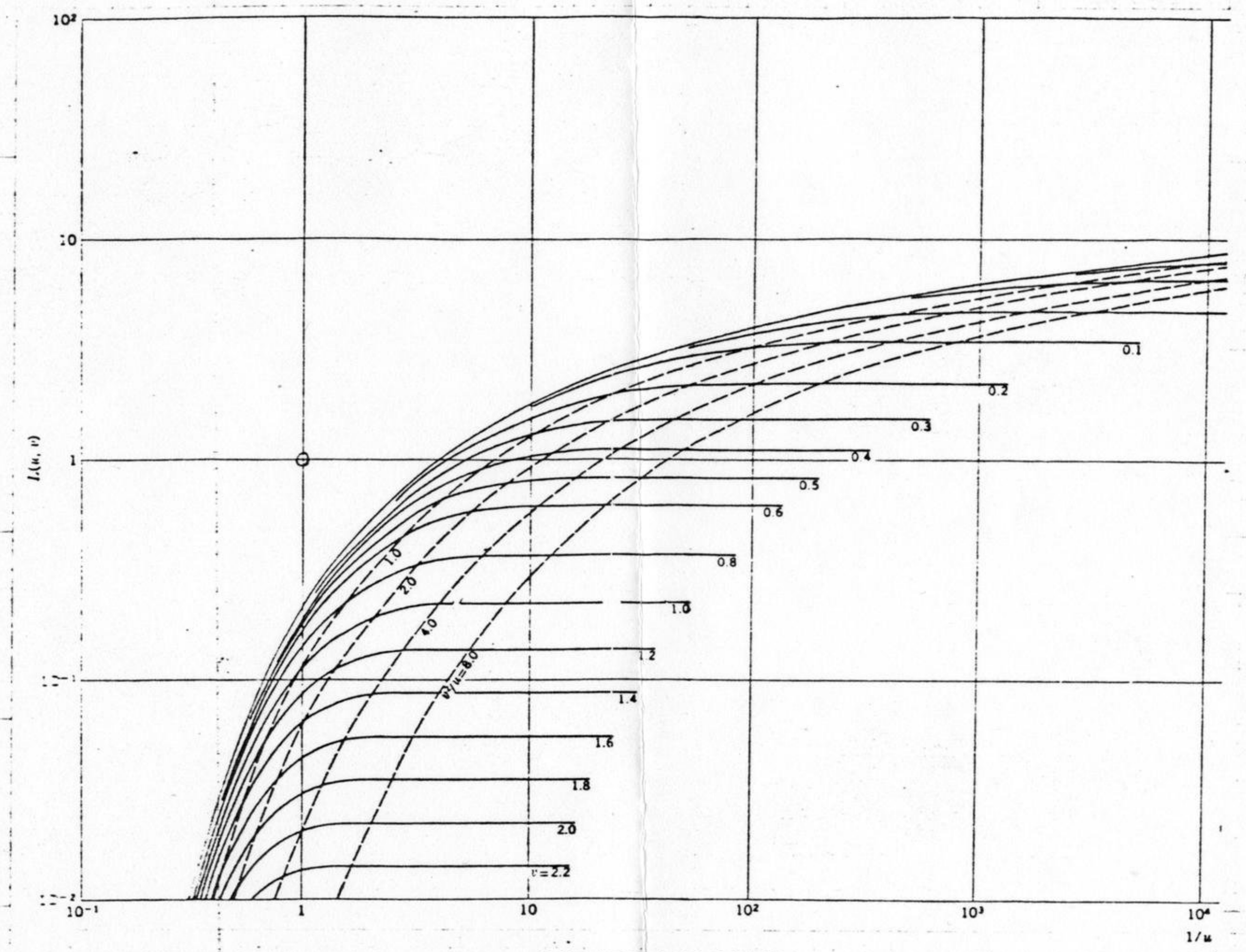
Well Nos.	Thicknesses in m (ft.)
TW-41	22.8 (75)
G41-G14A, B, C	19.5 (64)
G41-G14D, E, F	20.7 (68)
G41-G15, A, B	21.9 (72)
G41-E13 & DMB-1A	35.1 (115)
G41-K13, A	4.6 (15)
AVERAGE	20.8 (68)



PORTION OF THE TYPE CURVES FOR LEAKY AQUIFER BEHAVIOR.

DELAYED-YIELD TYPE CURVES

After Boulton(1963, fig. 1)



A. TYPE CURVES

CURVES FOR NONSTEADY RADIAL FLOW IN AN INFINITE LEAKY ARTESIAN AQUIFER

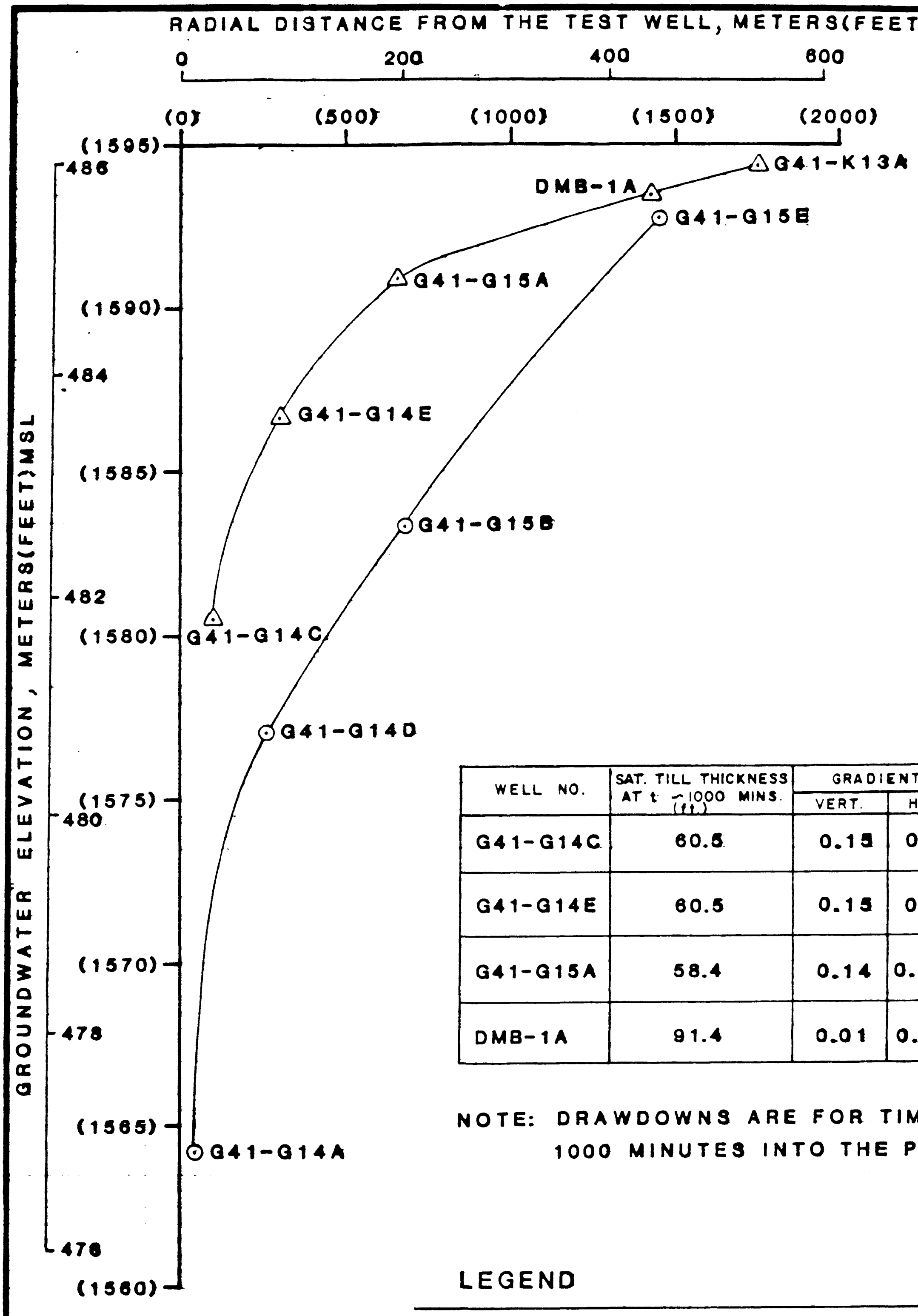
After Cooper,(1963, pl. 4)

NOTES

1. CURVES COPIED FROM PLATES 3 and 8 OF REFERENCE 4.
2. 2V(COOPER) = R/B(BOULTON)

JOB NO.	834-1389	SCALE	AS SHOWN	TYPE CURVE COMPARISON
DRAWN	CAB	DATE	1-18-84	
CHECKED		DWG. NO.	050-1-81131	
Golder Associates				EXXON MINERALS COMPANY
				FIGURE 1

AF 20440A-B



WELL NO.	SAT. TILL THICKNESS AT t ~1000 MINS. (ft.)	GRADIENTS		DEGREES FM. VERTICAL
		VERT.	HORZ.	
G41-G14C	60.5	0.15	0.06	21.9
G41-G14E	60.5	0.15	0.01	3.8
G41-G15A	58.4	0.14	0.005	2.0
DMB-1A	91.4	0.01	0.001	5.7

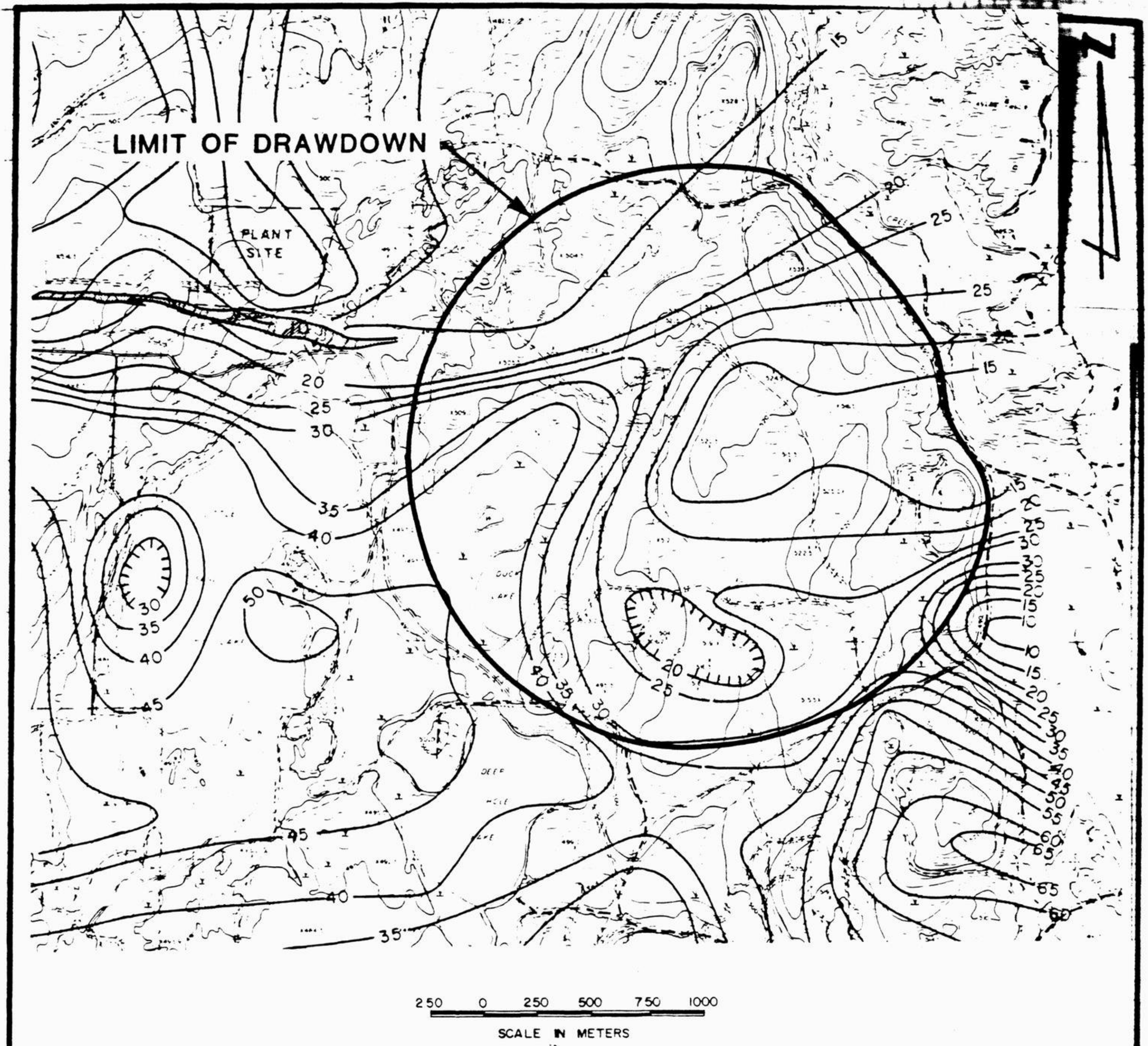
NOTE: DRAWDOWNS ARE FOR TIMES APPROXIMATELY 1000 MINUTES INTO THE PUMP TEST.

LEGEND

—△— UPPER TILL WATER LEVELS

—⊙— STRATIFIED DRIFT WATER LEVELS

JOB NO. 834-1388	SCALE AS SHOWN	GROUNDWATER ELEVATION vs. DISTANCE FROM THE TEST WELL AND FLOW DIRECTION IN TILL
DRAWN CAB	DATE 1-12-84	
CHECKED	DWG. NO. 050-1-81130	
Golder Associates		EXXON MINERALS COMPANY — FIGURE 2



NOTES

1. ISOPACH THICKNESS REPRESENTS TOTAL THICKNESS OF ALL SATURATED COARSE GRAINED STRAIFIED DRIFT.
2. IN THE CRANDON UNIT AND PLANT SITE VICINITY COARSE TILL MATERIAL IS ADDED TO TOTAL ISOPACH THICKNESS.
3. IN ALL AREAS OTHER THAN THE CRANDON UNIT AND THE PLANT SITE ONLY COARSE GRAINED STRATIFIED DRIFT IS ADDED TO THE ISOPACH.
4. SEE FIGURE 4.10 FOR REFERAL OF ORIGINAL DRIFT ISOPACH MAP.
5. SEE FIGURE 6.13 OF PUMP TEST REPORT FOR LIMIT OF DRAWDOWN BOUNDARY.

JOB NO. 834-1389	SCALE AS SHOWN	SATURATED DRIFT ISOPACH IN AREA OF TW-41 PUMP TEST	
DRAWN CAB	DATE 1-12-84		
CHECKED JFC	DWG NO. 050-1-81126		
Golder Associates		EXXON MINERALS COMPANY	FIGURE 8

APPENDIX A

Wisconsin DNR Memorandum

GHC

534 1389

[illegible] GEOLOGICAL AND NATURAL HISTORY SURVEY
1815 University Avenue, Madison, Wisconsin 53706 608-262-1705

MEMO

to: Ken Wade, Dept. of Natural Resources date: November 15, 1982

from: Ken Bradbury, Hydrogeologist KRB

Re: Review of Crandon Project Pump Test and Analysis,
Project Report 4, by Golder Associates

At the request of Ken Wade and Bob Grefe I have reviewed Golder's pump test report on the Crandon site. Although the report is generally complete and well documented, several areas may require additional explanation.

1. The method used to calculate the vertical hydraulic conductivity of the confining layer (K_v) is not clear. Determination of this parameter is not discussed in the Boulton method described by Kruseman and De Ridder(Golder's reference 5). It appears that the K_v calculations are based on the Hantush and Jacob leaky artesian formulae, which assume strictly vertical flow through a leaky confining bed overlying an artesian aquifer. In these equations parameter B is proportional to vertical hydraulic conductivity. On page 59, the Golder report describes the Crandon aquifer as semi-unconfined, which implies that horizontal flow does take place in the semi-confining layer (upper till, in this case). If horizontal flow is occurring, as implied, then the parameter B in the Boulton analysis is a function of both horizontal and vertical flow components, and cannot be used to estimate K_v without additional data. Kruseman and De Ridder make a statement to this effect on page 101 of their text. Thus some additional explanation is needed as to the determination of K_v for the till.

2. The method of determination of effective aquifer thickness as 70 feet (page 78) is not clear, and there is a seeming contradiction between "... a 70 foot thick sheet of coarse grained stratified drift ..." (p. 78) and the three aquifer zones (separated by 35 and 40 feet) described on page 30. At various places in the report the aquifer could be assumed to be 40-110 ft. thick (fig. 3.4-3.6), 122 ft. thick (screened interval on fig. 4.1) or 60 ft. thick (total thickness of zones in table 5.1). How was 70 ft. determined as the best average?

3. There are few data in the report to support the radial drawdown pattern in fig. 6.13 (and elsewhere). The perfectly circular pattern of the contours on this map suggest that they are analytically calculated drawdowns. If so, the analytical

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equation and parameters used should be clearly stated. According to the figure there are absolutely no data north of the pumping site with which to evaluate the shape of the drawdown cone there.

Specific comments follow:

Page iv. Paragraph 1. States that "well is screened over essentially the full depth of saturated material." According to fig. 4.1 the saturated material is 218 ft. thick and the screened interval is 122 ft. long. Thus it appears that only 56% of the saturated material was screened.

Page iv. Paragraph 4. Because drawdown was measured inside the pumped well, the maximum reported drawdown of 73 feet is probably caused by well loss effects, and it is unlikely that as much drawdown occurred in the aquifer adjacent to the well. Thus the final water level as shown outside the well in fig. 6.1 is probably in error.

Page 3. Paragraph 2. States that the test was not influenced by wetlands and lakes. Yet according to Fig. 6-13, the cone of depression did reach several lakes and wetlands. The data appear too sparse to adequately evaluate the influence of wetlands and lakes.

Page 30. Paragraph 2. What is the reference for the "approximate laminar flow formula?" How reliable are hydraulic conductivity determined by this method?

Page 41. Paragraph 4. Explanation assumes "well is fully open to the formation" which, from figure 4.1, is not the case.

Page 60 and 61. Assumptions given here are directly quoted from Kruseman and DeRidder (1979, pages 46 and 97). Such quotations should reference the source.

Page 60. Paragraph 2. The statement that the Boulton method allows evaluation of vertical hydraulic conductivity of the confining layer is contradicted by Kruseman and DeRidder (1979, p. 101).

Page 74. Paragraph 3. The discussion of anisotropy ratios in the stratified drift and outwash is weak. Knowledge of the anisotropy ratio has been shown to be critical in calibration of 3-dimensional numerical models of the type Exxon's consultants are preparing, and other model studies in glacial materials have used Kh:Kv ratios ranging from 2:1 to 1000:1 (Winter, 1978, WRR V14 No 2; Munter and Anderson, 1981, Ground Water V 19 No. 6). Thus a general "common" assumption of 10:1 and 3:1 ratios for the outwash and till may not be adequate for the modeling study.

Page 78. Conclusion(1) is simplistic and somewhat misleading because it refers to the conceptual model of figure 7.2 rather than to the true field situation. From the cross sections in figures 3.4, 3.5, and 3.6 the stratified drift ranges in thickness from 15 to 110 feet and is somewhat discontinuous. Furthermore according to fig. 3.3 there are no data points north of well TW 41 in order to evaluate the extent of the aquifer.

KB:gl

APPENDIX B

Supplemental Pump Test Analyses

Hydrogeologic data suggest that an applicable hydrogeologic model for the Crandon site would consist of a laterally extensive drift aquifer overlain and underlain by till aquitards. The top of the flow system was defined by the initial phreatic surface which was assumed to represent a constant head boundary. At the bottom of the flow system was an impermeable boundary conforming to the top of the bedrock. If the ratio of aquifer to aquitard hydraulic conductivity is sufficiently high, the model would predict essentially downward vertical flow in the upper aquitard, an upward vertical component of flow in the lower aquitard, and horizontal flow in the aquifer. Analyses presented in the 1981 report were based on modifications to this hydrogeologic model.

Golder Associates has reanalyzed the Site 41 pump test drawdown data using three different methods. This reanalysis is presented in detail in this appendix. The vertical hydraulic conductivity of the confining layer calculated with these new methods is consistent with the estimated values in the Golder 1981 report. Consequently, no revision of the 1981 estimated values of the vertical hydraulic conductivity of the confining layer is recommended.

METHODS OF ANALYSIS

The three methods used to reanalyze the Crandon pump test drawdown data were: the Hantush and Jacob/Cooper type curve method, the ratio test developed by Neuman and Witherspoon and the Neuman delayed yield type curve method. Each of these three methods of analysis are presented below; the results of the analyses are shown in Table 1.

HANTUSH AND JACOB/COOPER TYPE CURVE METHOD

The Hantush and Jacob analysis was developed for estimating the hydraulic characteristics of a leaky-confined aquifer. The particular analysis method used was based on type curve plots subsequently prepared by H. H. Cooper, Reference 1. This method is based on the following assumptions:

1. Flow in the aquifer is horizontal and axially symetric.
2. Flow in the aquitard is vertical.
3. The aquifer and aquitard are seemingly infinite in radial extent.

4. The aquitard has negligible compressibility.

5. Leakage into the aquifer is derived from instantaneous desaturation with lowering of the water table.

6. The aquifer is confined and of uniform thickness and permeability.

7. Well discharge is constant.

According to Cooper, the original leaky aquifer equation by Hantush and Jacob can be rewritten as:

$$s = (Q/4\pi T)L(u,v)$$

with $u = R^2S/4Tt$

$$v = R/2\ (k_v/b'T)^{1/2}$$

where:

s = aquifer drawdown (L)
Q = pump discharge rate (L^3/T)
T = transmissivity of pumped aquifer (L^2T)
L = function
R = distance from pump well (L)
S = storage coefficient
k_v = vertical hydraulic conductivity of the confining layer (L/T)
b' = thickness of the confining layer (L)

Cooper developed type curves for the function L(u,v). By plotting drawdown verses time on standard 3x5 cycle log paper and superimposing it on the type curves, estimates of T, S and k_v can be made. The results of Golder's analysis of the drawdown data is for selected wells presented in Table 1 and Figures A1 to A3.

RATIO TEST, NEUMAN AND WITHERSPOON

This method is based on essentially the same assumptions as the Cooper type curve method. The only exceptions are that the aquifer can be confined or unconfined and the nature of the upper aquitard boundary is of no consequence. If the aquitard is heterogeneous and isotropic this method will predict the average vertical permeability over the thickness of the confining layer being tested.

The ratio method is valid provided that the following conditions are met:

$\frac{R}{4} \; \frac{K_v S_s'}{TS}^{1/2} < 1.0$ Criteria (A)

$t < \frac{0.1 \; (b')^2}{D}$ Criteria (B)

where: S_s' = specific storage of the confining layer (L^{-1})
D = diffusivity of the confining layer (L^2/T)
other terms are as previously defined

If criterion (A) and (B) are satisfied, the ratio of aquitard to aquifer drawdown, at a specified radial distance, is given by:

$$s'/s = F\ (t_D,\ t_D')$$

$$t_D = Tt/SR^2$$

$$t_D' = Dt/z^2$$

where: F = dimensionless time function
s' = drawdown in the confining layer (L)
t_D = aquifer dimensionless time
t_D' = confining layer dimensionless time
z = distance from the top of the aquifer to the bottom of the confining layer piezometer (L)

The function $F(t_D,\ t_D')$ is tabulated in Reference 2 and is shown graphically in Figure 3. Neuman and Witherspoon describe the following procedure for calculating the vertical hydraulic conductivity:

1. Calculate the ratio (s'/s) from two aquitard/aquifer piezometers of the same radial distance at a specified pumping time. If radial distance to the aquifer piezometer differs from that in the aquitard, the value of (s) can be interpolated using measurements from other aquifer piezometers.

2. Calculate t_D based on known values of T and S. In this case, aquifer properties are determined using the Boulton method.

3. Determine t_D' from Figure A4 using the appropriate t_D curve.

4. Calculate aquifer diffusivity by solving the equation:

$$D = t_D' \, z^2/t$$

5. Based on an assumed value of aquitard specific storage, calculate aquitard vertical hydraulic conductivity:

$$K_v = D \, S_s'$$

6. Verify that calculated and assumed parameters satisfy criterion (A) and (B).

Figures A4 and A5 show aquifer/aquitard responses for piezometer clusters at various radial distances from the pumping well. Responses in the G41-G14A,C and G41-G15A,B clusters (Figures A5 and A6, respectively) have characteristics consistent with those predicted by the ratio method. This is indicated by a distinct time lag in aquitard response. Note that for well group G41-G14A and C that a correction was made for the distance-drawdown as shown on Figure A7. Criteria (B) was slightly violated in the G41-G15A,B calculation. Because this criteria tends to be over-conservative in practical application the results are not expected to have significant errors. Calculated vertical hydraulic conductivities are shown on Figures A5 and A6 and are summarized in Table 1.

The values of vertical hydraulic conductivity given by the ratio method are 2.4 to 6.0 times lower than the K_v values given by the Boulton analyses (see Table 1). Discrepancy between results of the Boulton and ratio methods may be explained as follows:

- Open standpipe piezometers in the aquitard may have exhibited a response lag time (i.e., piezometer water level response slower than actual formation hydraulic response). This would result in an under estimation of K_v when the ratio method is applied.

- In applying the ratio method, it was assumed that aquitard specific storage was identical to that of the aquifer. In most hydrologic situations, aquitard specific storage is greater than aquifer specific storage. If this is the case at Crandon, the assumed value of S_s' was probably artificially low, leading to an underestimation of K_v.

As a result of the above uncertainties, the ratio method is expected to give lower bound values of aquitard vertical hydraulic conductivity.

NEUMAN, DELAYED YIELD TYPE CURVE METHOD

This method is described in Reference 4 and is based on an unconfined homogeneous anisotropic aquifer with delayed gravity response. The following assumptions are also made:

1. Flow in the aquifer is axially symetric.
2. The aquifer is seemingly infinite in radial extent.
3. The aquifer is anisotropic with principal hydraulic conductivities in the horizontal and vertical directions.1
4. The process of delayed water table response is simulated using constant values of aquifer storativity and specific yield. Unsaturated flow above the phreatic surface is neglected.
5. Decline of the water table is small in relation to aquifer thickness.

For the conditions described, Neuman presents the following analytical solution for the general case of partially penetrating production and observation wells:

$$s = \frac{Q}{4\pi T} s_D \left(t_s, t_y, \sigma, \beta, \frac{p}{b}, \frac{d}{b}, \frac{z_1}{b}, \frac{z_2}{b}\right)$$

with: $t_s = Tt/SR^2$
$t_y = Tt/S_yR^2$
$\sigma = S/S_y$
$\beta = K_z(R^2/Tb)$

where: s_D = function for dimensionless drawdown
t_s = dimensionless time with respect to aquifer storativity
t_y = dimensionless time with respect to aquifer specific yield
β = dimensionless type-curve value
b = aquifer thickness (L)
b' = aquitard thickness (L)

p = distance from initial position of water table to bottom of perforations in pumping well (L)
d = distance from initial position of water table to top of perforations in pumping well (L)
z_1 = distance from base of aquifer to bottom of perforations in observation well (L)
z_2 = distance from base of aquifer to top of perforations in observation well (L)
S_y = specific yield
K_z = aquifer vertical hydraulic conductivity (L/T)

and all other parameters are as previously defined.

Parameters p and d describe the partial penetration characteristics of the production well, while z_1 and z_2 are related to characteristics of the observation well.

The large number of parameters in the dimensionless function (s_D) makes it practically impossible to construct a sufficient number of type-curves to cover the entire range of values necessary for field application. However, if the value of sigma (σ) is assumed small and geometric parameters (p, d, z_1, and z_2) are specified, it is possible to construct a single set of type-curves having a format similar to the type-curves of Boulton. In this case, each type-curve is associated with a particular value of β. This procedure requires that a unique family of type-curves be developed for each observation well, a task accomplished using a computer program developed by Neuman (Reference 4).

Determination of aquifer parameters follows the same curve-matching procedure as for the Boulton analysis. Matching early time drawdown data to the chosen type-curve (B^*) give the following values for any arbitrary (early) match point:

$$s_D^*, t_s^*, s^*, t^*$$

Matching late time data to the same type-curve gives the following (late) match point values:

$$s_D^{**}, t_y^{**}, s^{**}, t^{**}$$

Aquifer transmissivity can be calculated by either of the following two equations:

$$T^* = Q\ S_D{}^*/4\pi S^*$$

$$T^{**} = Q\ S_D{}^{**}/4\pi S^{**}$$

Transmissivities given by the above equations should be similar, although estimates based on early time data is generally considered more reliable. Aquifer storativity and specific yield are given by the following equations:

$$S = Tt^*/R^2 t_s{}^*$$

$$S_y = Tt^{**}/R^2 t_y{}^{**}$$

and aquifer vertical hydraulic conductivity is calculated as follows:

$$K_z = \beta^* Tb/R^2$$

In applying the Neuman method to Crandon pump test data, it was found that the type-curve program was very costly to execute. Since generation of a complete set of type-curves for an observation well would be exceedingly expensive, individual curves were produced and iteratively compared with field data until a curve having the "best fit" was selected. In this way, computer costs were kept to a minimum. In addition, only two wells were analyzed for comparison to Report values.

Drawdown data and superimposed best-fit curves are presented in Figures A8 to A11 for piezometers G41-G14D and G41-G15B, respectively. Associated calculations of aquifer parameters as shown on Figures A10 and A11 and the results are summarized in Table 1.

CONCLUSIONS REGARDING VERTICAL HYDRAULIC CONDUCTIVITY

The supplemental pump test calculations performed provide three additional independent methods for estimating the aquitard vertical hydraulic conductivity. Two of the methods (Hantush Jacob/Cooper, ratio test) were based on a leaky aquifer model, while the third (Neuman) assumed an anisotropic unconfined aquifer. Vertical hydraulic conductivities given by the above methods generally differed by a factor of less than 3 and were consistent with estimated values quoted in the Pump Test Report of 1981. Lowest values were given by the ratio method. However, due to practical considerations, it can be hypothesized that the ratio test should tend to provide lower bound values. Based on the work presented in this attachment, it is concluded that there is no justification for substantially revising the best estimate values of vertical hydraulic conductivity of the confining layer as originally presented in the Report.

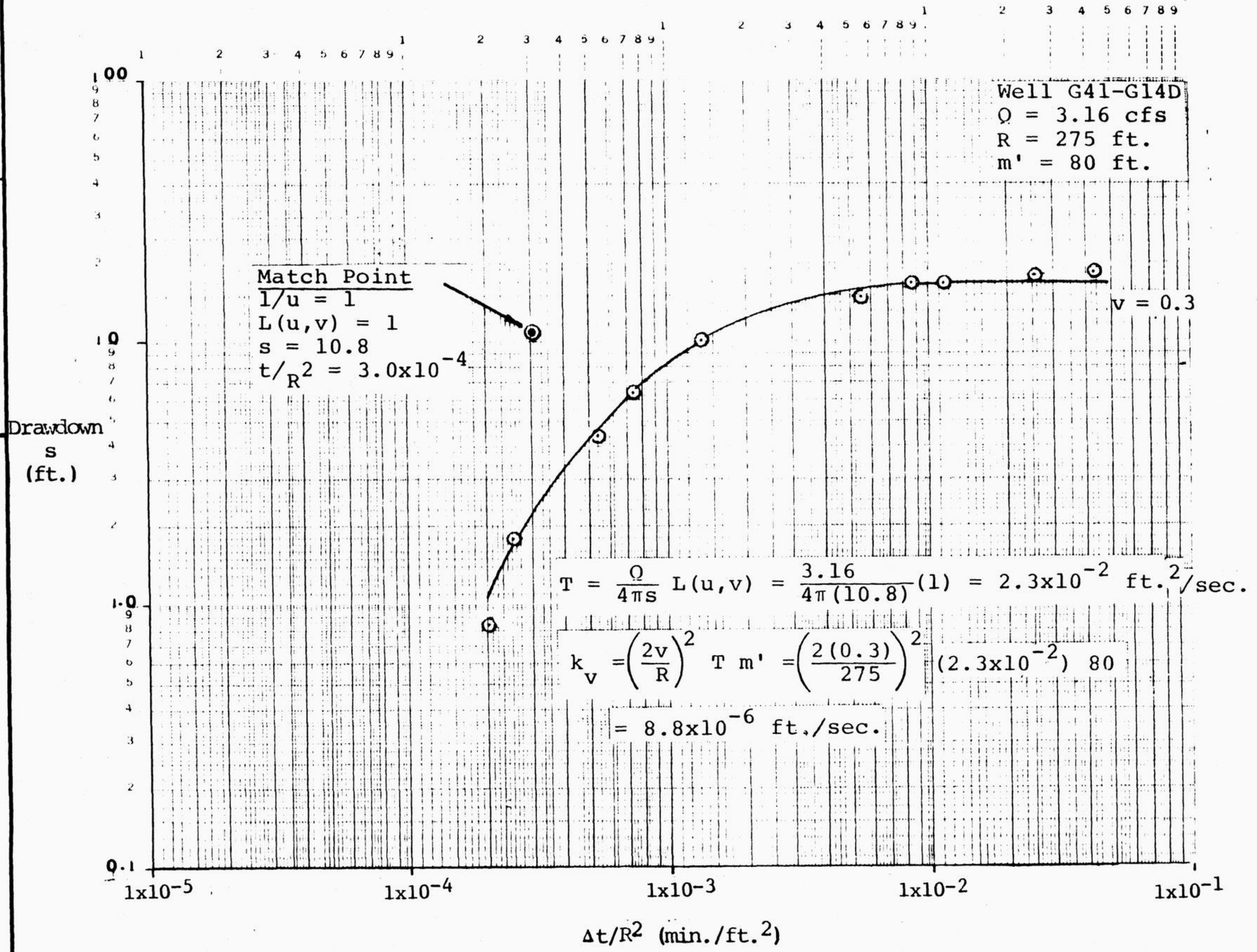
REFERENCES

1. Lohmen, S.W., "Groundwater Hydraulics", Geologic Survey Professional Paper 708, U.S. Department of Interior Geologic Survey, 1979.

2. Witherspoon, P.A., I. Javandel, D.P. Neuman, and R.A. Freeze, "Interpretation of Aquifer Gas Storage Conditions from Water Pumping Tests", American Gas Association, Inc., New York, 1967.

3. Neuman, S.P., and P.A. Witherspoon, "Field Determination of the Hydraulic Properties of Leaky Multiple Aquifer System", Water Resources Research, Vol. 8, No. 5, 1972.

4. Neuman, S.P., "Analysis of Pumping test Data from Anisotropic Unconfined Aquifers Considering Delayed Gravity Response", Water Resources Research, Vol. II, No. 2, 1975.



Well G41-G14D
$Q = 3.16$ cfs
$R = 275$ ft.
$m' = 80$ ft.

Match Point
$1/u = 1$
$L(u,v) = 1$
$s = 10.8$
$t/R^2 = 3.0\text{x}10^{-4}$

$v = 0.3$

$$T = \frac{Q}{4\pi s} L(u,v) = \frac{3.16}{4\pi(10.8)}(1) = 2.3\text{x}10^{-2} \text{ ft.}^2\text{/sec.}$$

$$k_v = \left(\frac{2v}{R}\right)^2 T\, m' = \left(\frac{2(0.3)}{275}\right)^2 (2.3\text{x}10^{-2})\ 80$$

$$= 8.8\text{x}10^{-6} \text{ ft./sec.}$$

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HANTUSH and JACOB/COOPER ANALYSIS
WELL G41-G14D

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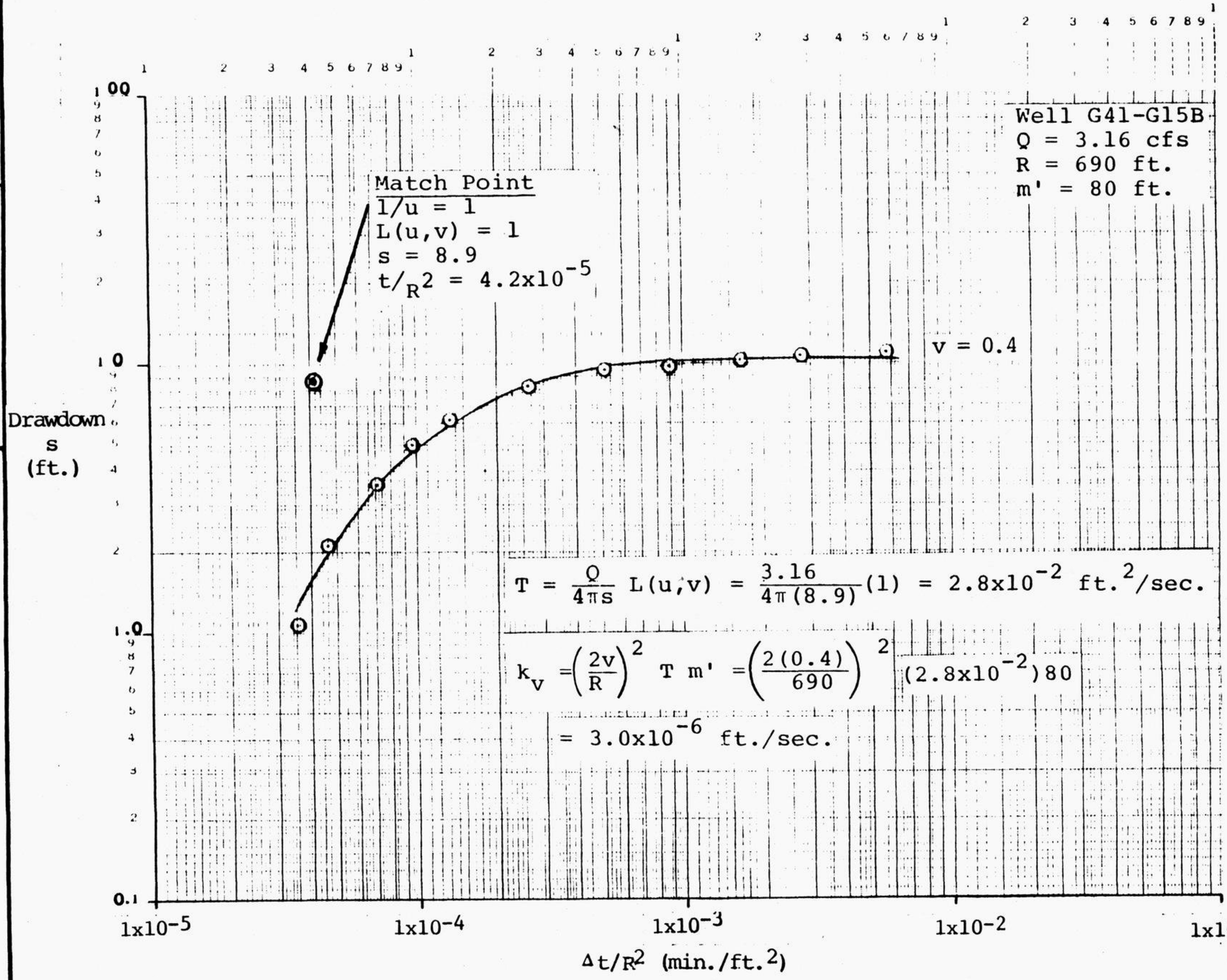
FIGURE B1



Well G41-G15B
$Q = 3.16$ cfs
$R = 690$ ft.
$m' = 80$ ft.

Match Point
$1/u = 1$
$L(u,v) = 1$
$s = 8.9$
$t/_{R}2 = 4.2 \times 10^{-5}$

$$T = \frac{Q}{4\pi s} L(u,v) = \frac{3.16}{4\pi(8.9)}(1) = 2.8\times10^{-2} \text{ ft.}^2\text{/sec.}$$

$$k_v = \left(\frac{2v}{R}\right)^2 T m' = \left(\frac{2(0.4)}{690}\right)^2 (2.8\times10^{-2})80$$

$$= 3.0\times10^{-6} \text{ ft./sec.}$$

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HANTUSH and JACOB/COOPER ANALYSIS
WELL G41-G15B

FIGURE B2

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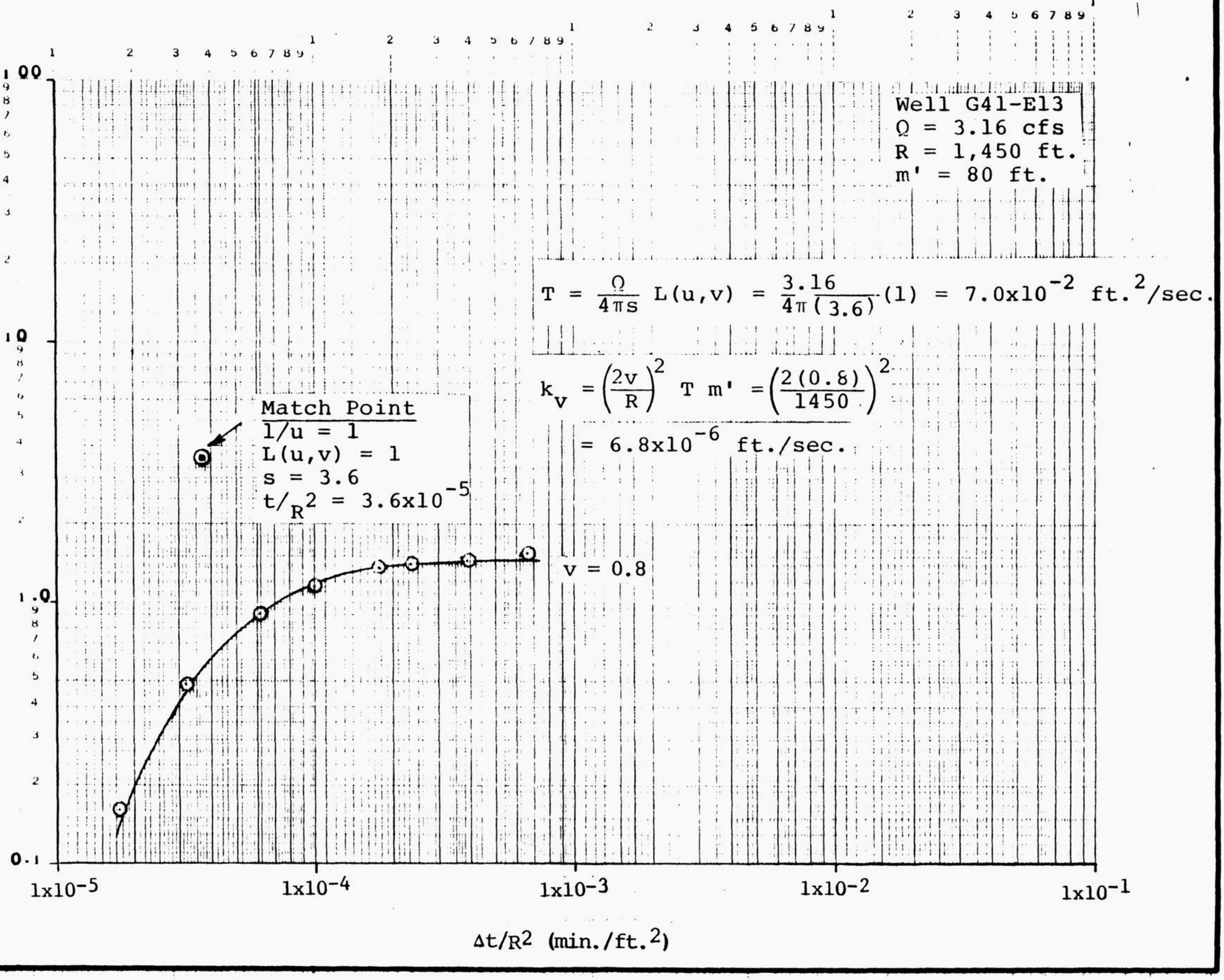

Well G41-E13
Q = 3.16 cfs
R = 1,450 ft.
m' = 80 ft.

$$T = \frac{Q}{4\pi s} L(u,v) = \frac{3.16}{4\pi(3.6)}(1) = 7.0\text{x}10^{-2} \text{ ft.}^2\text{/sec.}$$

$$k_v = \left(\frac{2v}{R}\right)^2 T\,m' = \left(\frac{2(0.8)}{1450}\right)^2$$

$$= 6.8\text{x}10^{-6} \text{ ft./sec.}$$

Match Point
1/u = 1
L(u,v) = 1
s = 3.6
$t/_{R}2 = 3.6\text{x}10^{-5}$

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HANTUSH and JACOB/COOPER ANALYSIS
WELL G41-E13
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FIGURE B3

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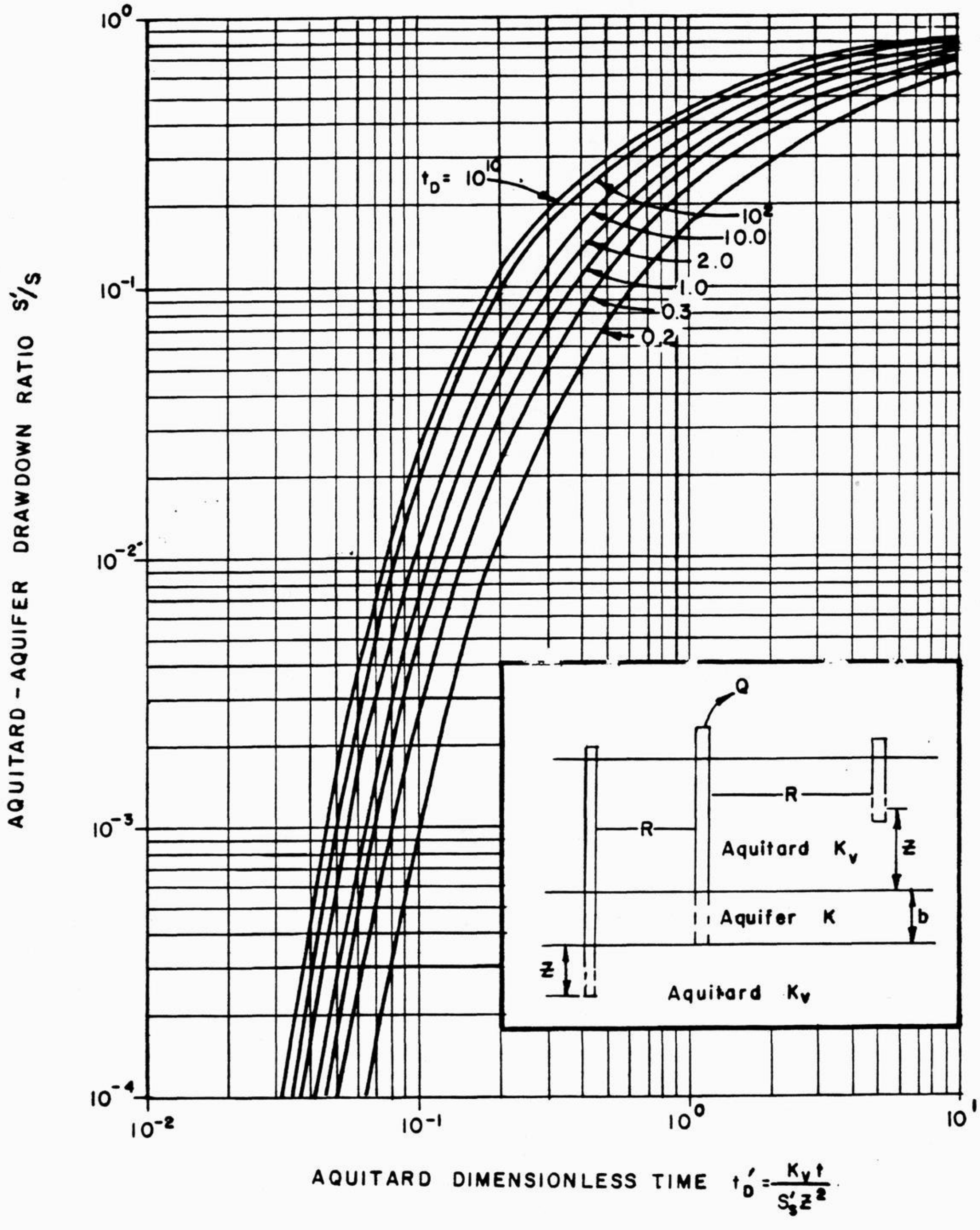
DIMENSIONLESS TIME AS A FUNCTION OF AQUITARD - AQUIFER DRAWDOWN RATIO



NOTE: TAKEN FROM REFERENCE 4.

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		FIGURE B4

Well G41-G14A & C

$s' = 1.5$ ft.

$s = 14.1$ ft.

$t = 20$ min.

$R = 100$ ft.

$T = 5\text{x}10^{-2}$ ft.^{2}/s

$S = 5.8\text{x}10^{-4}$

$Z = 25$ ft.

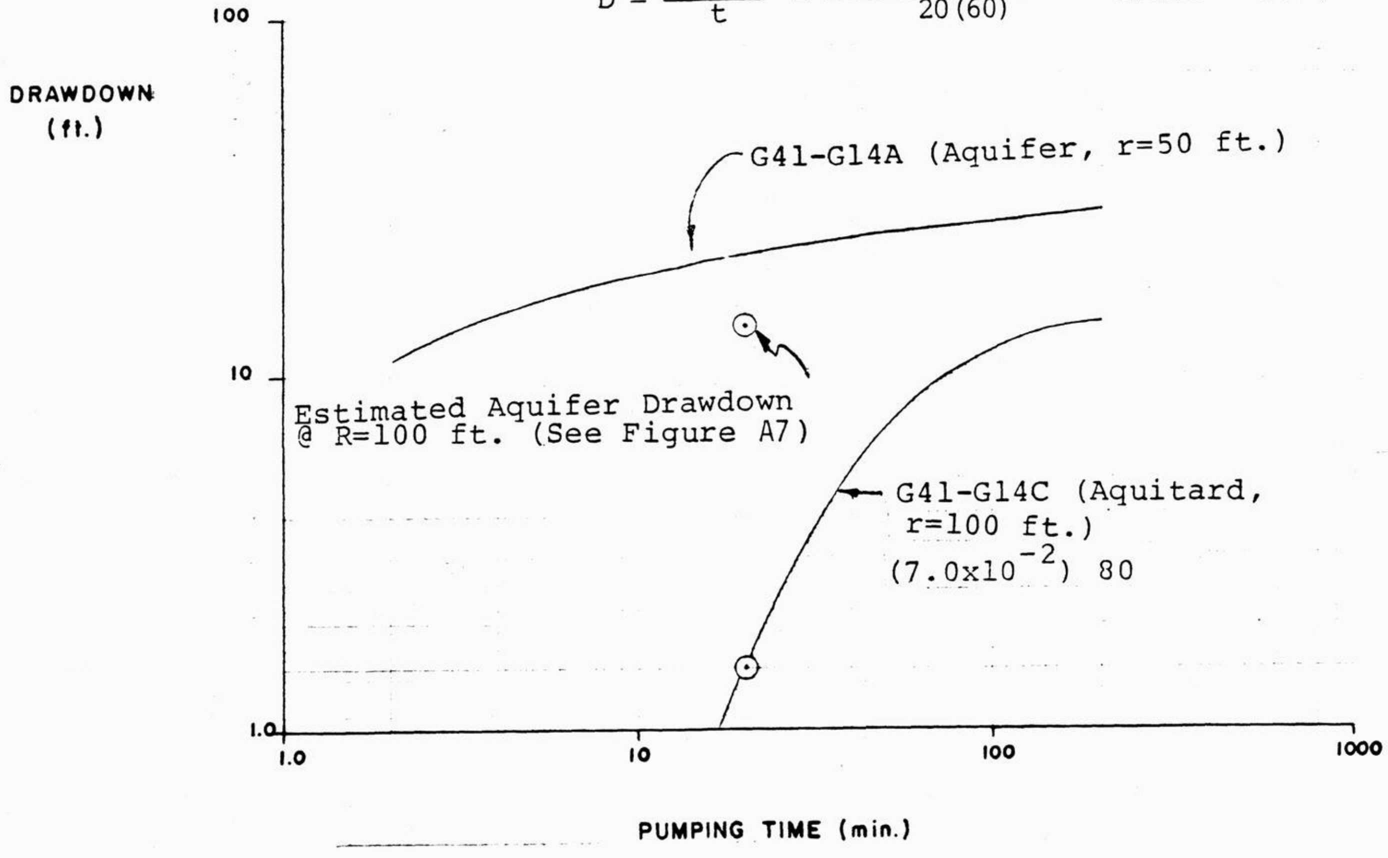
$S_s' = 4.6\text{x}10^{-6}$ ft.$^{-1}$

$$\frac{s'}{s} = .11$$

$$t_D = \frac{Tt}{Sr^2} = \frac{(5\text{x}10^{-2})(20)(60)}{(5.8\text{x}10^{-4})(100^2)} = 10.34$$

$$t_D' = 2.7\text{x}10^{-1}$$

$$D = \frac{t_D' z^2}{t} = \frac{(2.7\text{x}10^{-1})(25^2)}{20(60)} = 1.4\text{x}10^{-1} \text{ ft.}^2/\text{s}$$



$$K_v = DS_s' = (1.4\text{x}10^{-1})(4.6\text{x}10^{-6}) = 6.5\text{x}10^{-7} \text{ ft./s}$$

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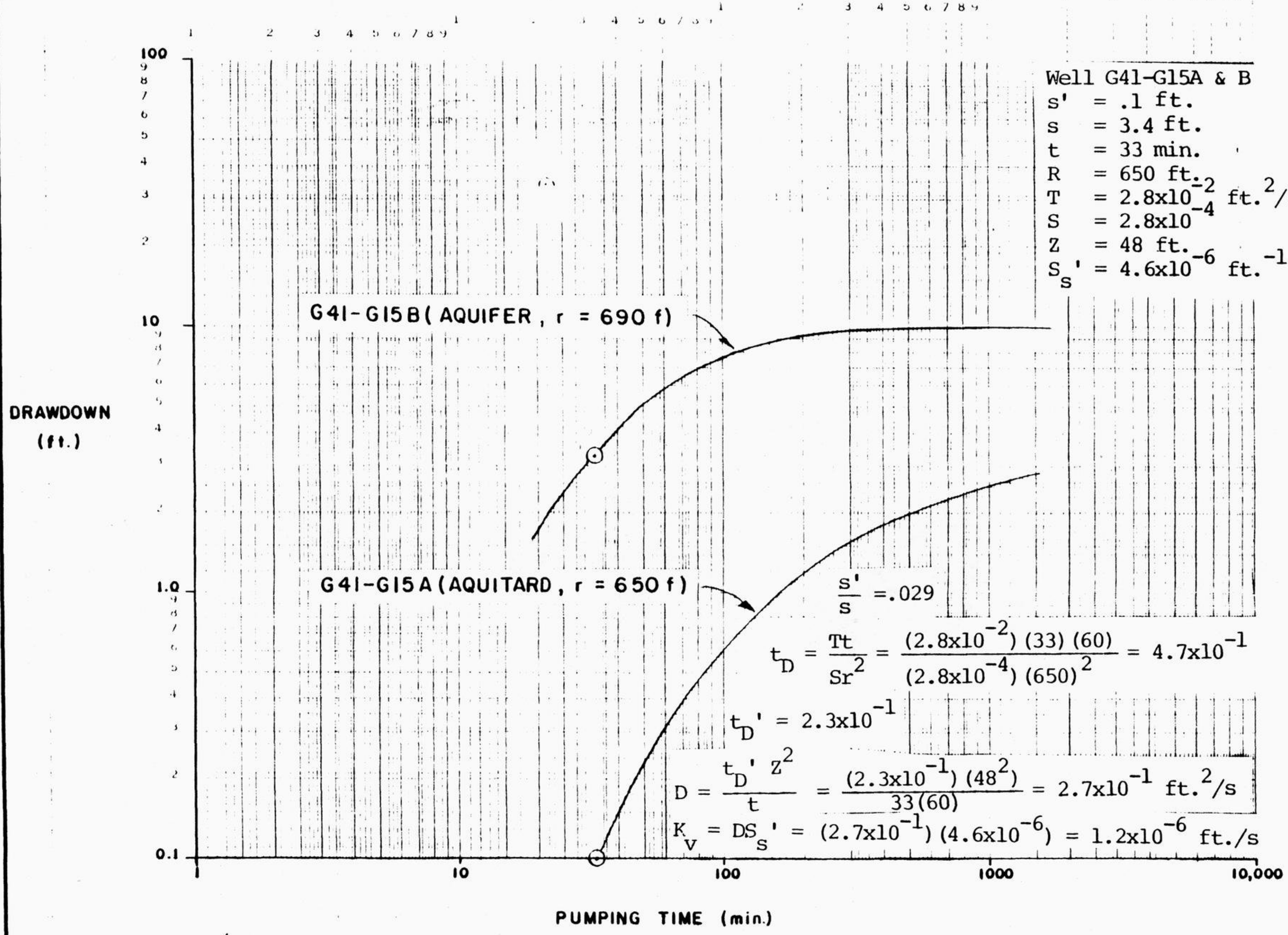
Golder Associates		EXXON MINERALS COMPANY — FIGURE B6



Well G41-G15A & B

$s' = .1$ ft.

$s = 3.4$ ft.

$t = 33$ min.

$R = 650$ ft.

$T = 2.8\text{x}10^{-2}$ ft.^{2}/s

$S = 2.8\text{x}10^{-4}$

$Z = 48$ ft.

$S_s' = 4.6\text{x}10^{-6}$ ft.$^{-1}$

$$\frac{s'}{s} = .029$$

$$t_D = \frac{Tt}{Sr^2} = \frac{(2.8\text{x}10^{-2})(33)(60)}{(2.8\text{x}10^{-4})(650)^2} = 4.7\text{x}10^{-1}$$

$$t_D' = 2.3\text{x}10^{-1}$$

$$D = \frac{t_D' Z^2}{t} = \frac{(2.3\text{x}10^{-1})(48^2)}{33(60)} = 2.7\text{x}10^{-1} \text{ ft.}^2\text{/s}$$

$$K_V = DS_s' = (2.7\text{x}10^{-1})(4.6\text{x}10^{-6}) = 1.2\text{x}10^{-6} \text{ ft./s}$$

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RATIO METHOD ANALYSIS

G41-G15A,B

FIGURE B6

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DISTANCE-DRAWDOWN PLOT AT TIME-20 MINUTES

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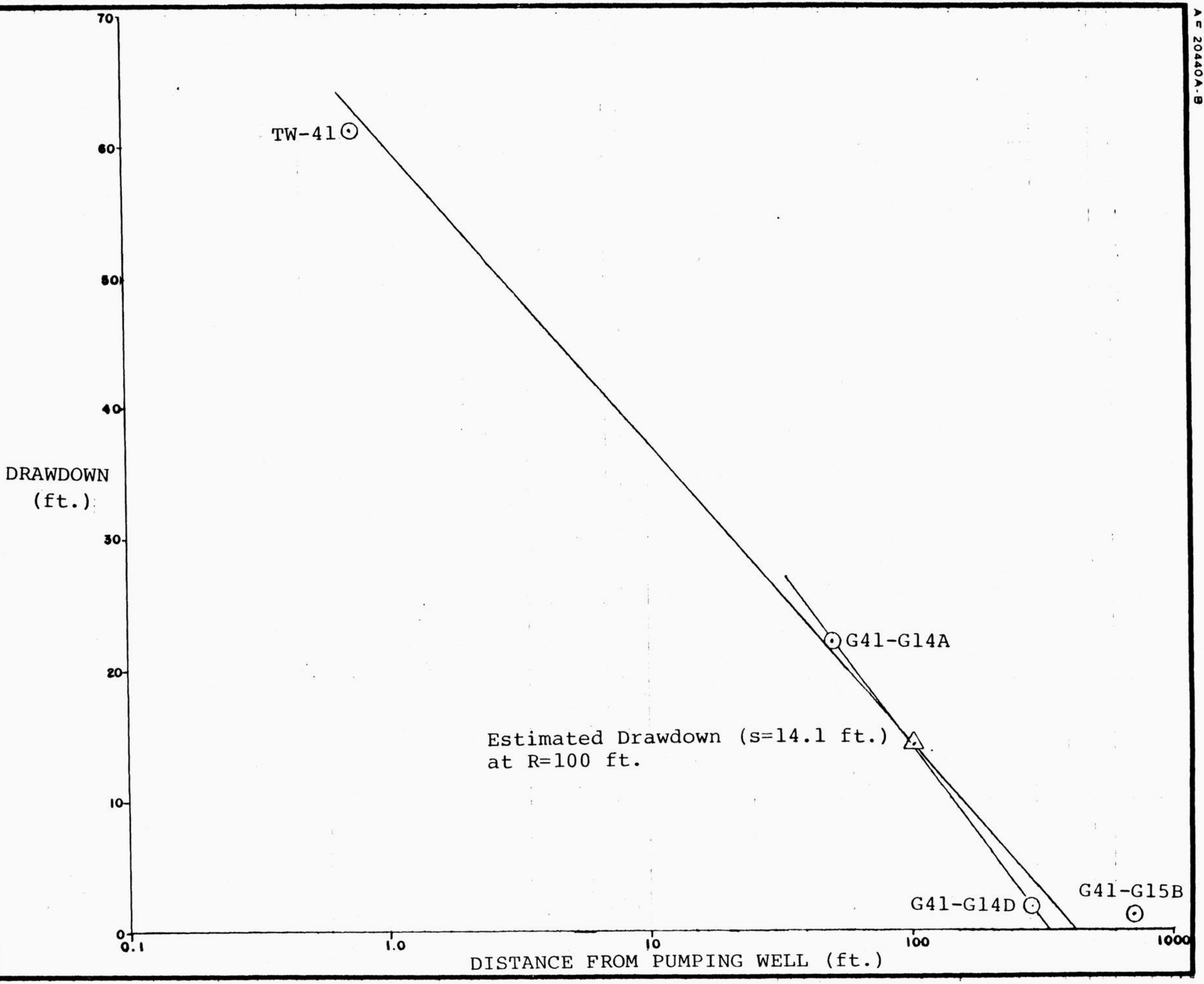
FIGURE B7



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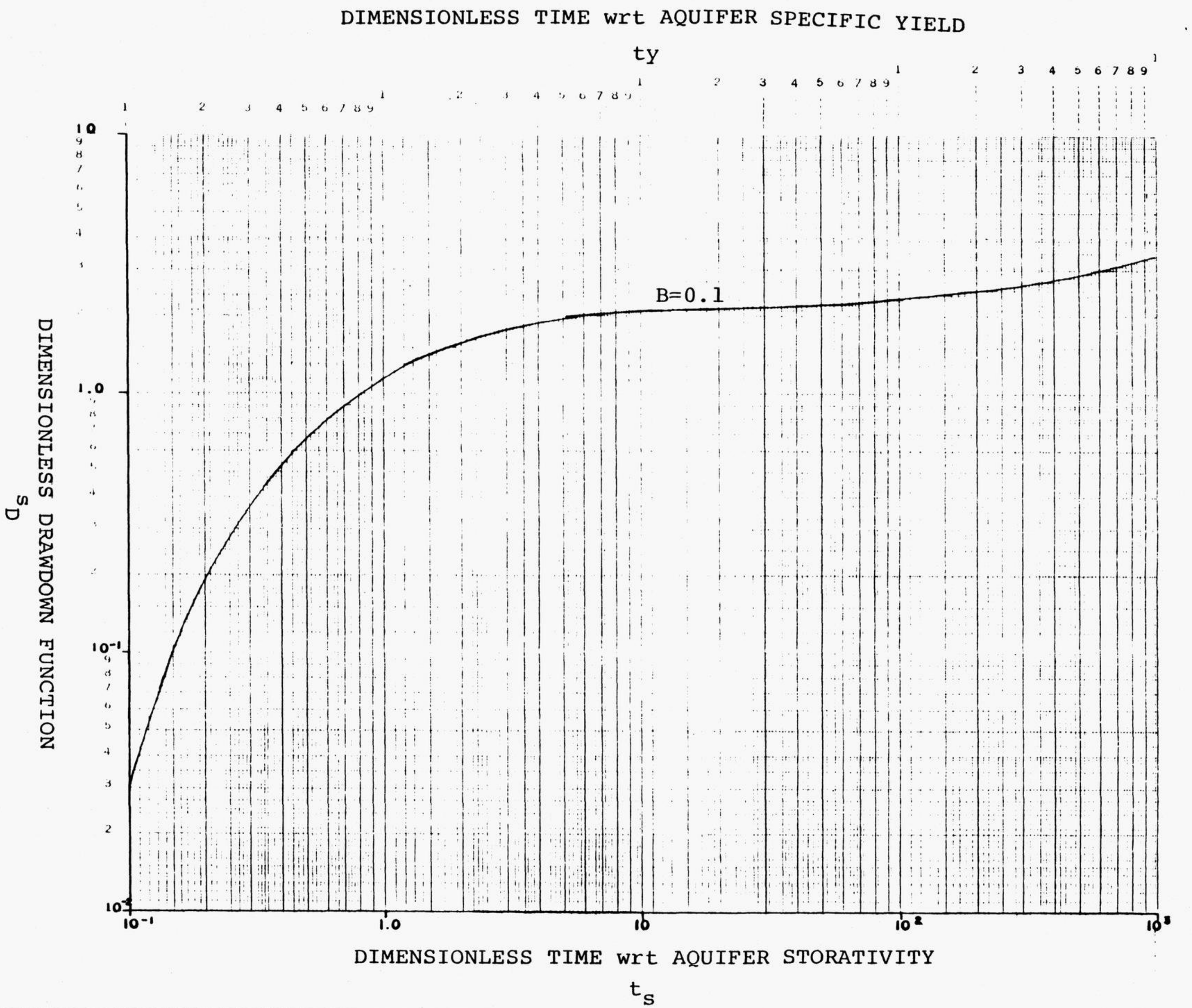

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DELAYED YIELD TYPE CURVE

G41-G14D

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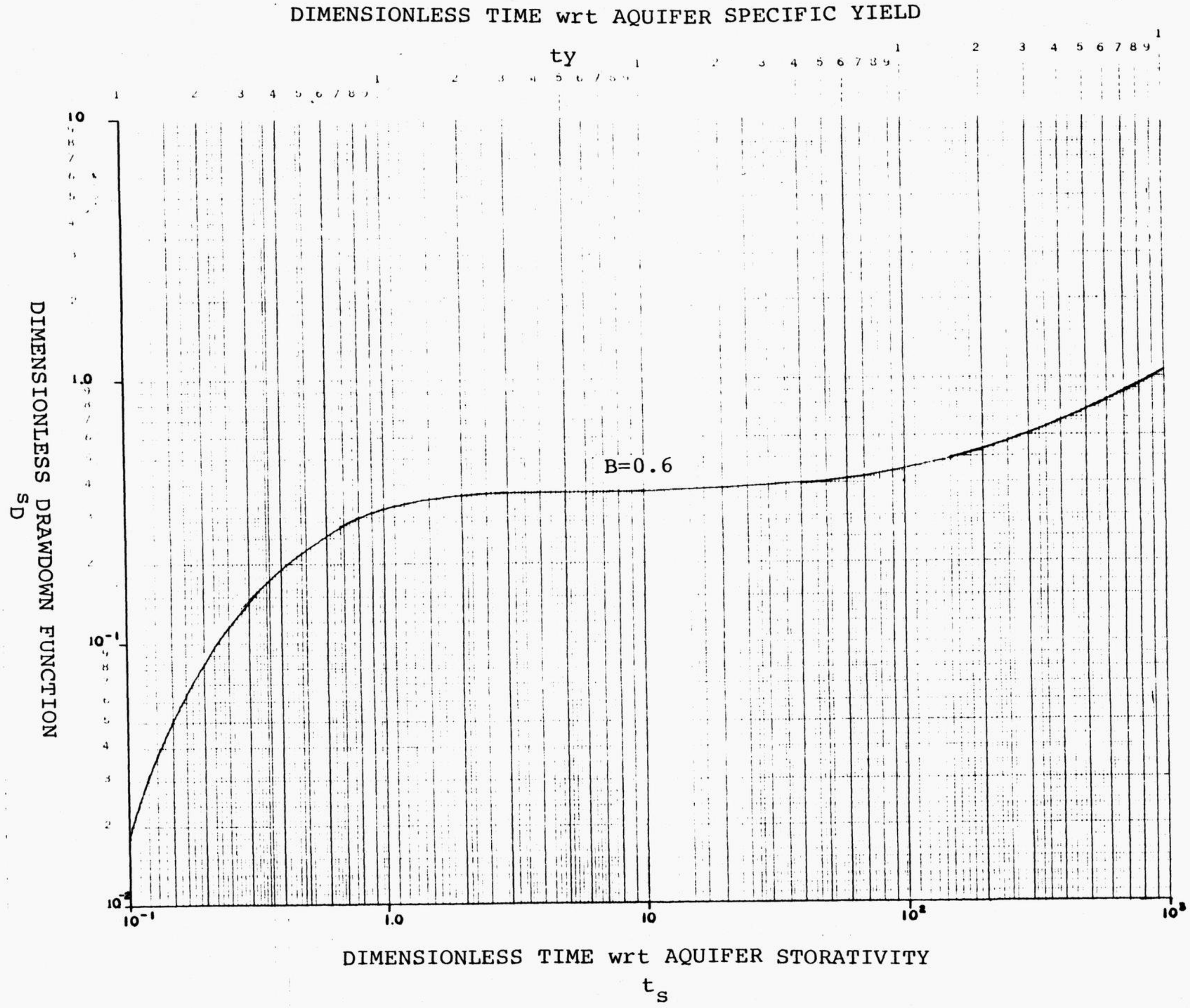
FIGURE B8



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DELAYED YIELD TYPE CURVE

G41-G15B

FIGURE	B9

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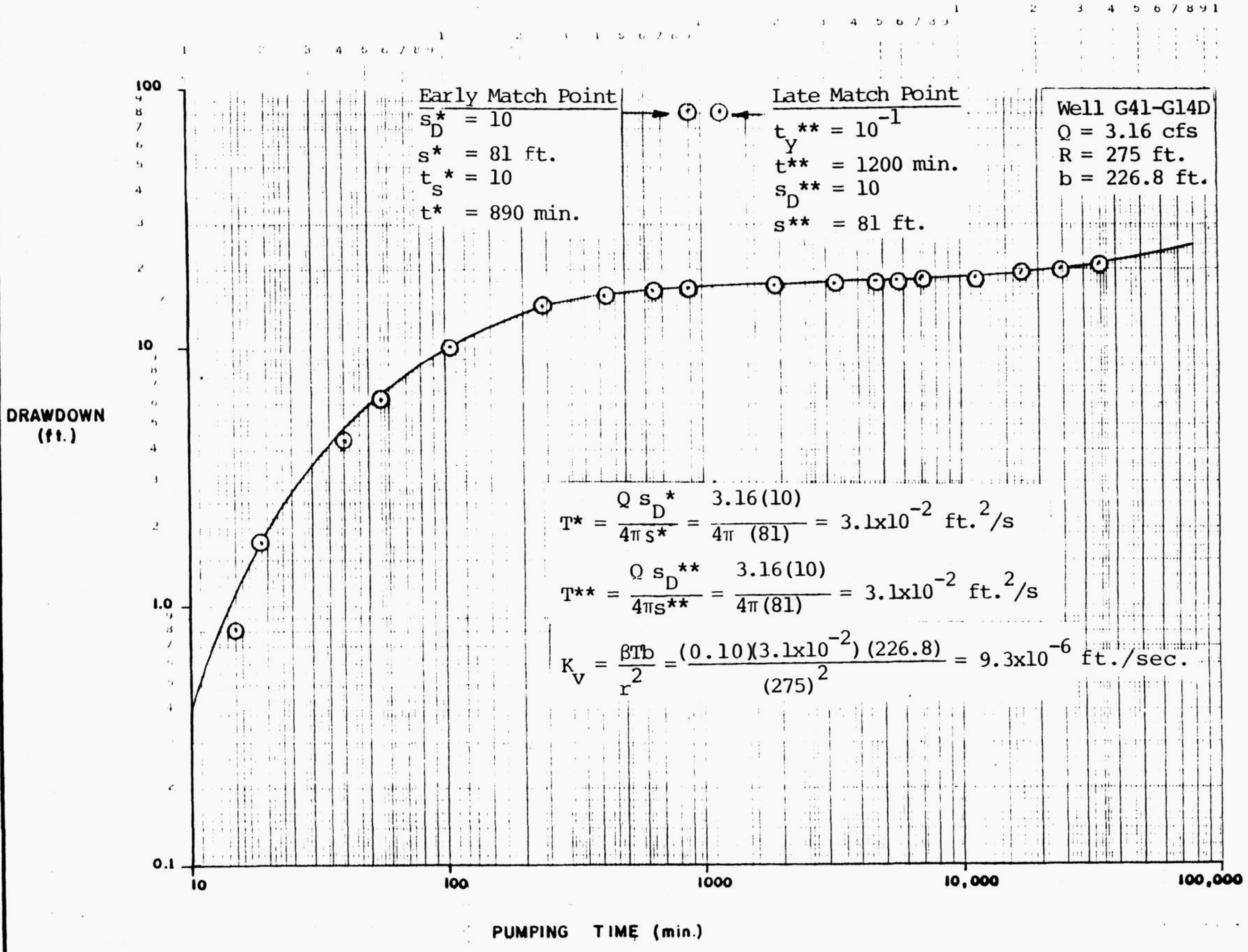


Early Match Point
$s_D^* = 10$
$s^* = 81$ ft.
$t_s^* = 10$
$t^* = 890$ min.

Late Match Point
$t_Y^{**} = 10^{-1}$
$t^{**} = 1200$ min.
$s_D^{**} = 10$
$s^{**} = 81$ ft.

Well G41-G14D
Q = 3.16 cfs
R = 275 ft.
b = 226.8 ft.

$$T^* = \frac{Q\, s_D^*}{4\pi s^*} = \frac{3.16(10)}{4\pi\ (81)} = 3.1\mathrm{x}10^{-2}\ \mathrm{ft.}^2/\mathrm{s}$$

$$T^{**} = \frac{Q\, s_D^{**}}{4\pi s^{**}} = \frac{3.16(10)}{4\pi (81)} = 3.1\mathrm{x}10^{-2}\ \mathrm{ft.}^2/\mathrm{s}$$

$$K_V = \frac{\beta T b}{r^2} = \frac{(0.10)(3.1\mathrm{x}10^{-2})(226.8)}{(275)^2} = 9.3\mathrm{x}10^{-6}\ \mathrm{ft./sec.}$$

Golder Associates

JOB NO. 834-1389
DRAWN SKB
CHECKED JBC
SCALE AS SHOWN
DATE 9-11-84
DWG. NO. 050-1-81139

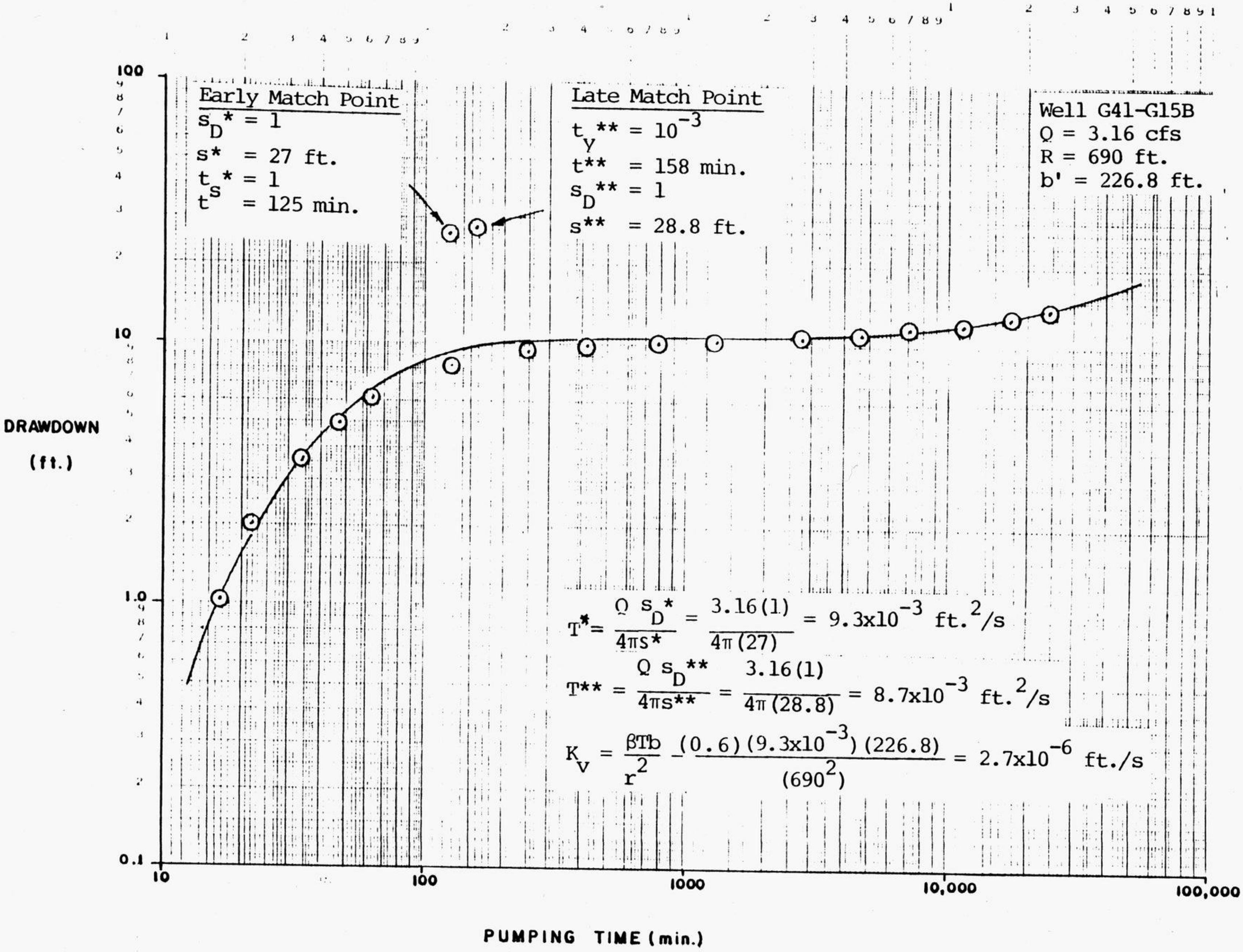
EXXON MINERALS COMPANY

DELAYED YIELD TYPE CURVE ANALYSIS
G41-G14D

FIGURE B10

OZALID DRAFTING MEDIA

AF 20440A-B



Early Match Point

$s_D^* = 1$

$s^* = 27$ ft.

$t_s^* = 1$

$t = 125$ min.

Late Match Point

$t_Y^{**} = 10^{-3}$

$t^{**} = 158$ min.

$s_D^{**} = 1$

$s^{**} = 28.8$ ft.

Well G41-G15B

Q = 3.16 cfs

R = 690 ft.

b' = 226.8 ft.

$$T^* = \frac{Q\ s_D^*}{4\pi s^*} = \frac{3.16(1)}{4\pi(27)} = 9.3\text{x}10^{-3}\ \text{ft.}^2/\text{s}$$

$$T^{**} = \frac{Q\ s_D^{**}}{4\pi s^{**}} = \frac{3.16(1)}{4\pi(28.8)} = 8.7\text{x}10^{-3}\ \text{ft.}^2/\text{s}$$

$$K_V = \frac{\beta T b}{r^2} = \frac{(0.6)(9.3\text{x}10^{-3})(226.8)}{(690^2)} = 2.7\text{x}10^{-6}\ \text{ft./s}$$

Golder Associates

JOB NO. 834-1388

DRAWN SKB

CHECKED

SCALE AS SHOWN

DATE 9-11-84

DWG. NO. 050-1-81137

EXXON MINERALS COMPANY

DELAYED TYPE CURVE ANALYSIS

G41-G15B

FIGURE B11