HYDROGEOLOGIC ASSESSMENT AT SAUKVILLE, WISCONSIN
MUNICIPAL WELLS PUMP TESTS AND LAUBENSTEIN WELL PACKER PUMP TESTS

OFFICE COPY
JAN 14 1985

Prepared for

Freeman Chemical Corporation
Port Washington, Wisconsin

Prepared by

Olver Incorporated
Consulting Engineers and
Environmental Laboratories

1531 North Main Street
Blacksburg, Virginia 24060

January 10, 1985

AMERICAN INSTITUTE OF PROFESSIONAL GEOLOGISTS
CERTIFICATE NUMBER
6217
AIPG
JAMES W. DAWSON

JAN 14 1985

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

As part of the hydrogeologic assessment at Saukville, Wisconsin, Freeman Chemical Corporation conducted pump tests of the municipal water supply wells for the Village of Saukville and performed a packer pump test in the Laubenstein well. The municipal water supply well pump tests and the Laubenstein well packer pump tests were conducted to:

1. Verify the nature of the shallow and deep aquifers (i.e., water table and confined);

2. Identify the aquifer characteristics of transmissivity and storage coefficient;

3. Delineate the relationship between the shallow and deep aquifers;

4. Assess the contamination potential for the municipal water supply wells; and

5. Provide necessary hydrogeologic data to permit development of remedial action plans and an aquifer rehabilitation program to mitigate the effects of contaminated ground water in the vicinity of the Freeman Chemical Corporation plant site.

HYDROGEOLOGIC SETTING

Figure 1 indicates the locations of the municipal wells, the Laubenstein well, and the Freeman Chemical Corporation plant site, while Appendix I is a more detailed map of the study area which also indicates piezometer locations. As review of Figure 1 indicates, the Milwaukee River runs approximately north to south through the study area, and all wells involved in the pump tests, with the exception of Municipal Well No. 3, lie to the west of the river.

Review of the geologic literature indicates that surficial units are comprised of Pleistocene glaciofluvial drift deposits of Woodfordian age, which

HYDROGEOLOGIC ASSESSMENT
AT
SAUKVILLE, WISCONSIN

LOCATION MAP

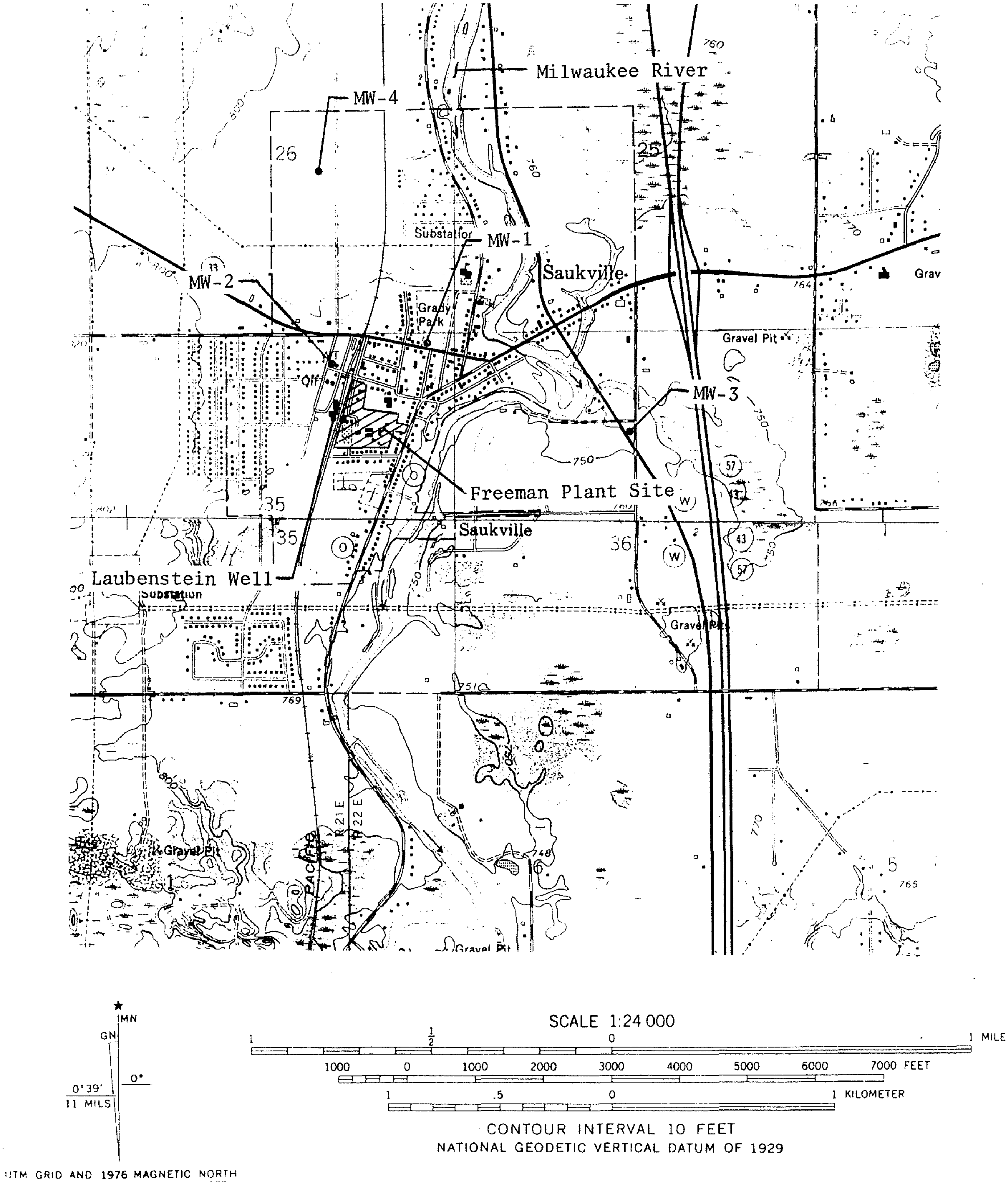


Figure 1

OLVER
INCORPORATED

are underlain by the Niagara dolomite of Silurian age (Lasca, 1970). Previous geologic studies in the Cedarburg-Saukville area (Mulica, 1973; Wilder, 1973; Wierman, 1979; and, Leischer, 1980) indicate that the glacial drift unit is heterogeneous both vertically and horizontally. Typical statigraphy for the unit consists of a sand layer (average thickness 30 feet), underlain by a clay layer (average thickness 14 feet), which in turn is underlain by a hardpan (average thickness 12 feet), and underlain by a weathered dolomite (average thickness 2 feet), with competent bedrock comprised of the Niagara dolomite (Wilder, 1973). The surficial deposits in the vicinity of the Freeman Chemical Corporation plant site in Saukville are substantially thinner than the sequence described by previous investigators, but the general sequence of the units in the glacial drift deposit remains the same. Soil borings in the study area indicate that the glacial drift unit is comprised of a black, clay or silty clay topsoil, underlain by a yellowish-brown sand, which is underlain by a gray and maroon clay or silty clay unit (identified as hardpan in parts) with stringers of silt, sand and gravel, underlain by dolomite.

Ground water encountered during the soil borings indicates that the sand layer in the glacial drift unit is present under water table conditions. Piezometers constructed into the dolomitic bedrock, in conjunction with review of drawdown data from the deep wells in the Niagara dolomite, indicate that the deep aquifer is present under partially confined conditions. The gray and maroon clay or silty clay material is probably the confining bed for the dolomitic aquifer and this bed averages approximately 15 feet in thickness. As described by Devaul (1967) and Wilder (1973), some interconnection between the glacial drift deposits and the dolomitic bedrock aquifer exists. The municipal well pump tests confirm that some interconnection is present throughout most of the study area, although the degree of this interconnection varies from location to location. The bedrock aquifer is in irregular (unconformable) contact (Wierman, 1979), as confirmed by the soil borings previously conducted on the site, which lends further complexity to the hydrogeology of the study area. However, as indicated by previous geologic studies (Wilder, 1973) and on-going investigations in the study area, hydraulic interconnection between the shallow and deep aquifers is limited by the basal clay or silty clay unit. As confirmed by geotechnical borings, the basal caly or silty clay unit is continuous throughout the study area. Variations in aquifer characteristics are related, in part, to facies changes in this surficial unit, fracture and joint patterns, and solutionization, in the dolomitic aquifer.

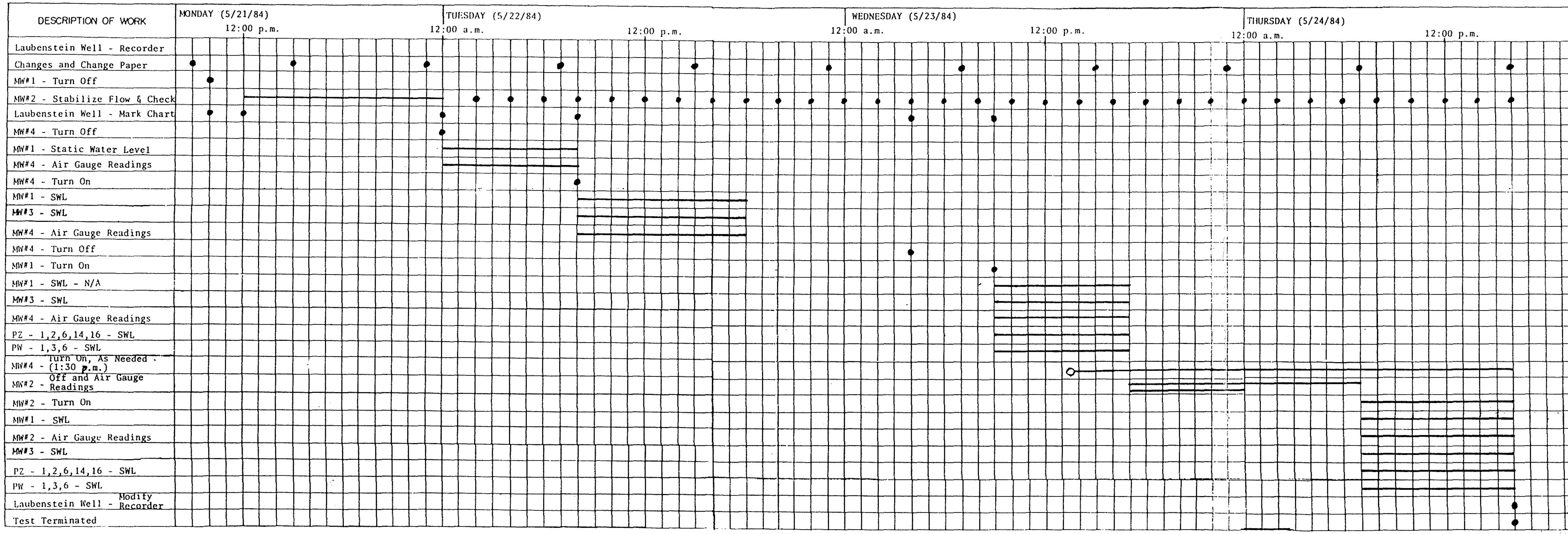
Piezometer nests installed in the vicinity of the plant site (see Appendix I) indicate a vertical ground water gradient in the vicinity of PZ-2/3 and PZ-7/8, with a minimal gradient (i.e.,approximately horizontal) in the vicinity of PZ-10/11. Information from the piezometers indicates that the ground water gradient is to the east, with ground water in the shallow aquifer discharged to the Milwaukee River. Based on pump test data, a portion of the ground water in the deep aquifer may discharge to the Milwaukee River, but the regional ground water discharge point is undoubtedly Lake Michigan. The degree to which the Milwaukee River is connected with the deep aquifer has not been determined, although data collected during the study indicates that some interconnection between the river and the dolomitic aquifer exists.

To facilitate design of the pump test program and evaluation of the data from those tests, an ideal aquifer configuration was determined. For purposes of data analysis, it was assumed that the hydrogeologic setting in the Saukville area consists of the deep, dolomitic aquifer with an average thickness of 450 feet, overlain by a confining bed comprised of clay and silty clay with an average thickness of 15 feet, which is overlain by a water table aquifer with an average thickness of 7 feet. Both the shallow and deep aquifers were considered to be horizontal, areally extensive, homogeneous, and anisotropic. Based on the geology of the area, it was assumed that vertical leakage through the confining bed occurs uniformly throughout the study area.

MUNICIPAL WELLS PUMPING TESTS

To determine the aquifer characteristics in the study area, a series of pump tests involving the Village of Saukville municipal wells was conducted and included pumping of individual municipal wells, with drawdown observations taken in other municipal wells, private water wells, and piezometers installed in the vicinity of the Freeman Chemical Corporation plant site (see Figure 1 and Appendix I for locations of wells and piezometers). Initial pump test scenarios for the program are presented in Appendix II, while a record of the actual test schedule is presented as Figure 2 and indicates pertinent information regarding these tests. The municipal wells pumping tests were conducted during the period of May 21-24, 1984. Flow measurements from pumping wells were taken with totalizing flow recorders, while drawdown measurements were conducted with chalked steel tapes, a continuous water level recorder (Laubenstein well), air line pressure gauges, and electronic water level detectors.

Field data was reduced to permit construction of logarithmic and semilogarithmic plots of the data, depending upon the analytical method used to interpret the field information. Three analytical techniques were employed to evaluate the pump test data: (1) the Hantush-Jacob Method; (2) the Hantush Modified Method; and (3) the Jacob-Lohman Method. Drawdown data from the observation wells were evaluated using the Hantush-Jacob and the Hantush Modified methods, while the Jacob-Lohman Method was employed for evaluation of drawdown data from pumping wells only. The Hantush-Jacob and Hantush Modified methods employ a curve matching technique, as developed by Theis (1935). The type curves used for the Hantush-Jacob Method are plots of L(u,v) vs. 1/u prepared by Cooper (1963, Plate 4), while the type curves for the Hantush Modified



LEGEND:

Isolated activity ●

Continuous activity ———

Time of isolated activity variable ○

Air Line		
	MW-4	110
	MW-3	300
	MW-2	280
	MW-1	250

OLVER INCORPORATED Consulting Engineers • Environmental Laboratories 1531 NORTH MAIN STREET BLACKSBURG, VIRGINIA 24060 (703) 552-5548	Designed	Scale N/A	FREEMAN CHEMICAL CORPORATION SAUKVILLE, WISCONSIN	Rev.	Description	Date	By	MUNICIPAL WELLS PUMPING TESTS SCHEDULE	Drawing No. FIGURE 2
	Drawn	Job No. 10519							
	Checked	Date 4/25/84							

Method are logarithmic plots of $H(u,\beta)$ vs. u, as presented in Lohman (1972). Logarithmic and semi-logarithmic plots of the drawdown data collected during the municipal wells pumping tests are presented in Appendix III, as is the match point information for each of those plots. Governing equations for each of the analytical methods employed and other information are presented in Table I, while a summary of the aquifer characteristics determined by the tests are presented in Table II.

Review of Table II indicates the range of values for transmissivity and storage coefficient that were determined as a result of the municipal wells pumping tests. Variations in the values determined can be attributable to a variety of factors, as indicated below.

1. Inaccurate field data caused by interferences in the observation well or other factors could appreciably affect plots utilized for the analysis. Further, the nature of the equipment utilized to determine water level measurements in the field can significantly affect the accuracy of those measurements. For example, water level measurements in Municipal Well No. 2 were collected utilizing an air line pressure gauge, which is only accurate to the nearest one-half foot. Specifically, the analyses of MW-2 drawdown data collected during constant discharge tests for MW-1 and MW-4 appear to be low when compared to the analyses of data from other wells. It should be noted that during both of these tests, an air line pressure gauge was utilized to collect drawdown information and further, Municipal Well No. 2 was operational at the time the data was collected. The fact that MW-2 was pumping, could contribute additional uncertainty to the accuracy of the water level measurements collected in that well. Water level measurements in the other wells were collected utilizing a chalked steel tape or, in the case of the Laubenstein well, a continuous water level recorder was employed, which would provide an accuracy to within 0.01 feet, or 0.10 feet, respectively.

TABLE I

GOVERNING EQUATIONS AND PERTINENT INFORMATION FOR
PUMP TEST DATA EVALUATION

HANTUSH-JACOB METHOD

$$T = \frac{Q}{4\pi s} L(u,v) \qquad S = 4T \frac{t/r^2}{1/u} \qquad \frac{K'}{b'} = 4T \frac{v^2}{r^2} = \frac{S\left(\frac{v^2}{u}\right)}{t}$$

where,

T = Transmissivity $[L^2/T]$
Q = Flow $[L^3/T]$ from well
s = Drawdown [L]
S = Storage Coefficient [dimensionless]
t = Time [T]
r = Distance of observation well to pumping well [L]
K' = Hydraulic conductivity of confining bed [L/T]
b' = Thickness of confining bed [L]
L (u,v) = Leakance function of u and v
$u = r^2S/4Tt$
$v = \frac{r}{2}\sqrt{\frac{K'}{b'T}}$

HANTUSH MODIFIED METHOD

$$T = \frac{Q}{4\pi s} H(u,\beta) \qquad S = \frac{4Ttu}{r^2} \qquad \beta = \frac{r}{4b}\left(\sqrt{\frac{K'Ss'}{KSs}} + \sqrt{\frac{K''Ss''}{KSs}}\right)$$

where,

K = Hydraulic conductivity of main aquifer [L/T]
K', K" = Hydraulic conductivity of semipervious confining layer(s) [L/T]
Ss, Ss', Ss" = Specific storage (storage coefficient per vertical unit of thickness) of the main aquifer and confining layer(s) (b, b' and b"), respectively (e.g., Ss = S ÷ b)
b = Thickness of aquifer
Other variables as described above.

TABLE I, Continued

JACOB-LOHMAN METHOD

$$T = \frac{2.30}{4\pi\,\Delta(s_w/Q)/\Delta\log_{10}t/r_w^2}$$

$$S = \frac{2.25\ Tt/r_w^2}{\log_{10}^{-1}\left[\frac{(s_w/Q)}{\Delta(s_w/Q)}\right]}$$

where,

s_w = Drawdown in pumping well [L]
r_w = Effective radius of pumping well [L]
Other parameters as defined above.

Source: Lohman (1972)

PERTINENT INFORMATION

MW-1: $Q = 20{,}600\ ft^3/day$

Distance to:		
	MW-2	= 1500 ft.
	MW-3	= 3250 ft.
	MW-4	= 2975 ft.
	Laubenstein	= 1800 ft.

MW-2: $Q = 38{,}800\ ft^3/day$

Distance to:		
	MW-1	= 1500 ft.
	MW-3	= 4525 ft.
	MW-4	= 2840 ft.
	Laubenstein	= 760 ft.

MW-4: $Q = 167{,}800\ ft^3/day$

Distance to:		
	MW-1	= 2975 ft.
	MW-2	= 2840 ft.
	MW-3	= 5950 ft.
	Laubenstein	= 3600 ft.

TABLE II

HYDROGEOLOGIC ASSESSMENT AT SAUKVILLE, WISCONSIN
MUNICIPAL WELLS PUMP TEST SUMMARY

TEST DATE	TEST TYPE[1]	PUMP. WELL	ANALYTICAL METHOD[2]	OBSERVATION WELL(S)	T (ft^2/day)	S	β
5/23	C.D.	MW-1	H-M	MW-3[3]	685	2.0×10^{-5}	1
5/23	C.D.	MW-1	H-M	LAUBENSTEIN	195	1.7×10^{-8}	30
5/23*	REC.	MW-1	H-M	LAUBENSTEIN	140	1.5×10^{-8}	15
5/23	C.D.	MW-1	H-J	MW-2&3, LAUB.	230	1.7×10^{-5}	N/A
5/23	REC.	MW-2	J-L	MW-2	510	1.3×10^{-6}	N/A
5/23	REC.	MW-2	H-M	LAUBENSTEIN	540	1.5×10^{-5}	1.5
5/24	C.D.	MW-2	J-L	MW-2	460	2.7×10^{-4}	N/A
5/24	C.D.	MW-2	H-M	MW-1	1100	1.5×10^{-4}	0.3
5/24	C.D.	MW-2	H-M	LAUBENSTEIN	520	5×10^{-7}	7
5/24	C.D.	MW-2	H-J	MW-1, LAUB.[3]	2220	8.1×10^{-6}	N/A
5/22	REC.	MW-4	H-M	MW-1	1908	1.5×10^{-7}	1.5
5/22	C.D.	MW-4	J-L	MW-4	4400	5.5×10^{-6}	N/A
5/22	C.D.	MW-4	H-M	MW-3	4250	8.5×10^{-5}	0.7
5/22	C.D.	MW-4	H-M	MW-1	1750	8.5×10^{-7}	1
5/22	C.D.	MW-4	H-M	LAUBENSTEIN	950	1.4×10^{-7}	20
5/22	C.D.	MW-4	H-J	MW-1&3, LAUB.	4450	1×10^{-6}	N/A
5/23	REC.	MW-4	H-M	MW-1	1760	1.3×10^{-6}	0.7
5/23	REC.	MW-4	H-M	LAUBENSTEIN	1650	1.3×10^{-6}	7
5/23†	C.D.	MW-4	H-M	LAUBENSTEIN	920	4.0×10^{-5}	0.5
5/23†	C.D.	MW-4	H-M	MW-2	290	2.1×10^{-5}	0.5

NOTES:

1) C.D. = Constant Discharge / REC. = Recovery
2) H-M = Hantush Modified / H-J = Hantush-Jacob / J-L = Jacob-Lohman
3) Questionable, due to encountering possible recharge boundary (Milwaukee River)

T = Transmissivity (ft^2/day)
S = Storage Coefficient (dimensionless)
β = See Table I (dimensionless)

*Determined from record of MW-2 Recovery Test.
†Determined from record of MW-1 Pump Test.

OLVER INCORPORATED

2. Influences from pumping wells may provide an erroneous evaluation of the data. For example, the values for transmissivity and storage coefficient determined for MW-1 which were measured during the MW-2 recovery tests may be influenced by pumping from MW-4, which was operational during the MW-2 recovery test. Since MW-4 would contribute drawdown to the Laubenstein well, the determined values for transmissivity and storage coefficient for MW-1 during the MW-2 recovery test may not be the same as the values that would have been determined if MW-4 were not operational.

3. The curve matching technique employed and the plots of the drawdown data for each well are subject to some interpretation. The curve matching technique involves matching theoretical type curves ($H(u,\beta)$ vs. u for Hantush Modified Method, $L(u,v)$ vs. $1/u$ for Hantush-Jacob Method) to observed data plots (s vs. t for Hantush Modified Method, s vs. t/r^2 for Hantush-Jacob Method). When a best-fit match is made, match point information is determined from the graphs and utilized in solving the respective governing equations presented in Table I. When performing the actual curve matching operation, some variation in determining the match points will occur, depending upon the closeness of fit of the observed values to the theoretical type curves. While not appreciable, differences in the selection of the match points can account for some variation in determined values for transmissivity and storage coefficient.

4. Differences between assumed and actual aquifer characteristics will account for some of the variations noted for transmissivity and storage coefficient. Depending upon the degree of anisotropy and heterogenaity within the aquifer, values for transmissivity and storage coefficient will vary from point to point. For example, due to fracturing and solutionalization within the dolomite aquifer, it is reasonable to assume that transmissivity within the aquifer is not constant in all directions and consequently, variation in the

values of transmissivity and storage coefficient, with direction, will occur (i.e., the aquifer as anisotropic). However, the bedrock formation is fairly homogeneous, due to the fact that the Niagara dolomite is a consistent carbonate unit which occurs in southeastern Wisconsin. The degree and nature of fractures or solution cavities within the dolomite aquifer and the extent to which each well intersects those features, imparts anisotropy to the aquifer and will affect the values of transmissivity and storage coefficient determined from the pump tests.

5. The degree to which the aquifer is at steady state condition at the start of each pump/recovery test will affect the values of transmissivity and storage coefficient determined from each test. Corrections for residual drawdown have been made for some of the data plots of the various wells, for which that information could be determined. However, residual drawdown corrections were not possible for all of the tests (notably MW-2 constant discharge test).

As described above, several factors can affect the accuracy of the values of transmissivity and storage coefficient determined from the pump tests. One additional factor regarding the Laubenstein well must be noted: drawdown values determined in that well may be somewhat suspect, since there is an indication that water from the glacial drift aquifer may be entering the Laubenstein well due to leakage around the casing (see Caliper Log, Appendix IV). This possibility would have the effect of reducing the observed drawdown, thereby providing values of transmissivity and storage coefficient that are somewhat greater than the actual values.

In light of the above factors, some of the values presented in Table II can be disregarded, while others are more representative of aquifer characteristics. As discussed in a later section, comparison of observed to theoretical drawdown data is used to determine values of transmissivity and storage coefficient that are more representative of the aquifer.

LAUBENSTEIN WELL PACKER PUMP TESTS

To determine the characteristics of the Laubenstein well (PW-8 in Appendix I), packer pump tests were conducted in the well during the period July 16-24, 1984. In general, the tests involved isolating a suspected production zone in the well with pneumatic packers, pumping the zone at a constant rate, and measuring drawdown levels in observation wells and piezometers. Selection of the suspected production zones to be pumped was based on evaluation of borehole geophysical surveys conducted in the well. Copies of these surveys are presented in Appendix IV, and indicate that the most likely production zones are at depths of 340 feet to the bottom of the well, 280 to 330 feet, 190 to 240 feet, and 30 to 80 feet. Each zone was to be pumped for a period of six hours, with drawdown data collected in different municipal wells, private wells, and piezometers installed in the vicinity of the Freeman Chemical Corporation plant site. During the pumping of each zone, water quality samples were collected from the discharge line at an approximate interval of one sample every 15 minutes for the first hour of the test, followed by sample collection at 30-minute intervals thereafter. The samples were analyzed for the organic contaminants of interest for the study, with a composite value for Chemical Oxygen Demand (COD) to be determined from the aggregate samples collected.

During the tests, difficulties were encountered which required alteration of the initial pump test schedule. These problems included: (1) the top packer for the test of the 280-330 foot zone "blew out," which necessitated pulling of the pump, replacing the packer, and resetting the pump string to a depth of 270-320 feet; (2) the zone 190-240 feet had insufficient water, which required movement of the pump string to a depth of 140 to 190 feet; (3) the zone 140-190 feet had insufficient water, which required moving the pump string to pump the uppermost 140 feet of the well; and (4) the uppermost 140 feet of the well had insufficient water for the capacity of the pump utilized in the test, which necessitated pulling the pump string and using a smaller capacity pump to test the uppermost 140 feet of the well.

Drawdown measurements from the observation wells were utilized to construct plots of drawdown versus time, as presented in Appendix V. A curve matching technique was employed (Hantush Modified and Hantush-Jacob methods) to evaluate these plots (see Table I for governing equations and Table III for pertinent information). Based on the curve matching technique developed by Theis (1935), values of transmissivity and storage coefficient for each zone evaluated during the packer pump tests were determined and are summarized in Table III.

During the packer pump tests, water quality samples were collected from the pump discharge line for determination of selected organic contaminants. Samples were collected approximately every 15 minutes for the first hour of the test, and then at approximate 30-minute intervals thereafter. Analyses of selected samples for organic contaminant concentration were conducted and are presented in Appendix VI. As review of this data indicates, organic contaminant concentration decreases with increased depth in the well and with increased pumping times.

As review of Table III indicates, values of transmissivity and storage coefficient are different for each zone pumped and the direction of the observation point from the Laubenstein well. As discussed previously, this is to be expected due to the anisotropic nature of the aquifer as related to the pres-

TABLE III

LAUBENSTEIN WELL PACKER PUMP TEST SUMMARY
AND PERTINENT INFORMATION

TEST DATE	PACKER SETTING	OBSERVATION WELL	T (ft^2/day)	S	β
7/16/84	340' - BOT	MW-1	213.7 = 215	1.83×10^{-7}	1.5
7/17/84	280 - 330	MW-1	481.89 = 480	1.69×10^{-6}	5.0
7/17/84	N/A	(MW-4 CUT ON) MW-1	3297 = 3300	3.2×10^{-5}	0.7
7/17/84	280 - 330	MW-2	437.39 = 440	4.66×10^{-7}	5.0
7/17/84	N/A	(MW-4 CUT ON) MW-2	8614.9 = 8615	1.75×10^{-5}	3.0
7/18/84	270 - 320	MW-1	200.93 = 200	2.78×10^{-7}	1.5
7/18/84	270 - 320	MW-2	459.28 = 460	2.1×10^{-6}	3.0
7/18/84	N/A	(MW-4 CUT ON) MW-2	4768.96 = 4770	1.56×10^{-4}	0.3
7/24/84	<140	PZ-6	40.13 = 40	4.15×10^{-6}	15

WELL YIELD

ZONE: 340' - BOT, Q = 12,890 ft^3/day
ZONE: 280' - 330', Q = 6,540 ft^3/day
ZONE: 270' - 320', Q = 4,040 ft^3/day
ZONE: <140', O = 580 ft^3/day

DISTANCES

LAUBENSTEIN TO: MW-1 = 1800 ft.
MW-2 = 760 ft.
PZ-6 = 180 ft.

MW-2 to MW-4 = 2840 ft.

MW-1 to MW-4 = 2975 ft.

ence of fractures and solution cavities within the dolomite. However, as discussed in the previous section, it is possible to evaluate this data and determine average values for transmissivity and storage coefficient, which are presented in a later section.

At the conclusion of the packer pump tests in the Laubenstein well, a single pneumatic packer was set at a depth of 80 feet and a continuous water level monitoring device was installed in the well. The purpose of this packer was to isolate the uppermost portion of the aquifer (less than 80 feet) and to measure changes in water levels in the well, as those changes may be related to pumping of the Village of Saukville municipal wells. The record of water level fluctuations in the Laubenstein well after installation of the packer is presented in Appendix VII, and indicates that fluctuations do occur in response to pumping from Municipal Well No. 2 and (possibly) Municipal Well No. 4. The fact that water level fluctuations occur in the Laubenstein well, even though the uppermost portion of the well is isolated from the deeper zones, indicates that the uppermost and lower portions of the dolomite aquifer are interconnected.

DISCUSSION

The pump tests conducted in the Village of Saukville municipal wells and in the Laubenstein well are valuable tools for determining aquifer characteristics of transmissivity and storage coefficient and can be interpreted to evaluate the leakage through the overlying glacial drift deposits into the dolomite aquifer. However, use of the values determined from the pumping tests must be tempered with a realization of the conditions and assumptions under which the tests were conducted. The theoretical data plots to which the actual drawdown plots were compared are based on certain aquifer assumptions which may or may not (and usually are not) consistent with actual field conditions. As stated by Theis (1935) and presented by Lohman (1972), the constant discharge tests involve the following assumptions: (1) the aquifer is homogeneous and isotropic; (2) the water body has infinite areal extent (in a practical sense, its boundaries are beyond the discharging well in the time considered); (3) the discharging well penetrates the entire thickness of the aquifer; (4) the well has an infinitesimal diameter (of no practical significance for pumping tests longer than a few minutes); and (5) the water removed from storage is discharged instantaneously with the decline in head.

The extent to which the actual aquifer correlates to the assumed conditions will affect the values of transmissivity and storage coefficient determined from the pumping tests. As presented earlier, the hydrogeologic setting in the Saukville area was modeled as a two-aquifer system consisting of a semi-confined, bedrock aquifer, overlain by a confining bed composed of clay or silty clay, and overlain by an unconfined aquifer consisting of sand. Additionally, it was assumed that aquifer boundaries were not encountered during the pumping tests, although the Milwaukee River (a potential recharge/discharge boundary) lies between one of the observation wells (MW-3) and the discharging wells.

The pump test conditions which probably have the greatest effect on the accuracy of the values of transmissivity and storage coefficient determined from the tests are: (1) the aquifer is homogeneous and isotropic; (2) the discharging well penetrates the entire thickness of the aquifer; and (3) the steady state condition of the aquifer at the start of each pump test. The Niagara Formation is a consistent carbonate unit which occurs in southeastern Wisconsin and can be characterized as fairly homogeneous. However, the extent of jointing, fracturing, and solutionization of the bedrock varies with location in the aquifer. The predominance of ground water storage and flow in the bedrock aquifer occurs in fractures and solution cavities (i.e., features which provide secondary porosity and permeability) and since the distribution and interconnection of these features varies with location, the values of transmissivity and storage coefficient will vary also, as documented by the test results. Therefore, the bedrock aquifer can be characterized as homogeneous and anisotropic. Consequently, values of transmissivity and storage coefficient determined for each well are useful for calculating interferences between wells and estimating impacts for different directions in the aquifer.

The assumption that the discharging well penetrates the entire thickness of the aquifer is a difficult condition to meet for a consolidated rock aquifer. As originally proposed (Theis, 1935), this assumption was applicable to flow through a porous media (i.e., sand bed, where interstitial spaces provide porosity and permeability) with a well defined upper and lower boundary of relatively impermeable material. In a carbonate rock aquifer, the aquifer material itself (i.e., the bedrock) is relatively impermeable, while joints, fractures, solution cavities or other similar features provide the necessary porosity and permeability. Realistically, only the joints, fractures, and solution cavities which intersect the borehole supply water to the well. Therefore, the thickness of the aquifer is an item which can be open to debate: Is the aquifer considered to be the entire rock unit in which the well is constructed (i.e., depth of the well), or is the aquifer considered to be just that portion of the unit which supplies water to the well (i.e., fractures, joints, solution cavities, etc.)? For the purpose of these tests, it was assumed that the aquifer thickness was equal to the entire depth of the well minus the depth of overburden around the well. For the dolomite aquifer in the study area, the average aquifer thickness was assumed to be 450 feet with a range of 425 to 472 feet.

The hydraulic condition of the aquifer (i.e., stabilized or non-stabilized) can have a significant impact on the accuracy of the values of transmissivity and storage coefficient determined from the tests. The duration of each test and residual drawdown condition must be considered in evaluation of the pump test data. Of the data presented in Table II, some must be disregarded due to the factors discussed previously. Of the three major tests conducted (MW-4, MW-1 and MW-2), available information indicates that the aquifer was at a steady state condition (i.e., stabilized) at the start of the MW-4 pump test. Residual drawdown corrections were possible for most MW-1 constant discharge test data, while some of the data from the MW-2 test were also corrected. Consequently, values of transmissivity and storage coefficient from MW-4 tests are felt to be reasonably accurate representations of aquifer conditions, while MW-1 and MW-2 transmissivity and storage coefficient values are more suspect since the aquifer was not stabilized by the start of those tests.

As review of Tables I and II indicate, the curve matching technique provides information on a "leakage" factor for the confining bed overlying the dolomite aquifer. Table IV presents a summary of the different leakage values determined from the pump test data. As review of this table indicates, the permeability values of the confining layer range from 1.5×10^{-2} feet per day to 9.0×10^{-8} feet per day. It should be recognized that the values presented in Table IV are average values for the area of the aquifer affected by the specific pump test for which the leakage value was determined. As such, actual "leakage" from the confining bed may differ from the indicated values. To evaluate the potential impact that ground water in the glacial drift aquifer

TABLE IV

HYDROGEOLOGIC ASSESSMENT AT SAUKVILLE, WISCONSIN
VERTICAL HYDRAULIC CONDUCTIVITY VALUES OF CONFINING BED

TEST/DATE	OBSERVATION WELL	β	K' (ft/day)
MW-1 C.D. TEST (5/23/84)	MW-3	1	1.6×10^{-6}
	LAUBENSTEIN	30	1.1×10^{-6}
	MW-2 (H-J)	N/A	1×10^{-5}
	MW-3 (H-J)	N/A	1.6×10^{-3}
	LAUBENSTEIN (H-J)	N/A	4.4×10^{-3}
MW-1 RECOVERY TEST (5/23/84)	LAUBENSTEIN	15	1.8×10^{-7}
MW-2 RECOVERY TEST (5/23/84)	LAUBENSTEIN	1.5	3.9×10^{-5}
MW-2 C.D. TEST (5/24/84)	MW-1	0.3	8.2×10^{-6}
	LAUBENSTEIN	7	2.8×10^{-5}
	MW-1 (H-J)	N/A	1.5×10^{-2}
	LAUBENSTEIN (H-J)	N/A	5.8×10^{-4}
MW-4 RECOVERY TEST (5/22/84)	MW-1	1.5	9.0×10^{-8}
MW-4 C.D. TEST (5/22/84)	MW-1	1	2.1×10^{-7}
	MW-3	0.7	6.1×10^{-6}
	LAUBENSTEIN	20	5.1×10^{-6}
	MW-1 (H-J)	N/A	7.5×10^{-5}
	LAUBENSTEIN (H-J)	N/A	4.2×10^{-2}
MW-4 RECOVERY TEST (5/23/84)	MW-1	0.7	1.6×10^{-7}
	LAUBENSTEIN	7	9.6×10^{-6}
LAUBENSTEIN PACKER TEST (7/16-24/84)			
DEPTH: <140'	PZ-6	15	5.9×10^{-3}
DEPTH: 270-320'	MW-1	1.5	2.4×10^{-6}
	MW-2	3.0	1.9×10^{-5}
DEPTH: 280-330'	MW-1	5.0	7.7×10^{-6}
	MW-2	5.0	1.1×10^{-5}
DEPTH: >340'	MW-1	1.5	3.4×10^{-8}

NOTES:

1) Governing equations presented in Table II.
2) Physical aquifer characteristics:
   b = 450 ft. b' = 15 ft. S' = 0.2

3) Values determined from data collected in MW-3 may be affected by a potential recharge boundary (Milwaukee River), while values determined from Laubenstein well data may be affected by possible leaking around the casing in that well.

may have on the dolomite aquifer, an average vertical hydraulic conductivity (K') was calculated from the data presented in Table IV. Since a potential recharge boundary (i.e., Milwaukee River) lies between the pumping wells and one observation well, K' values determined from MW-3 data are not included in the calculation. Further, only data collected in the Laubenstein well for the MW-1 and MW-2 pump tests, and in MW-1, MW-2, and PZ-6 for the Laubenstein well packer pump tests were used because that information is considered to be more representative of the aquifer in the vicinity of the Freeman Chemical Corporation plant site. The average vertical hydraulic conductivity (K') so calculated is approximately 1.6×10^{-3} ft/day.

The Laubenstein well packer pump test values for transmissivity and storage coefficient presented in Table III are based on observed drawdown values which were not corrected for any residual drawdown from other pumping wells (e.g., MW-4 and MW-2). Additionally, the short duration of the tests precluded further adjustment of the observed drawdown data. However, review of the transmissivity and storage coefficient values in Table III indicates very close agreement with some of the values determined from the municipal wells pump tests presented in Table II. Based on the factors mentioned previously, some of the values presented in Table III must be disregarded. As discussed in the previous section, it is evident that the majority of ground water withdrawn from the Laubenstein well is produced by the lower portions of the dolomite aquifer. Comparison of Tables II and III indicate that the 270'-320' zone (or possibly 270'-bottom of well) is the main zone in which hydraulic interconnection with MW-2 and MW-1 exists. The transmissivity and storage coefficient values determined for the following zones are considered to be representative of aquifer characteristics in those zones: 340'-bottom and 270' - 320'. The data for the 280'- 330' zone must be disregarded due to the short duration of that test (see previous section). The value determined from data collected in PZ-6 are considered to be good approximations of the upper portion of the aquifer, based on information for private water wells in the Saukville area.

CONCLUSIONS

Based on the results of the municipal wells pumping tests and the Laubenstein well packer pump test, and in consideration of the constraints involved with those tests, the following conclusions concerning the hydrogeology of the study area have been reached:

1. The surficial glacial deposits constitute an upper water table aquifer underlain by a low permeability confining bed;

2. Ground water in the glacial deposits discharges to the Milwaukee River;

3. A semiconfined, homogeneous and anisotropic dolomite aquifer underlies the surficial glacial deposits;

4. The glacial drift and dolomite aquifers are hydraulically interconnected, but this interconnection is limited by the basal clay or silty clay unit in the surficial glacial deposits;

5. The Milwaukee River represents a partial recharge/discharge boundary for the dolomite aquifer, but the degree of aquifer/river interconnection has not been determined;

6. Average values for transmissivity and storage coefficient are presented in Table V, which delineates the variation of these characteristics with direction in the aquifer;

7. Hydraulic interconnection between the Laubenstein well and MW-1 and MW-2 occurs in the lower portion of the dolomite aquifer (i.e.,>270').

TABLE V

HYDROGEOLOGIC ASSESSMENT AT SAUKVILLE, WISCONSIN
AQUIFER CHARACTERISTICS

DIRECTION (WELL TO WELL)	T (ft^2/day)	S	β
MW-1 : LAUBENSTEIN	195	1.7×10^{-8}	30
MW-1 : MW-3	685	2.0×10^{-5}	200
MW-2 : LAUBENSTEIN	520	5×10^{-7}	7
MW-2 : MW-1	1100	1.5×10^{-4}	0.3
MW-4 : LAUBENSTEIN	950	1.4×10^{-7}	20
MW-4 : MW-1	4275	1.8×10^{-5}	2.5
MW-4 : MW-2	4770	1.56×10^{-4}	0.3
MW-4 : MW-3	4250	8.5×10^{-5}	0.7
Laubenstein: MW-1 (270'-320' zone)	200	2.8×10^{-7}	1.5
Laubenstein: MW-2 (270'-320' zone)	460	2.1×10^{-6}	3.0
Laubenstein: PZ-6 (<140' zone)	40	4.2×10^{-6}	15

8. Vertical hydraulic conductivity of the confining bed (15 feet in thickness) is in the range of 1.5 x 10^{-2} to 9 x 10^{-8} feet per day, with an average of 1.6 x 10^{-3} feet per day in the vicinity of the Freeman Chemical Corporation plant site.

9. The maximum volume of water discharged through the confining bed into the dolomite aquifer from the highly contaminated area on the Freeman plant site (approximately 4.5 acres, as defined by PZ-2/3, 5, 6, 9 and 14), with a vertical hydraulic gradient of 0.518 (average for period of record as determined by piezometer nests PZ-2/3 and PZ-7/8), is approximately 1200 gallons per day;

10. For the total area around the Freeman plant site identified as having some contamination (approximately 7.5 acres, from odor determinations), the maximum volume of water discharged to the dolomite aquifer is approximately 2270 gallons per day.

VERIFICATION

To determine the validity of the transmissivity and storage coefficient values obtained from the pump tests, comparison of theoretical and observed drawdown in the Laubenstein well was conducted. The continuous water level recorder was replaced in the Laubenstein well after conclusion of the municipal wells pumping tests in May 1984, and a portion of that record (from June 8-15, 1984) is included as Appendix VIII. Review of this chart shows an obvious decline in the water level starting on Monday, June 11, 1984. Using the values of transmissivity and storage coefficient calculated for MW-4 and MW-2, in the direction of the Laubenstein well, drawdown calculations were made. Total calculated drawdown, as observed in the Laubenstein well for MW-4 and MW-2, was 6.56 feet, while the observed drawdown for the period was 6.65 feet. Consequently, the values of transmissivity and storage coefficient determined from the municipal wells pump tests are appear to be representative of actual aquifer characteristics.

Values of transmissivity and storage coefficient determined from the Laubenstein well packer pump test appear to be reasonably accurate, in consideration of the constraints under which the pump tests were conducted. Comparison of transmissivity and storage coefficient values determined from MW-1, MW-2 and Laubenstein pump tests are very close and thus, are considered to be good approximations of actual aquifer characteristics. Finally, the close similarity of these values from the 270'-320' zone in the Laubenstein well to values determined in the MW-1 and MW-2 pump tests supports the conclusion that hydraulic interconnection between these wells occurs in the lower portion of the dolomite aquifer.

REFERENCES

1. Cooper, H. H., Jr., 1963, Type curves for nonsteady radial flow in an infinite leaky artesian aquifer, in Bentall, Ray, Shortcuts and special problems in aquifer tests: U.S. Geological Survey Water-Supply Paper 1545-C, pp. C48-C55.

2. Devaul, R. W., 1967, Trends in ground water levels in Wisconsin through 1966: Wisconsin Geological and Natural History Survey Information Circular No. 1, 17 p.

3. Lasca, N. P., 1970, The Pleistocene geology of southeastern Wisconsin, an introduction: Wisconsin Geological and Natural History Survey Information Circular No. 15, p. B-1 to B-7.

4. Leischer, C. C., 1980, The effect of coal flyash leachate on the shallow groundwater system near Saukville, Wisconsin: M.S. thesis, University of Wisconsin - Milwaukee.

5. Lohman, S. W., 1972, Ground-water hydraulics: U.S. Geological Survey Professional Paper 708, 70 p.

6. Mulica, W. S., 1973, The hydrogeology of the Cedarburg bog area: M.S. thesis, University of Wisconsin - Milwaukee.

7. Theis, C. V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground water storage: American Geophysical Union Transactions, V. 16, pp. 519-524.

8. Wierman, D. A., 1979, The hydrogeology of the Cedarburg bog area: M.S. thesis, University of Wisconsin - Milwaukee.

9. Wilder, S. V., 1973, The groundwater hydrology of the Cedarburg bog: M.S. thesis, University of Wisconsin - Milwaukee.

APPENDIX I

SITE MAP

OLVER INCORPORATED

APPENDIX II

MUNICIPAL WELLS PUMP TEST SCENARIOS

HYDROGEOLOGICAL ASSESSMENT AT SAUKVILLE, WISCONSIN
MUNICIPAL WELLS PUMPING TESTS

Introduction

Review of ground water level fluctuations in the Laubenstein well for the past few months indicates that the Laubenstein well is influenced by pumping activities in municipal wells no. 2 and no. 4, and probably municipal well no. 1. In order to determine aquifer characteristics of transmissivity and storage coefficient, and to identify which municipal wells effect water level fluctuations in the Laubenstein well, pumping tests for the municipal wells are delineated below. These pumping tests have been devised to provide sufficient data for determination of aquifer characteristics, while maintaining adequate pumping levels and water storage volumes to assure protection of water quality in the municipal wells and to provide for adequate fire protection. Total storage for the tower and reservoir is approximately 800,000 gallons; the Village of Saukville has determined that the minimum permissible storage required for adequate fire protection is approximately 400,000 gallons. Therefore, the pump test scenarios presented below have been designed to ensure that adequate storage is maintained at all times, and have been designed to maximize data acquisition, while minimizing any disruption to the public water supply system for the Village of Saukville, Wisconsin.

Scenario No. 1

The purpose of this test is to determine the impact that pumping from municipal wells no. 1 and no. 4 have on the water level in the Laubenstein well. For this pumping test, municipal well no. 3 will not be employed and municipal well no. 2 will be pumping continuously. Approximately 12 hours before the start of the pumping test, the discharge from municipal well no. 2 will be stabilized through the use of the in-line flow recorder and valve so that the discharge from the well is approximately constant at 300 gallons per minute. The intent of regulating the flow from municipal well no. 2 is to provide a constant discharge from that well during the pumping test, and consequently, flow from the well may have to be regulated to less than 300 gpm to achieve this condition. Additionally, municipal well no. 1 will be shut off for a minimum of 12 hours prior to commencement of the pumping test. Municipal well no. 4 will be used to supply water for both the tower and the reservoir and will pump, as necessary, to fill both storage structures to capacity by 12:00 midnight on the date that the test commences.

At midnight on the date that the test commences, municipal well no. 4 will be shut off. Air line pressure gauge readings will be taken, for calculation of water depths, at municipal wells no. 1 and no. 4 at the intervals indicated on the pump test drawdown/well recovery logsheet (Figure 1). Simultaneously, the static water level, date, and time will be indicated on the chart recorder installed in the Laubenstein well. During this test, the Laubenstein well recorder will have a gear ratio of 1:12, in order to increase the recorder sensitivity to allow for a more precise determination of water level fluctuations, and the chart speed for the recorder will be changed to an 8-hour clock period.

FIGURE 1

HYDROGEOLOGICAL ASSESSMENT AT SAUKVILLE, WISCONSIN
PUMP TEST DRAWDOWN/WELL RECOVERY LOGSHEET

WELL ID:__________ DATE:________________ START TIME:__________

OBSERVER:________________ GAUGE READING:_____ DIRECT READING:_____

min	TIME (hrs:min)	GAUGE (psi)	SWL (ft)	min	TIME (hrs:min)	GAUGE (psi)	SWL (ft)
1				150			
2				200			
3				250			
4				300			
5				350			
6				400			
7				450			
8				500			
9				550			
10				600			
15				650			
20				700			
25				750			
30				800			
35				850			
40				900			
45				950			
50				1000			
55				1100			
60				1200			
70				1300			
80				1400			
90				1500			
100							

GAUGE TO SWL CONVERSION: LENGTH OF AIR LINE (FT) - (2.307 x GAUGE READING) = SWL

Water to meet system demand will be provided from storage in the tower and underground reservoir. Maximum available storage for the test will be approximately 400,000 gallons, or at the point where both tower and reservoir storage is reduced to one-half capacity. Based on water usage and maximum water demand, it is anticipated that municipal well no. 4 will not have to be turned on until 12:00 p.m. on the day of the test. When available water storage has declined to the minimum level, municipal well no. 4 will be manually turned on, and will continue to pump until the tower and reservoir are filled to capacity (estimated 8-12 hours). When municipal well no. 4 is turned on, air line pressure gauge readings will be conducted on municipal wells no. 1 and no. 4 at the frequency indicated in Figure 1. Simultaneously, the time and static water level measurement will be indicated on the chart recorder in the Laubenstein well.

When municipal well no. 4 has fully satisfied the water storage requirements of the system, the well will be shut off and air line pressure readings will be collected from municipal wells no. 1 and no. 4, in accordance with the schedule indicated in Figure 1.

Water to meet public water supply demands will be taken from tower and reservoir storage until approximately one-quarter of the available storage is utilized (i.e., 200,000 gallons). At that point in time, municipal well no. 1 will be turned on to provide water to the reservoir and water storage tower. At the time that municipal well no. 1 is turned on, air line pressure gauge readings will be conducted in both municipal wells no. 1 and no. 4, in accordance with the schedule delineated in Figure 1. Simultaneously, the time, date, and static water level will be indicated on the chart recorder in the Laubenstein well. Pumping from municipal well no. 1 will continue until such time that the reservoir and the water tower have reached capacity, provided that municipal well no. 1 keeps up with demand. If well no. 1 does not keep up with demand, well no. 4 will be manually turned on when storage capacity has been reduced to the minimum storage permissible (i.e., 400,000 gallons). When storage is satisfied, municipal well no. 1 will be shut off and air line pressure gauge readings for that well will be conducted for a period of four hours following shut-down of the well. Simultaneously, the static water level, date and time will be indicated on the chart recorder located in the Laubenstein well.

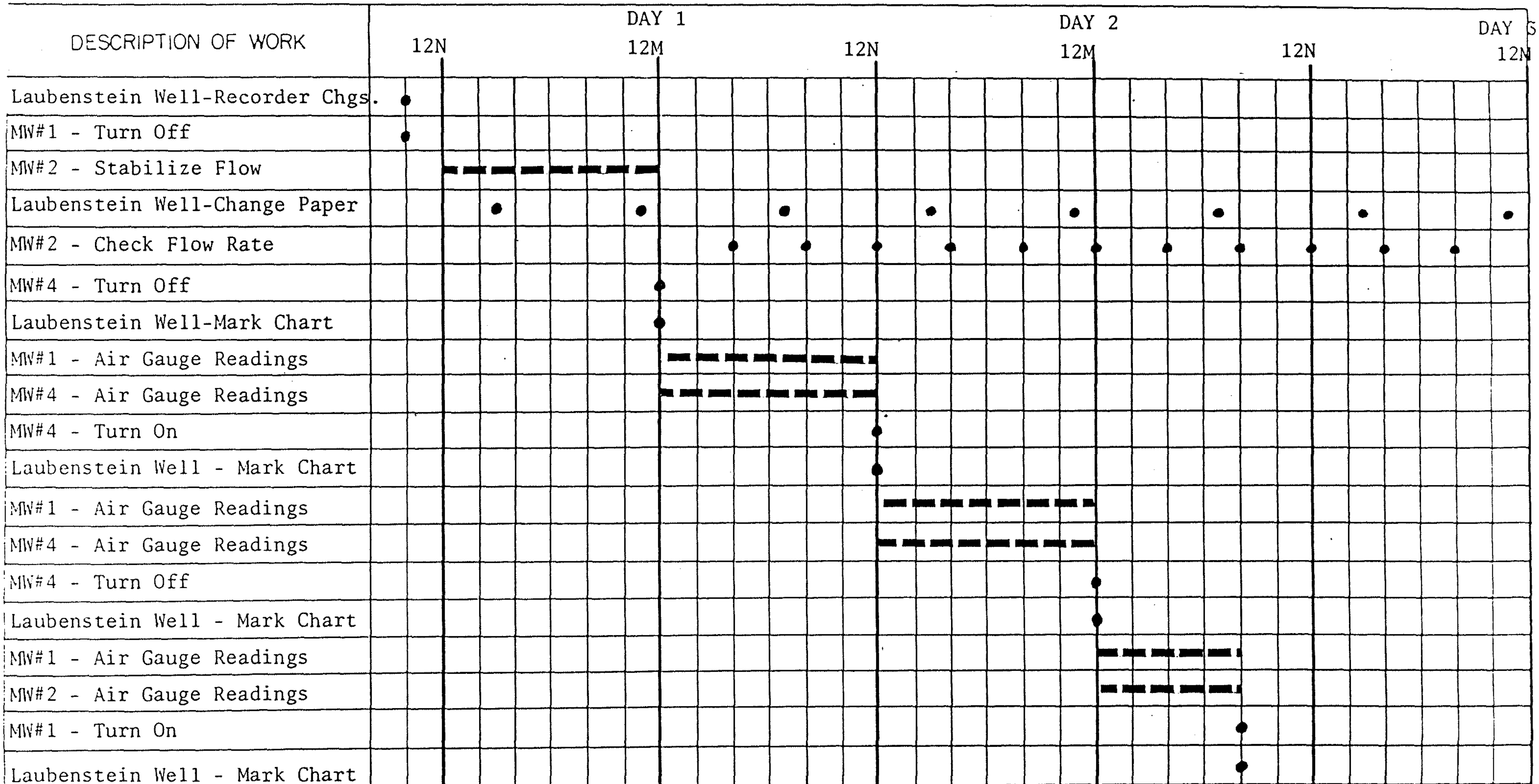
After four hours have elapsed from the time that municipal well no. 1 is shut off, the pumping test will have been concluded, and normal pumping operations may resume. At any time during the pumping test, if an emergency situation arises which requires initiation of pumping activities from either municipal wells no. 3 or no. 4, they will commence, although the time of pump start-up will be recorded. Air line pressure gauge readings will continue to be recorded during the unanticipated start-up of those wells, if at all possible. A pump test schedule depicting all aspects and times associated with this pump test is presented as Figure 2.

<u>Scenario No. 2</u>

The purpose of this pumping test is to determine the impact that pumping from municipal well no. 2 has on the Laubenstein well and shallow ground water resources, as well as to determine the impact, if any, that pumping from

OLVER INCORPORATED
1531 North Main Street Blacksburg, Virginia 24060

PROJECT SCHEDULE



REMARKS:
Municipal Wells Pump Test
Scenario #1 - MW#1 and MW#4
Each Block = 2 hours

MADE BY: JWD

DATE: 3/22/84

LAST REV. DATE:

FOR: Hydrogeological Assessment at Saukville, Wisconsin

JOB NO. 10519

SHEET 1 OF 2

FIGURE 2

OLVER INCORPORATED
1531 North Main Street Blacksburg, Virginia 24060

PROJECT SCHEDULE

DESCRIPTION OF WORK	DAY 1 12N	12M	12N	DAY 2 12M	12N	DAY 3 12M
MW#1 - Air Gauge Readings					- - - - - - -	
MW#4 - Air Gauge Readings					- - - - - - -	
MW#4 - Turn On As Required					•	
Laubenstein Well-Refit Recorder						•
Test Terminated						•

REMARKS:
Municipal Wells Pump Test
Scenario #1 - MW#1 and MW#4
Each Block = 2 Hours

MADE BY: JWD

DATE: 3/22/84

LAST REV. DATE:

FOR: Hydrogeological Assessment at Saukville, Wisconsin

JOB NO. 10519

SHEET 2 OF 2

FIGURE 2

municipal well no. 1 has on shallow ground water resources in the vicinity of the plant site. During this pumping test, municipal well no. 3 will not be operational. Municipal well no. 1 will be shut off for a period of approximately 12 hours prior to commencement of the test. Additionally, the underground reservoir and water tower will be at maximum capacity, utilizing the supply from municipal well no. 4. During this test, the water level recorder in the Laubenstein well will be fitted with a 1:12 gear ratio and an 8-hour clock drive.

At approximately noon on the day before the test, municipal wells no. 1 and no. 2 will be shut off and air line pressure gauge readings will be conducted, in accordance with Figure 1, at these wells. Simultaneously, the date, time, and static water level will be indicated on the chart recorder in the Laubenstein well. Twelve hours after municipal well no. 2 is shut off, air line pressure gauge readings in municipal wells no. 1 and no. 2 will be terminated. Collection of air line pressure gauge readings may be halted prior to the 12-hour time period, if those readings indicate stabilization of the water levels in the wells. Twenty-four hours after municipal well no. 2 is shut off, municipal well no. 4 will be turned off and water from storage will be used to meet system demands. Approximately 36 to 42 hours after municipal well no. 2 has been turned off, the pump test will commence.

At the time that municipal well no. 2 is turned on, air line pressure gauge readings will be collected in municipal wells no. 1 and no. 2, while static water level measurements will be taken from piezometers 1, 2, and 15 (or 16), and private wells 1, 3, and 6. Collection of air line pressure gauge readings and static water levels will be conducted for 12 hours. Frequency of data collection will be in accordance with that presented in Figure 1. During the pump test, municipal well no. 4 will be manually turned on when system storage has been reduced to the minimum permissible volume (i.e., 400,000 gallons) and will continue, as necessary, to bring the storage to maximum capacity. The exact time that municipal well no. 4 is turned on will be recorded.

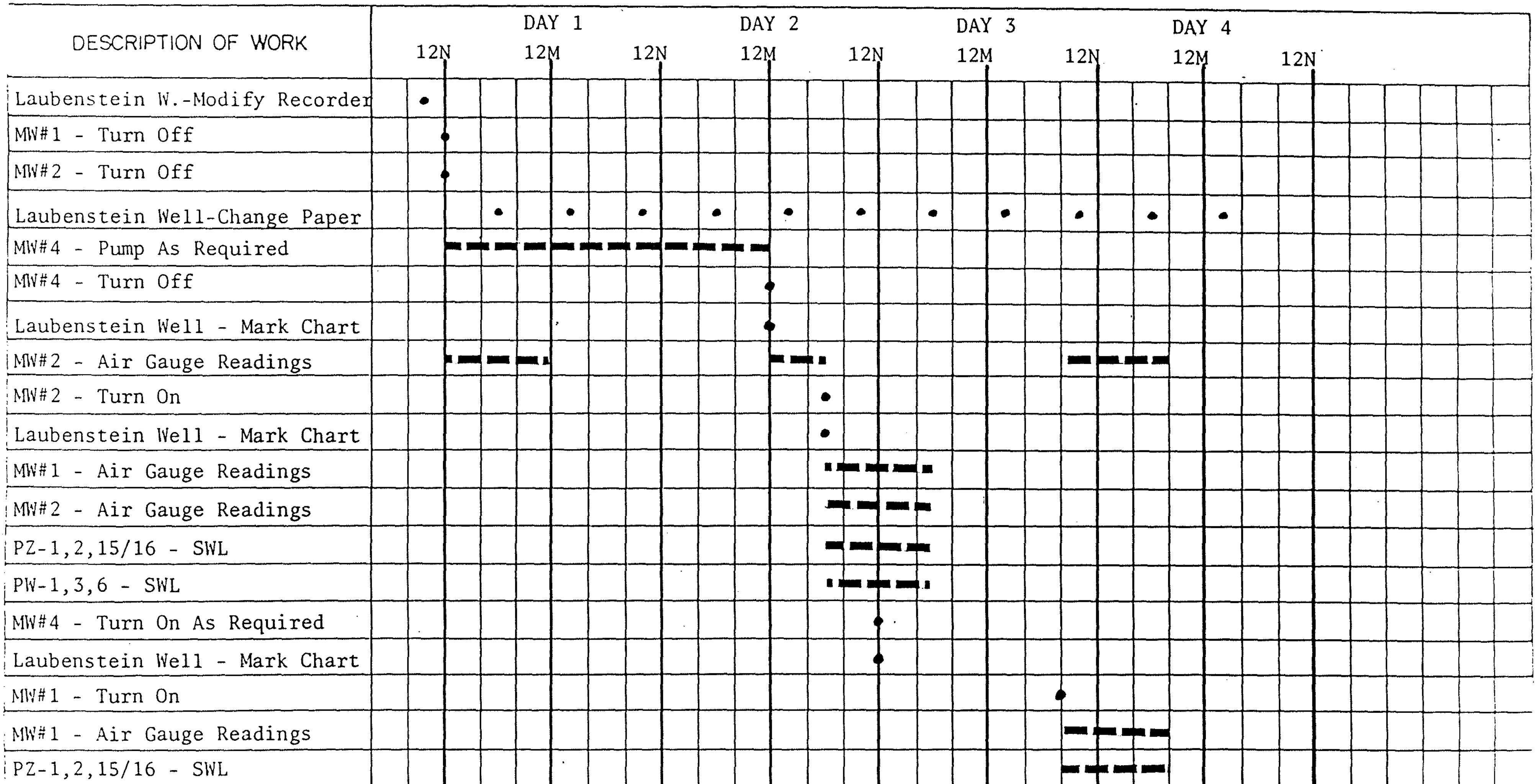
Start-up of municipal well no. 1 will occur 12 to 24 hours after start-up of municipal well no. 2, which will remain on during the pump test. To prevent possible contamination of municipal well no. 1 during the pump test, municipal well no. 2 will pump continuously. At the time of start-up of municipal well no. 1, air line pressure gauge readings will be conducted in municipal wells no. 1 and no. 2. Simultaneously, the time, date, and static water level measurement will be indicated on the chart recorder located in the Laubenstein well. Simultaneously during start-up of municipal well no. 1, static water level measurements will be manually recorded in piezometers 1, 2, and 15 (or 16), and private wells 1, 3, and 6. Collection of air line pressure gauge readings and static water level measurements will be conducted for a period of approximately 12 hours, or until water levels in the wells under study have stabilized, in accordance with the schedule presented in Figure 1. A pumping test schedule which delineates all activities associated with this test is included as Figure 3.

Scenario No. 3

The purpose of this test is to determine if there is any impact on the Laubenstein well from pumping activities in municipal well no. 3. In order to

OLVER INCORPORATED
1531 North Main Street Blacksburg, Virginia 24060

PROJECT SCHEDULE



REMARKS:
Municipal Wells Pump Test
Scenario #2 - MW#1 and MW#2
Each Block = 4 Hours

MADE BY: JWD

DATE: 3/22/84

LAST REV. DATE:

FOR: Hydrogeological Assessment at Saukville, Wisconsin

JOB NO. 10519

SHEET 1 OF 2

FIGURE 3

OLVER INCORPORATED

1531 North Main Street Blacksburg, Virginia 24060

PROJECT SCHEDULE

DESCRIPTION OF WORK	DAY 1	DAY 2	DAY 3	DAY 4
	12N 12M	12N 12M	12N 12M	12N 12M 12N
PW-1,3,6 - SWL				
Laubenstein Well-Refit Recorder				
Test Terminated				

REMARKS:

Municipal Wells Pump Test
Scenario #2 - MW#1 and MW#2
Each Block = 4 Hours

MADE BY: JWD

DATE: 3/22/84

LAST REV. DATE:

FOR: Hydrogeological Assessment at Saukville, Wisconsin

JOB NO. 10519

SHEET 2 OF 2

FIGURE 3

reduce demands on the ground water supply system, this will be a test conducted on a weekend, or other period when manufacturing operations at Freeman Chemical Corporation are reduced. During this pumping test, municipal wells no. 1, no. 2, and no. 4 will be shut off. Water to meet public water supply demands will come from storage until approximately one-quarter of the available storage volume has been utilized. Pumping from municipal well no. 3 will occur for a maximum of four, two-hour intervals, to provide recharge to the reservoir and water tower. However, water from this well may be discharged from the water supply system, if the Village of Saukville determines that its quality (i.e., excessive sand) is not compatible with their water supply requirements. Between pumping intervals, municipal well no. 3 will be allowed to recharge for a period of two hours. During pumping and recharge intervals, air line pressure gauge readings will be conducted for municipal well no. 3. Simultaneously, the date, time, and static water level measurements will be indicated on the chart recorder in the Laubenstein well. During this test, the recorder in the Laubenstein well will be fitted with a 1:1 gear ratio and an 8-hour clock drive. This pumping test will continue until one-half the available water storage volume has been utilized, at which time municipal well no. 4 will be turned on to provide the necessary water supply to the reservoir and water tower. When municipal well no. 4 is activated to provide additional water to the reservoir and tower, this pumping test will be terminated. At the conclusion of the test, the chart recorder in the Laubenstein well will be refitted with a 1:24 gear ratio and an 8-day clock drive for resumption of routine water level monitoring activities. A schedule for this pump test is presented as Figure 4 and delineates the activities that must be accomplished in order to facilitate conductance of this test.

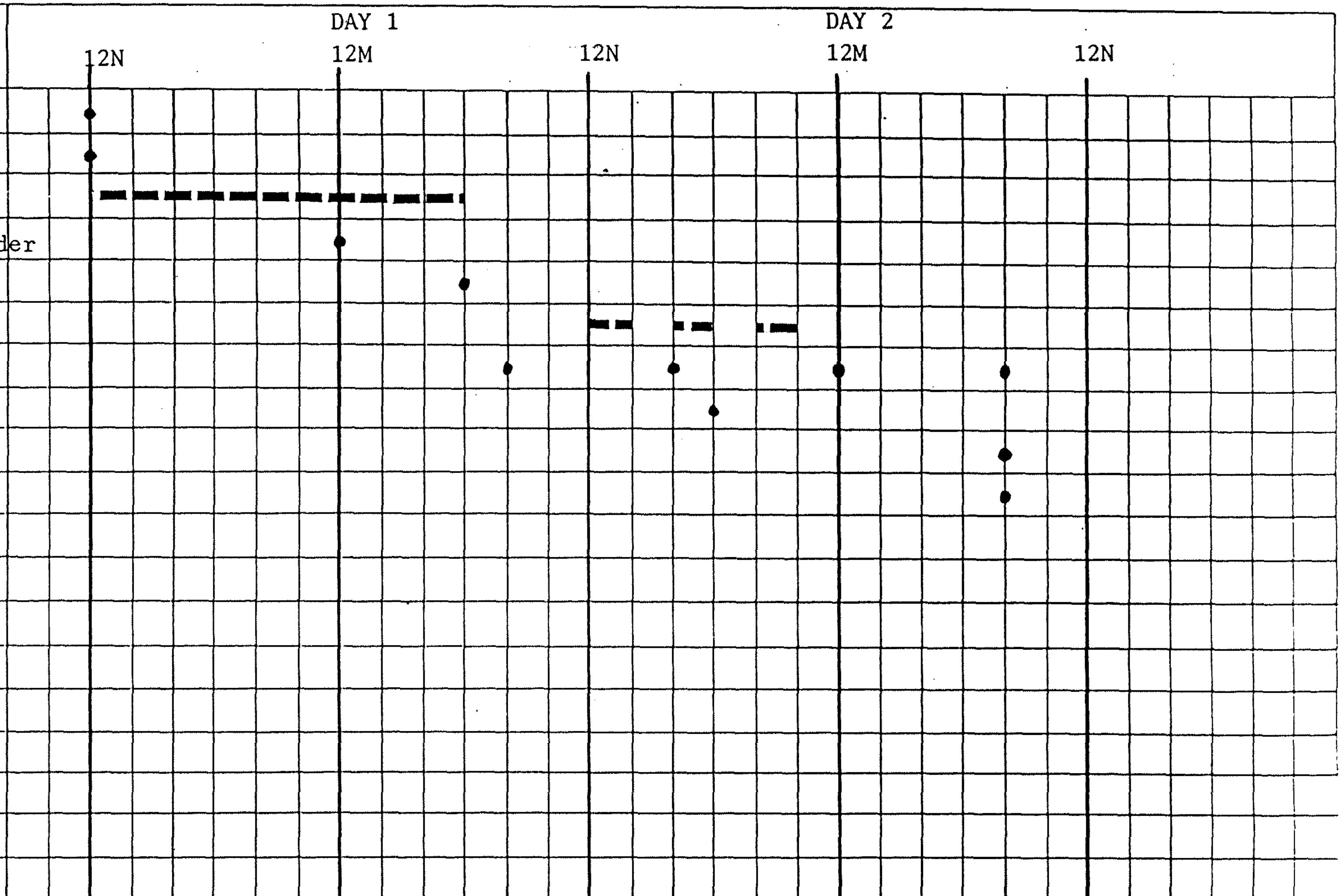
Discussion

It should be noted that the selection of specific times for commencement of pumping activities is somewhat arbitrary, in that the actual times will be dictated more by water usage and demands of the system. However, utilization of the night time hours (12:00 midnight to 6:00 a.m.) for portions of the tests (e.g., recovery test) is desirable, since minimal water usage during this time will provide a greater period for measurement of recovery water levels. In this manner, the ground water flow system will be allowed to come closer to reaching steady state, nonpumping conditions, prior to the initiation of the various pumping tests. Data collected during the tests should be adequate to permit determination of aquifer characteristics of transmissivity, storage coefficient, anisotropy, and heterogeneity. Further, the pumping tests will permit determination of the interactions between the various municipal wells and the Laubenstein well, and shallow ground water resources in the vicinity of the Freeman Chemical Corporation plant site.

OLVER INCORPORATED
1531 North Main Street Blacksburg, Virginia 24060

PROJECT SCHEDULE

DESCRIPTION OF WORK
MW#1 - Off
MW#2 - Off
MW#4 - Pump As Required
Laubenstein Well-Modify Recorder
MW#4 - Turn Off
MW#3 - Pump As Scheduled
Laubenstein Well-Change Paper
MW#4 - Turn On As Required
Laubenstein Well - Refit
Test Terminated



REMARKS:
Municipal Well Pump Test
Scenario #3 - MW#3
Each Block = 2 Hours

MADE BY: JWD

DATE: 3/22/84

LAST REV. DATE:

FOR: Hydrogeological Assessment at Saukville, Wisconsin

JOB NO. 10519

SHEET 1 OF 1

FIGURE 4

APPENDIX III

MW-1 PUMP/RECOVERY TEST DATA PLOTS
MW-2 PUMP/RECOVERY TEST DATA PLOTS
MW-4 PUMP/RECOVERY TEST DATA PLOTS

MW-1 CONSTANT DISCHARGE TEST

HANTUSH MODIFIED METHOD

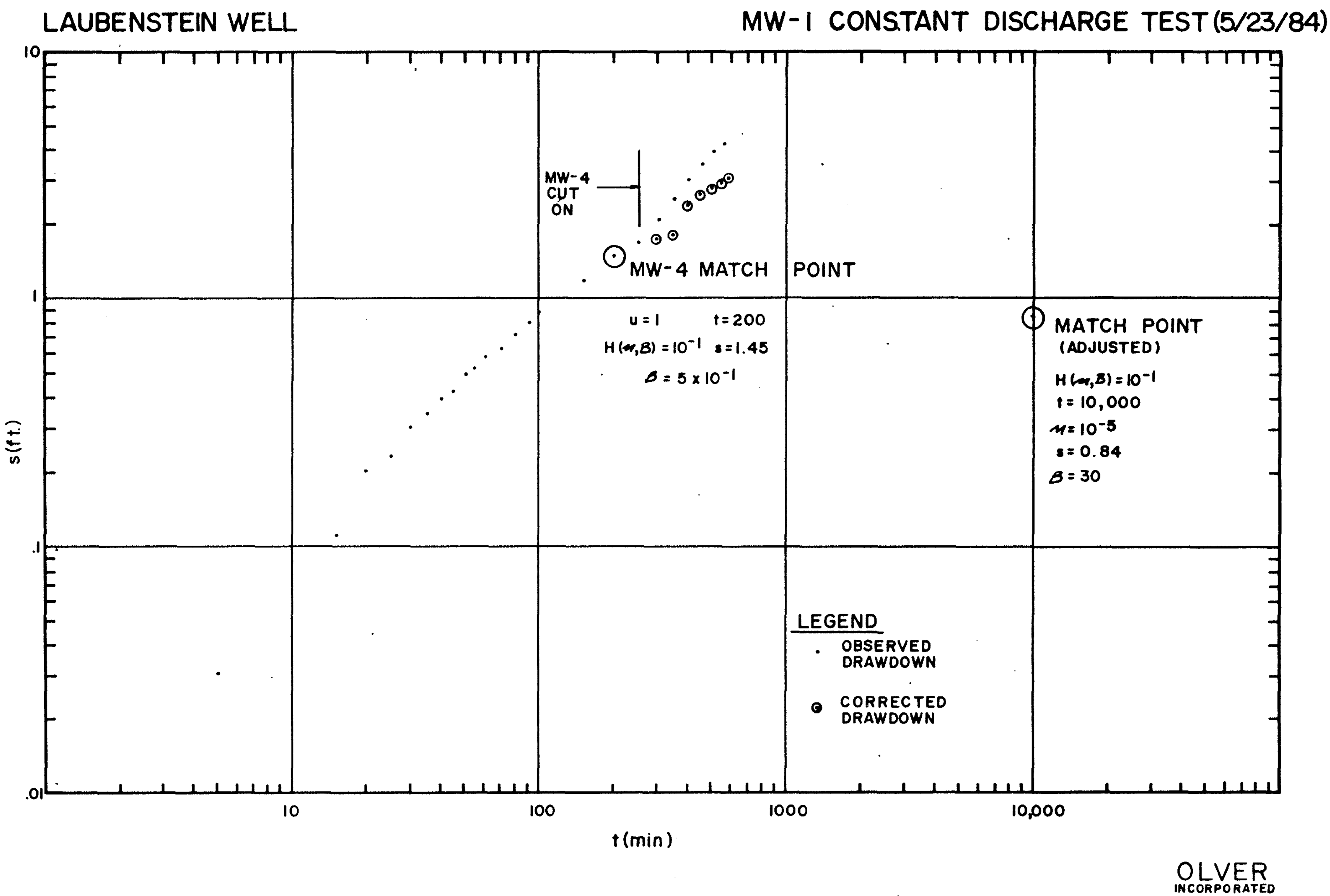
Laubenstein Well Data Plot
MW-2 Data Plot
MW-3 Data Plot

HANTUSH-JACOB METHOD

MW-1 RECOVERY TEST

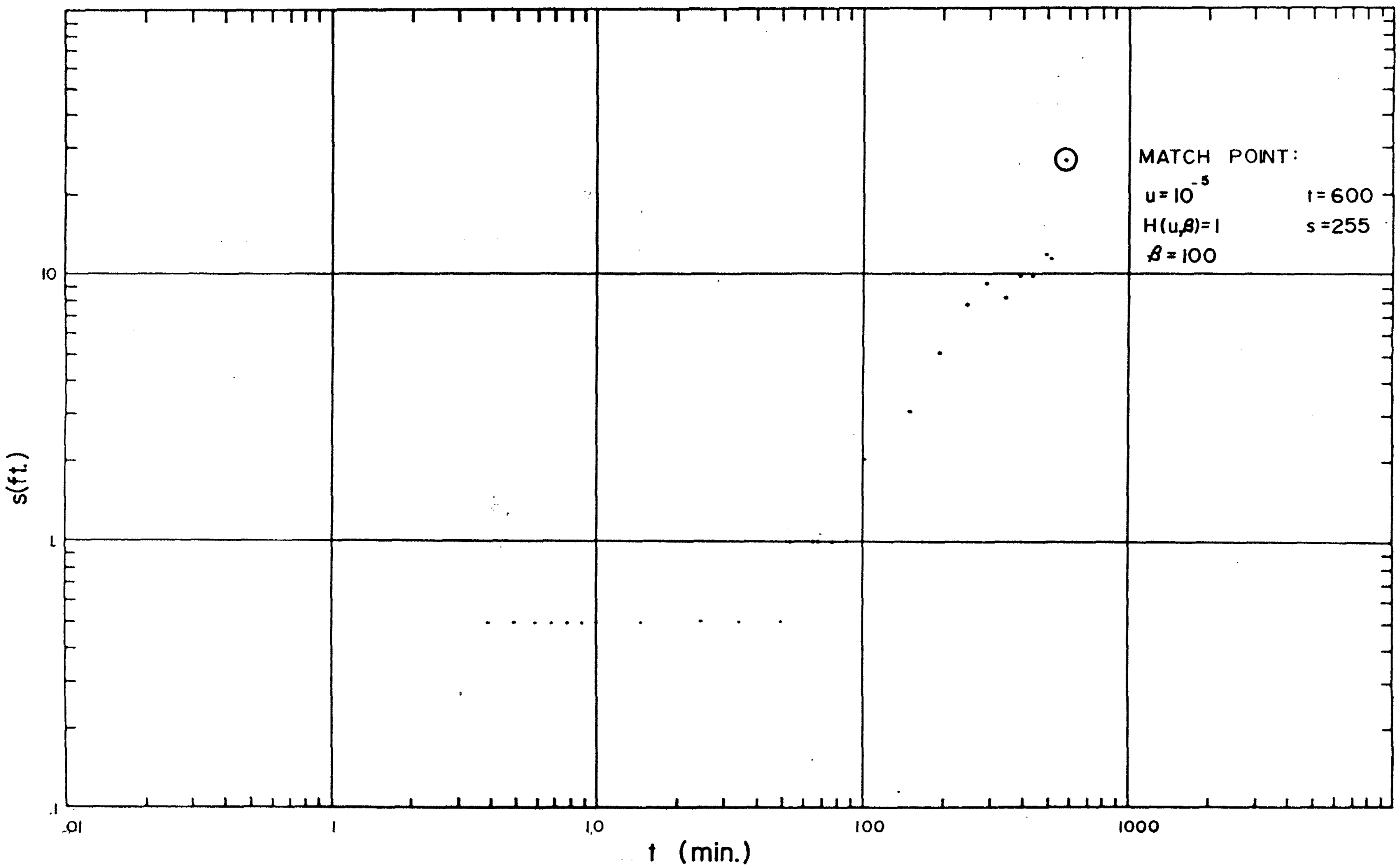
HANTUSH MODIFIED METHOD

Laubenstein Well Data Plot


LAUBENSTEIN WELL
MW-1 CONSTANT DISCHARGE TEST (5/23/84)
MW-4 CUT ON
MW-4 MATCH POINT
u = 1
t = 200
H (u,β) = 10⁻¹
s = 1.45
β = 5 x 10⁻¹
MATCH POINT (ADJUSTED)
H (u,β) = 10⁻¹
t = 10,000
u = 10⁻⁵
s = 0.84
β = 30
LEGEND
OBSERVED DRAWDOWN
CORRECTED DRAWDOWN
s (ft.)
t (min)
10
1
.1
.01
10
100
1000
10,000
OLVER INCORPORATED

MW-2

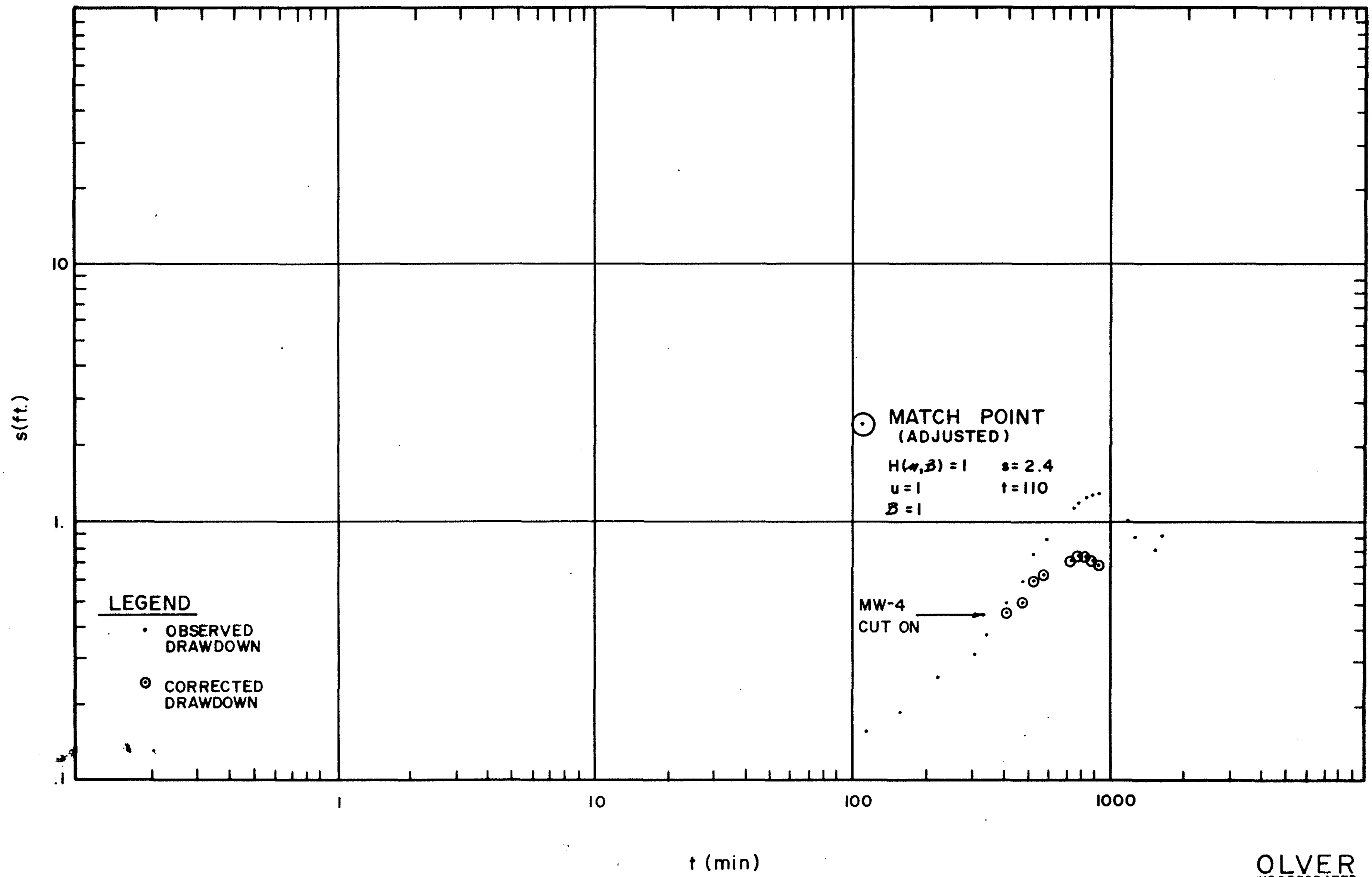
MW-1 CONSTANT DISCHARGE TEST



OLVER INCORPORATED

MW-3

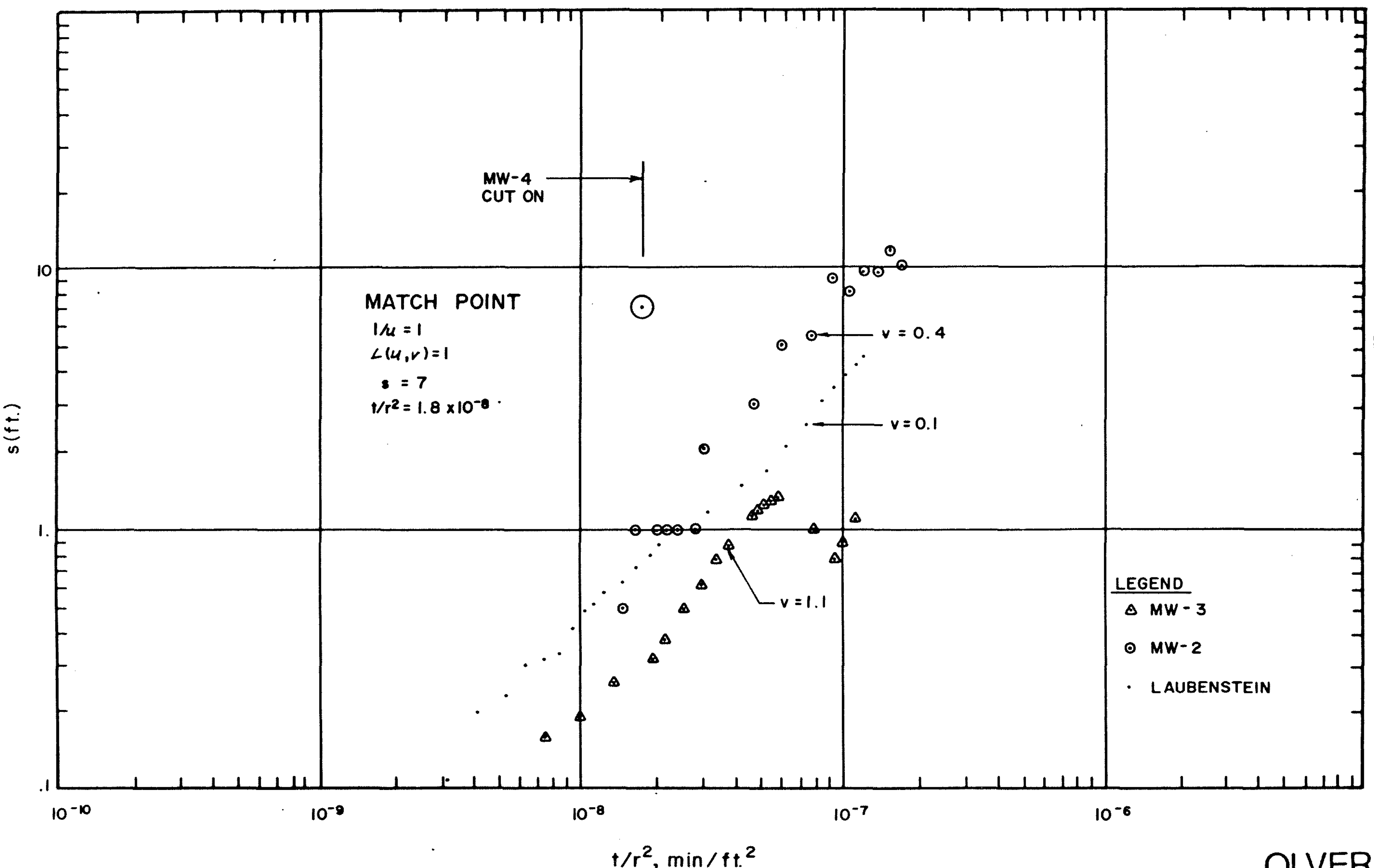
MW-1 CONSTANT DISCHARGE TEST



OLVER INCORPORATED

HANTUSH - JACOB METHOD

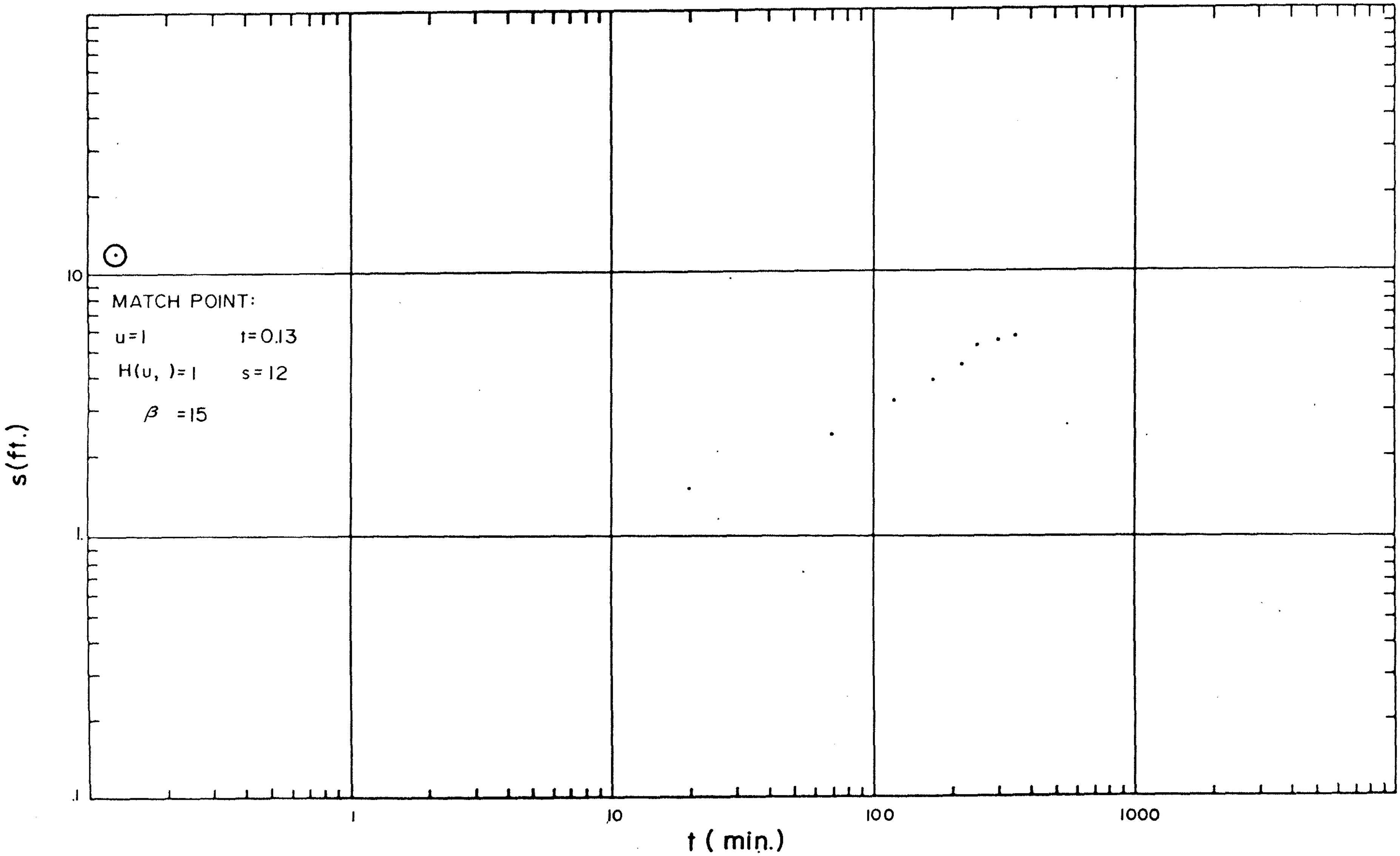
MW-1 CONSTANT DISCHARGE TEST



OLVER INCORPORATED

LAUBENSTEIN WELL

MW-1 RECOVERY TEST
(DURING MW-2 RECOVERY TEST)



OLVER INCORPORATED

MW-2 CONSTANT DISCHARGE TEST

JACOB-LOHMAN METHOD

HANTUSH MODIFIED METHOD

Laubenstein Well Data Plot
MW-1 Data Plot

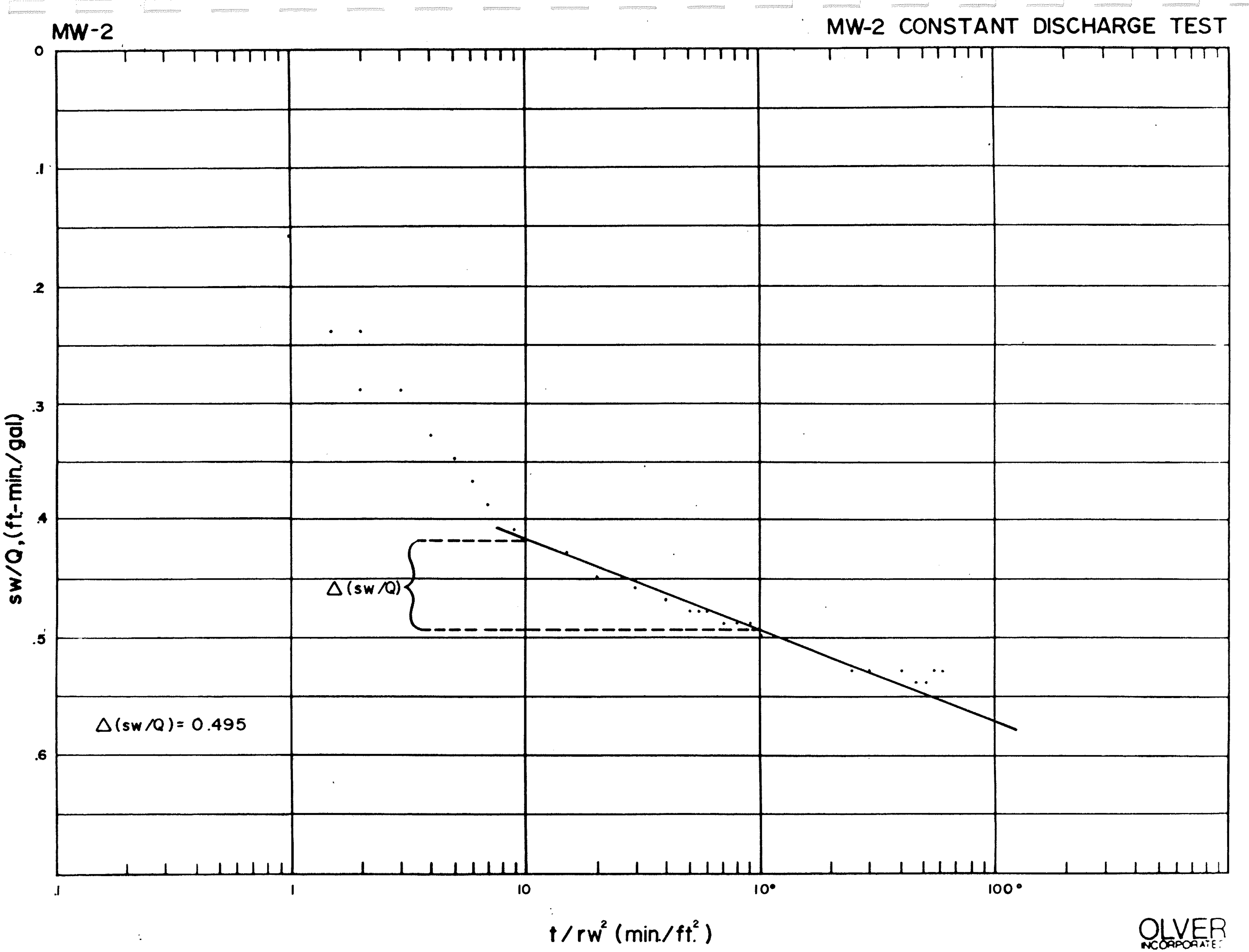
HANTUSH-JACOB METHOD

MW-2 RECOVERY TEST

JACOB-LOHMAN METHOD

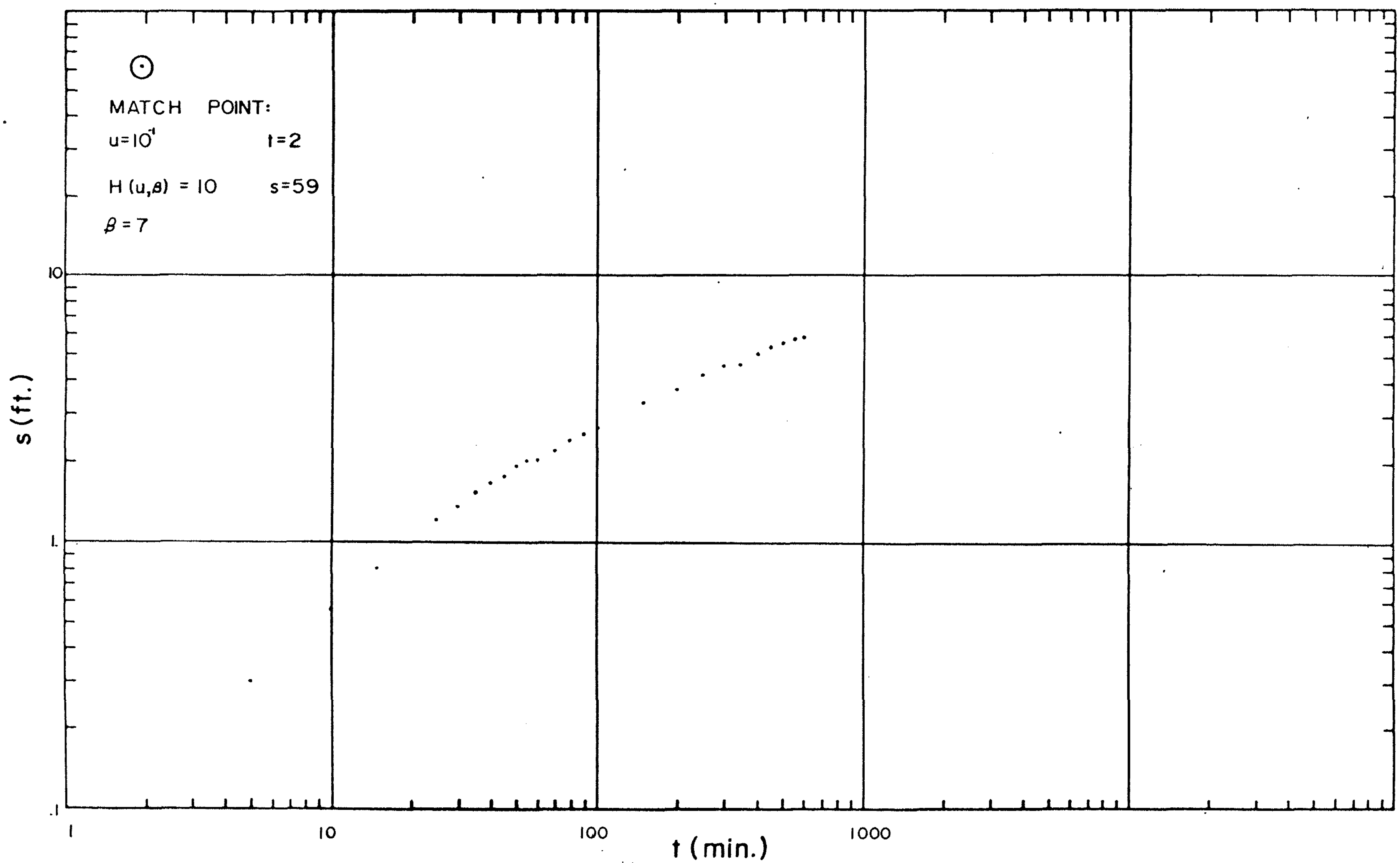
HANTUSH MODIFIED METHOD

Laubenstein Well Data Plot


MW-2
MW-2 CONSTANT DISCHARGE TEST
sw/Q, (ft-min/gal)
0
.1
.2
.3
.4
.5
.6
Δ (sw/Q)
Δ (sw/Q) = 0.495
.1
1
10
10²
100²
t / rw² (min./ft.²)
OLVER INCORPORATED

LAUBENSTEIN WELL

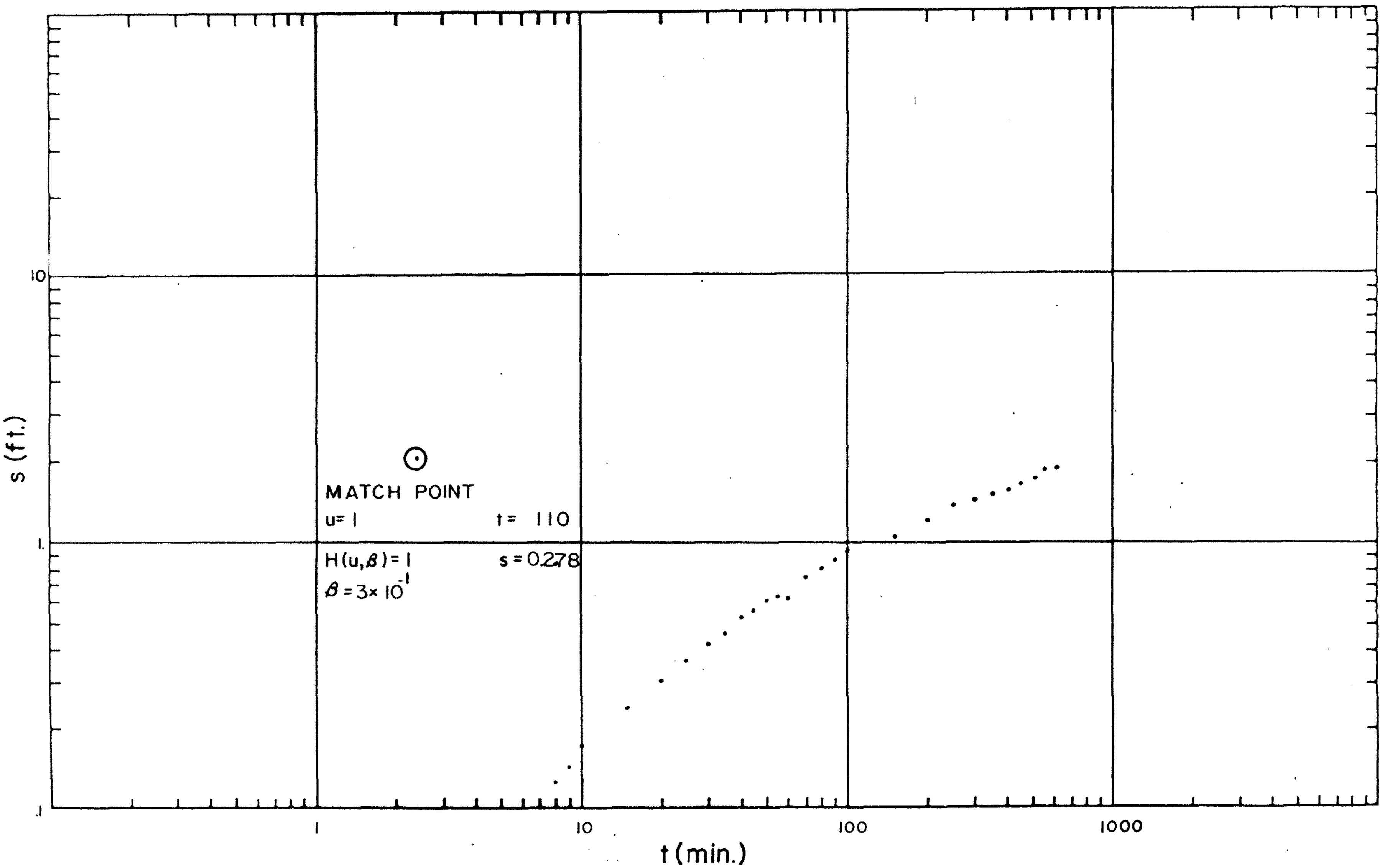
MW-2 CONSTANT DISCHARGE TEST



OLVER INCORPORATED

MW-1

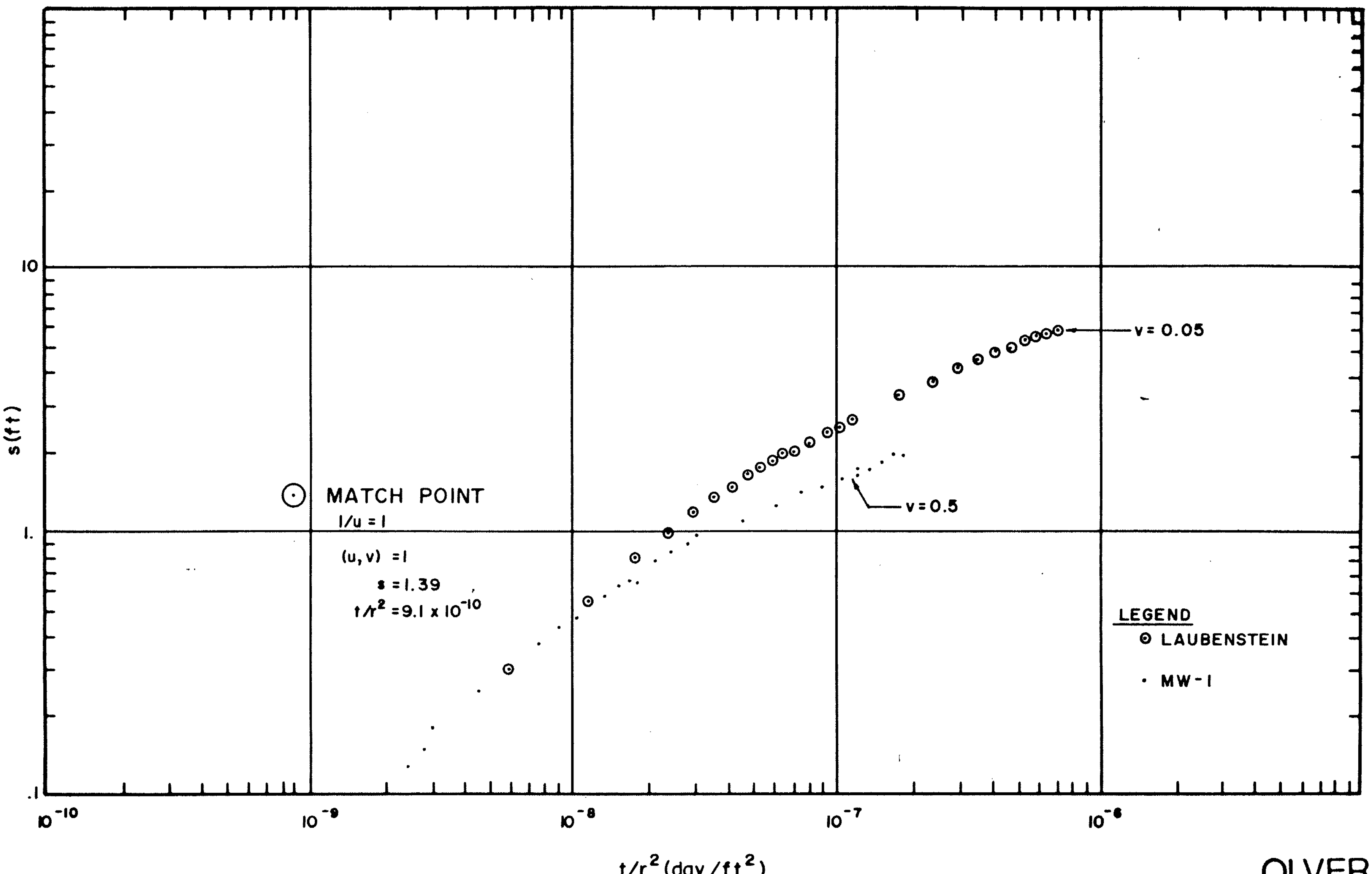
MW-2 CONSTANT DISCHARGE TEST



OLVER INCORPORATED

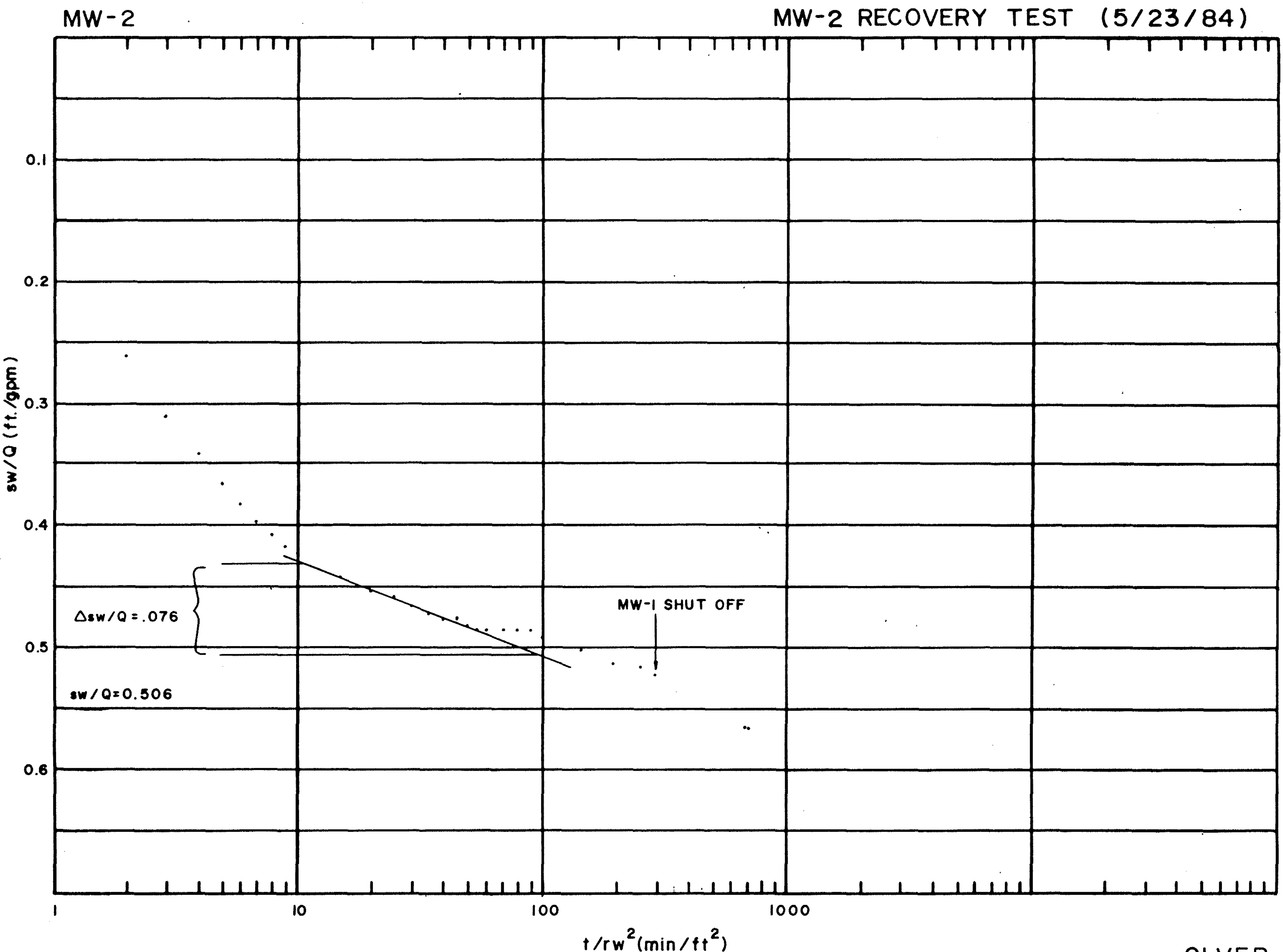
HANTUSH - JACOB METHOD

MW-2 CONSTANT DISCHARGE TEST



OLVER INCORPORATED

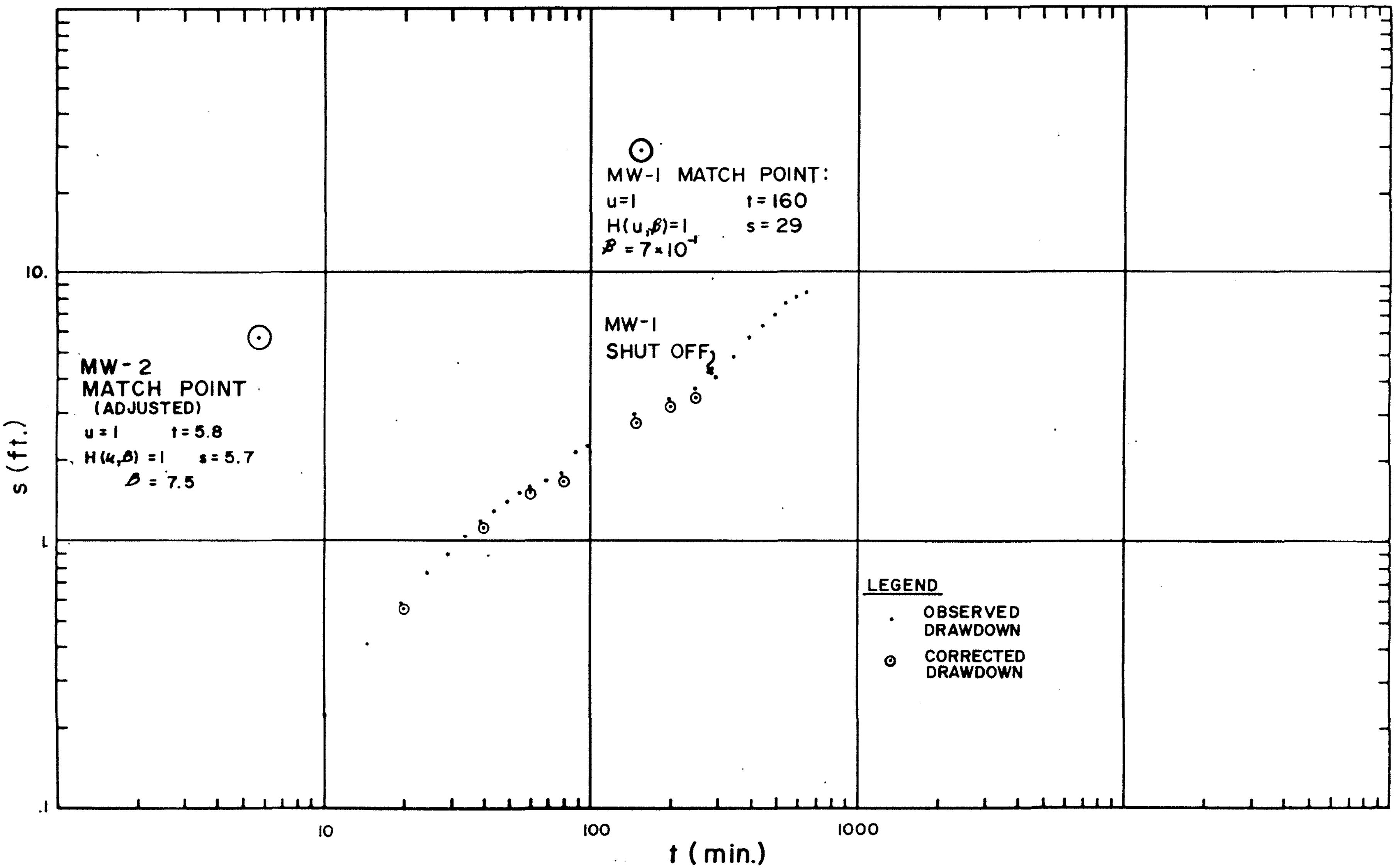
MW-2



OLVER INCORPORATED

LAUBENSTEIN WELL

MW-2 RECOVERY TEST



OLVER INCORPORATED

MW-4 CONSTANT DISCHARGE TEST

JACOB-LOHMAN METHOD

HANTUSH MODIFIED METHOD

Laubenstein Well Data Plots
MW-1 Data Plot
MW-3 Data Plot

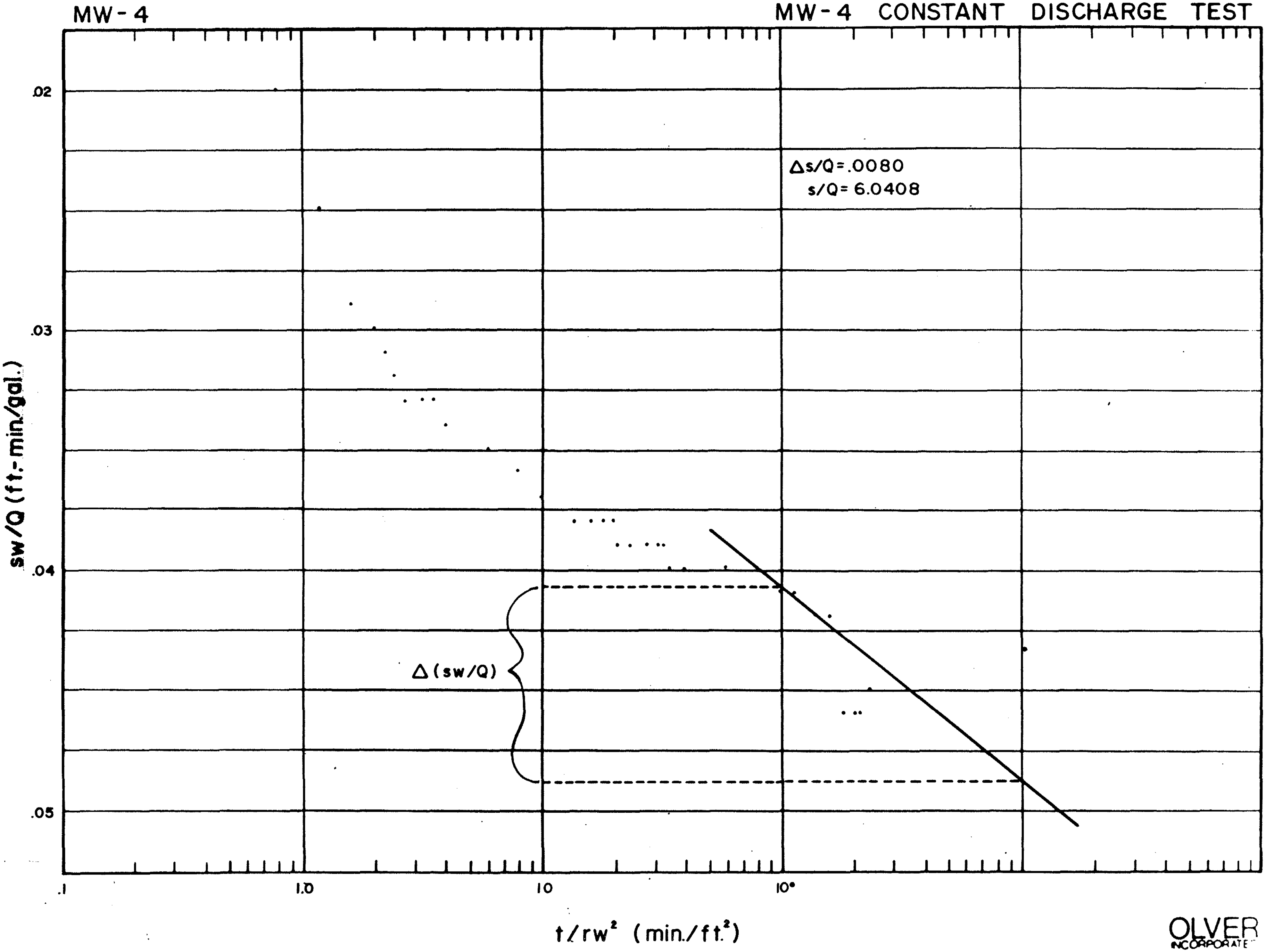
HANTUSH-JACOB METHOD

MW-4 RECOVERY TEST

HANTUSH MODIFIED METHOD

Laubenstein Well Data Plots 5/23/84
MW-1 Data Plots (5/22 & 23/84)

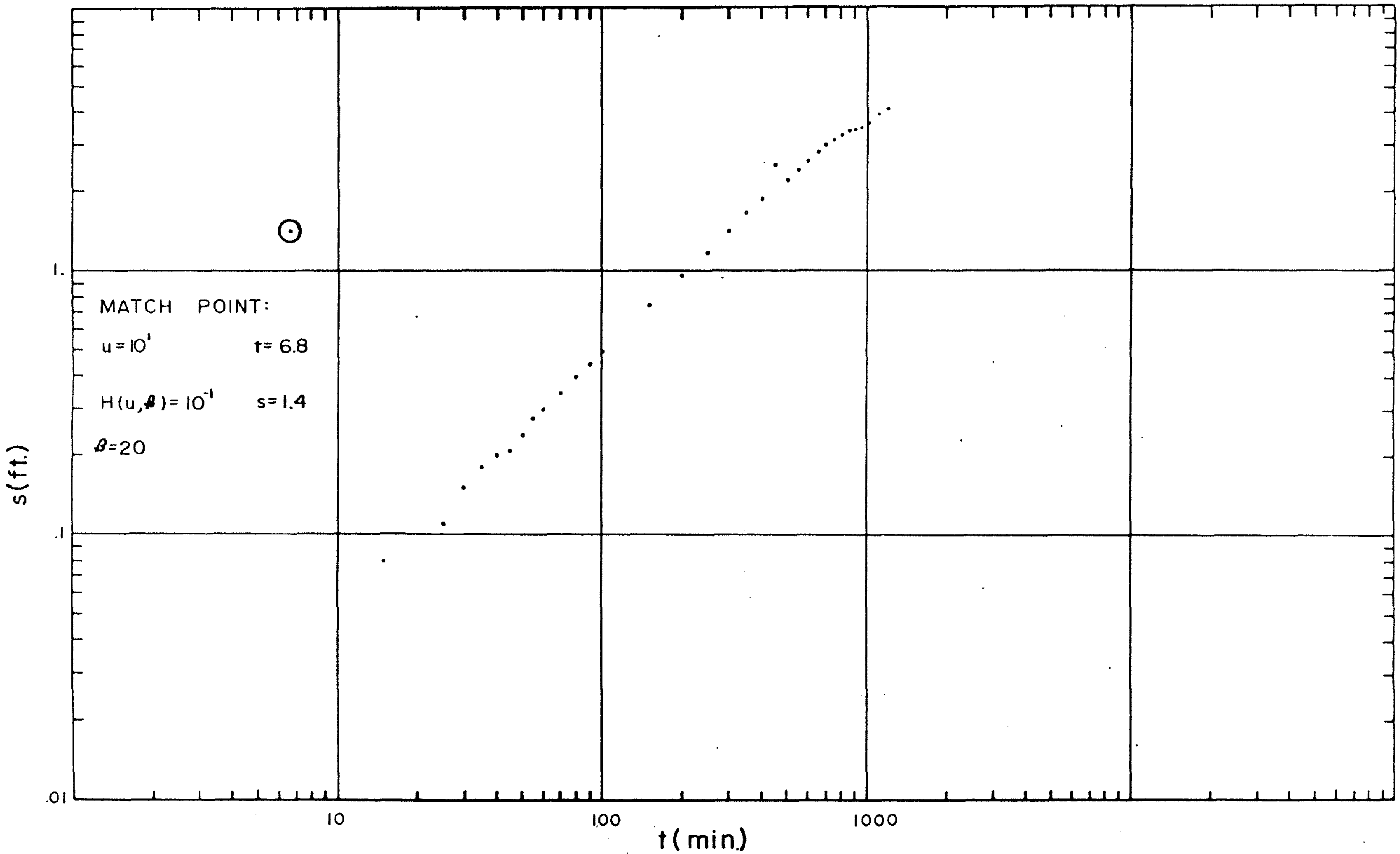
MW-4 CONSTANT DISCHARGE TEST



OLVER INCORPORATED

LAUBENSTEIN WELL

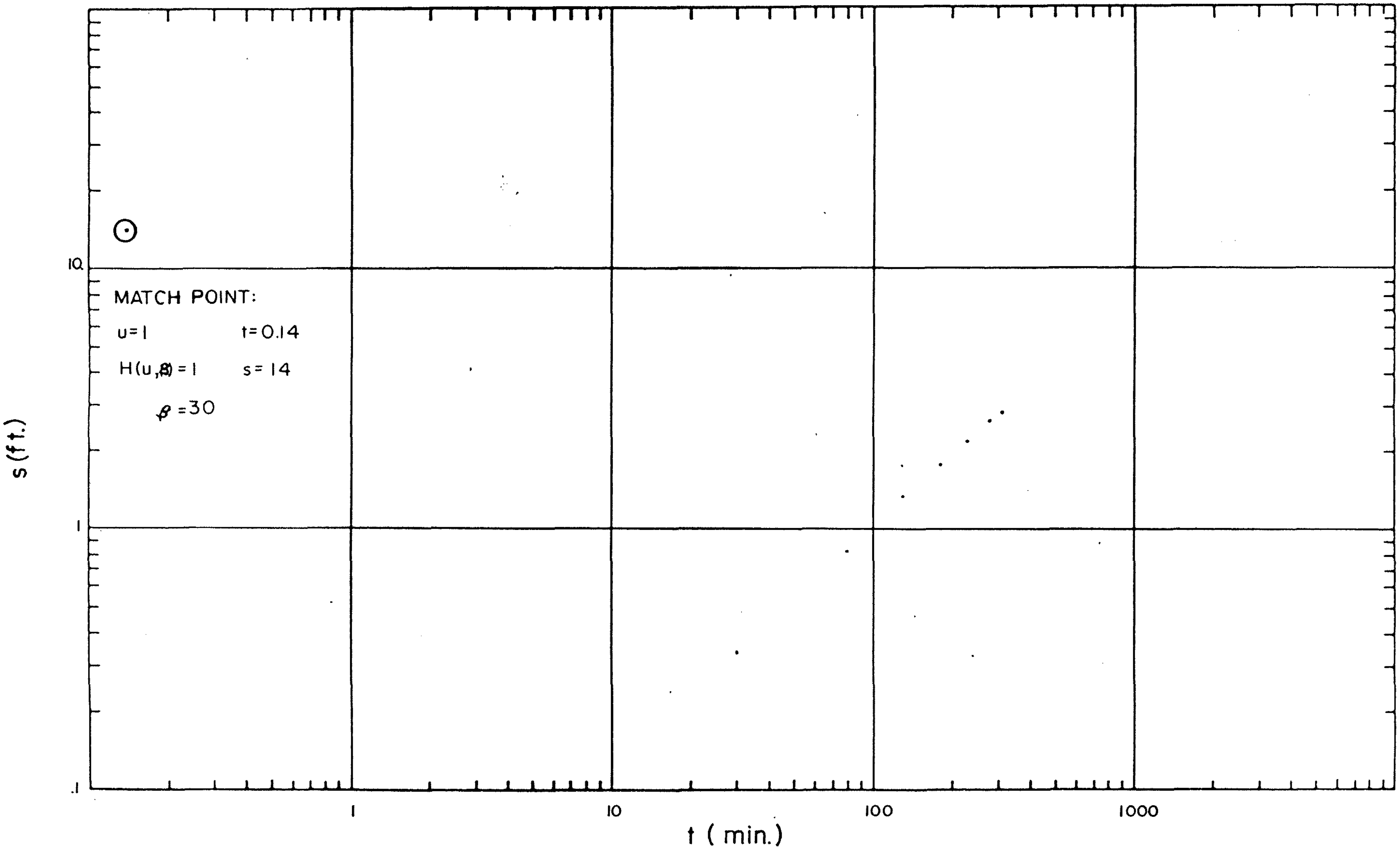
MW-4 CONSTANT DISCHARGE TEST



OLVER INCORPORATED

LAUBENSTEIN WELL

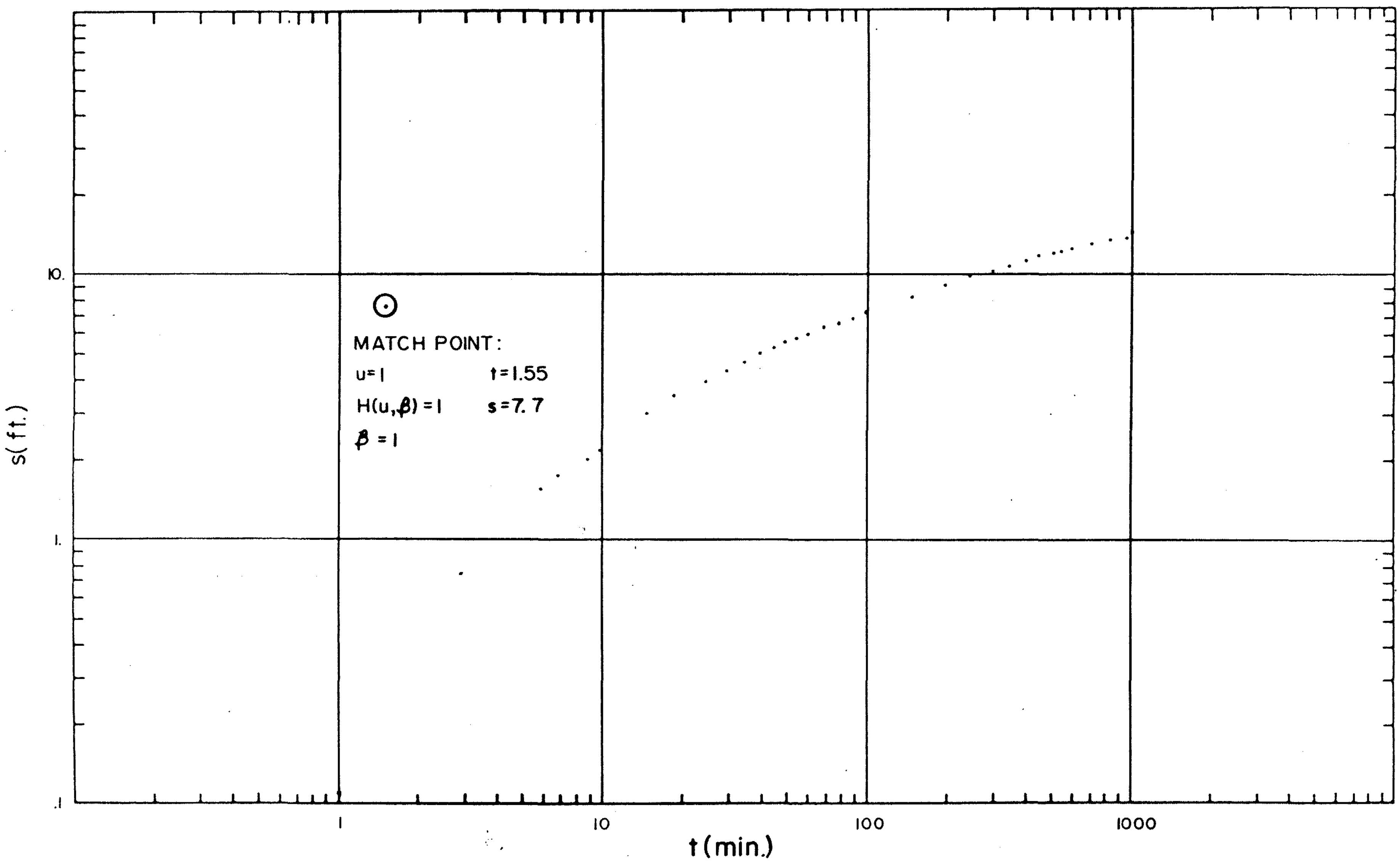
MW-4 CONSTANT DISCHARGE TEST
(WELL CUT ON DURING MW-1 TEST)



OLVER INCORPORATED

MW-1

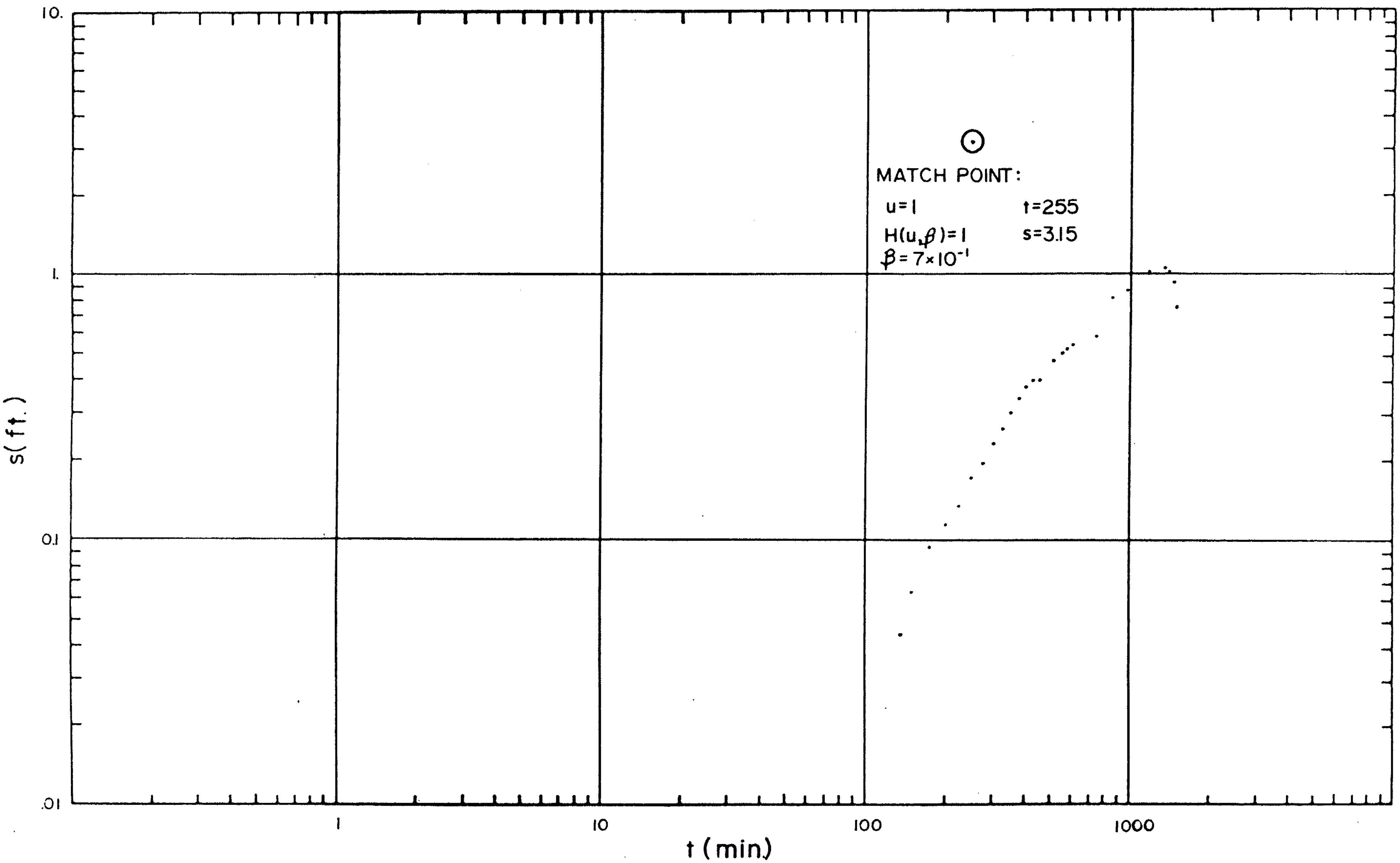
MW-4 CONSTANT DISCHARGE TEST



OLVER INCORPORATED

MW-3

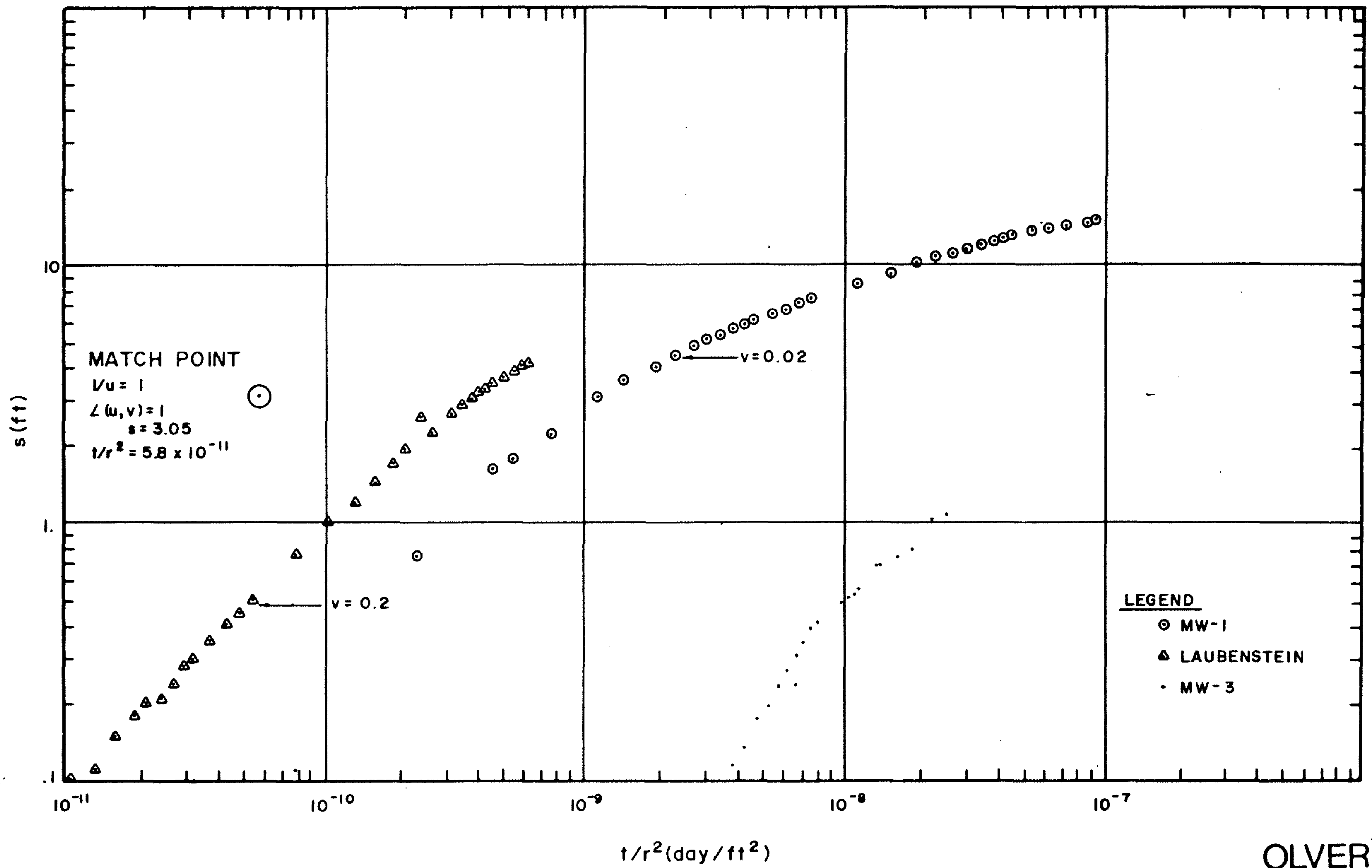
MW-4 CONSTANT DISCHARGE TEST



OLVER INCORPORATED

HANTUSH - JACOB METHOD

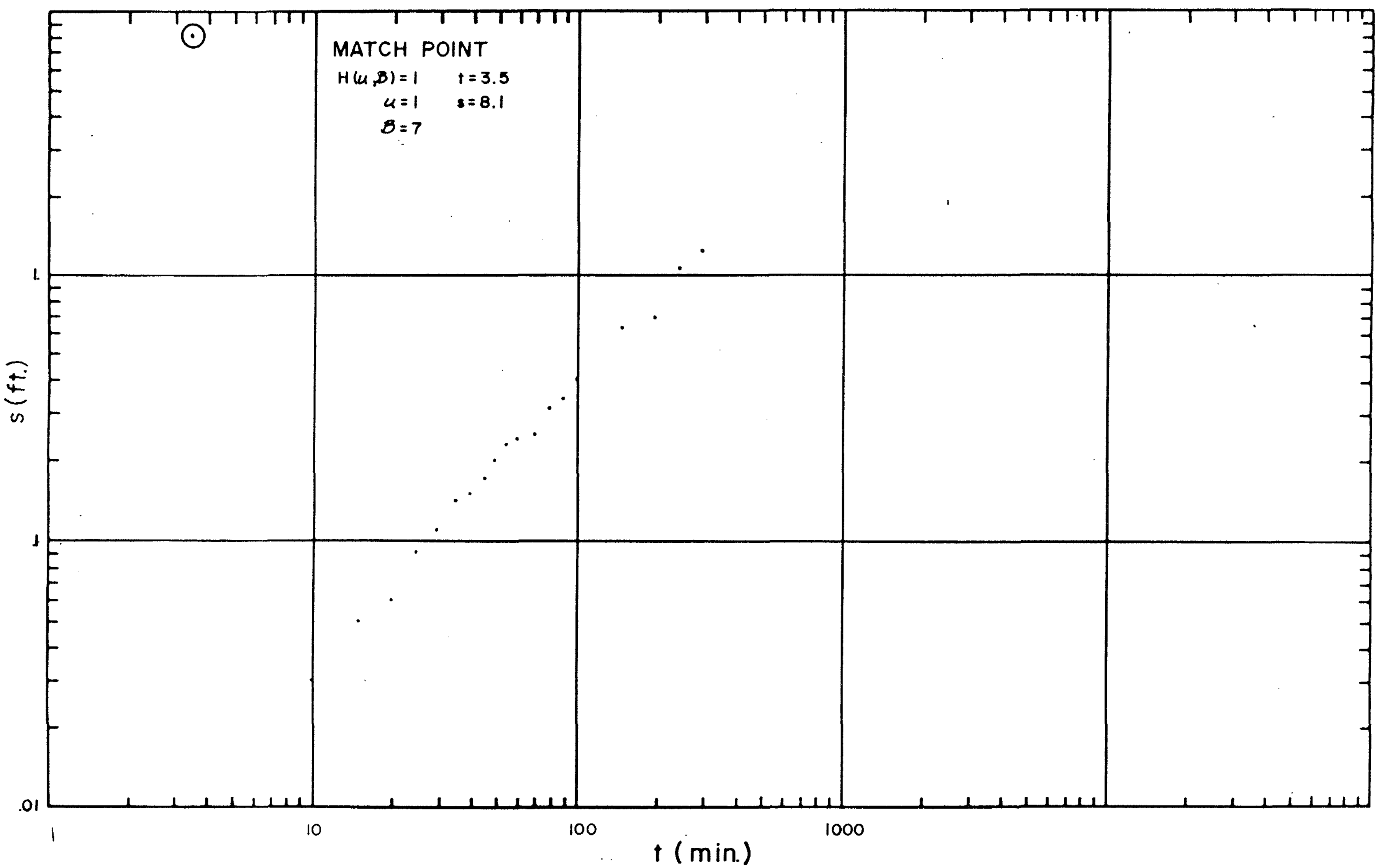
MW-4 CONSTANT DISCHARGE TEST



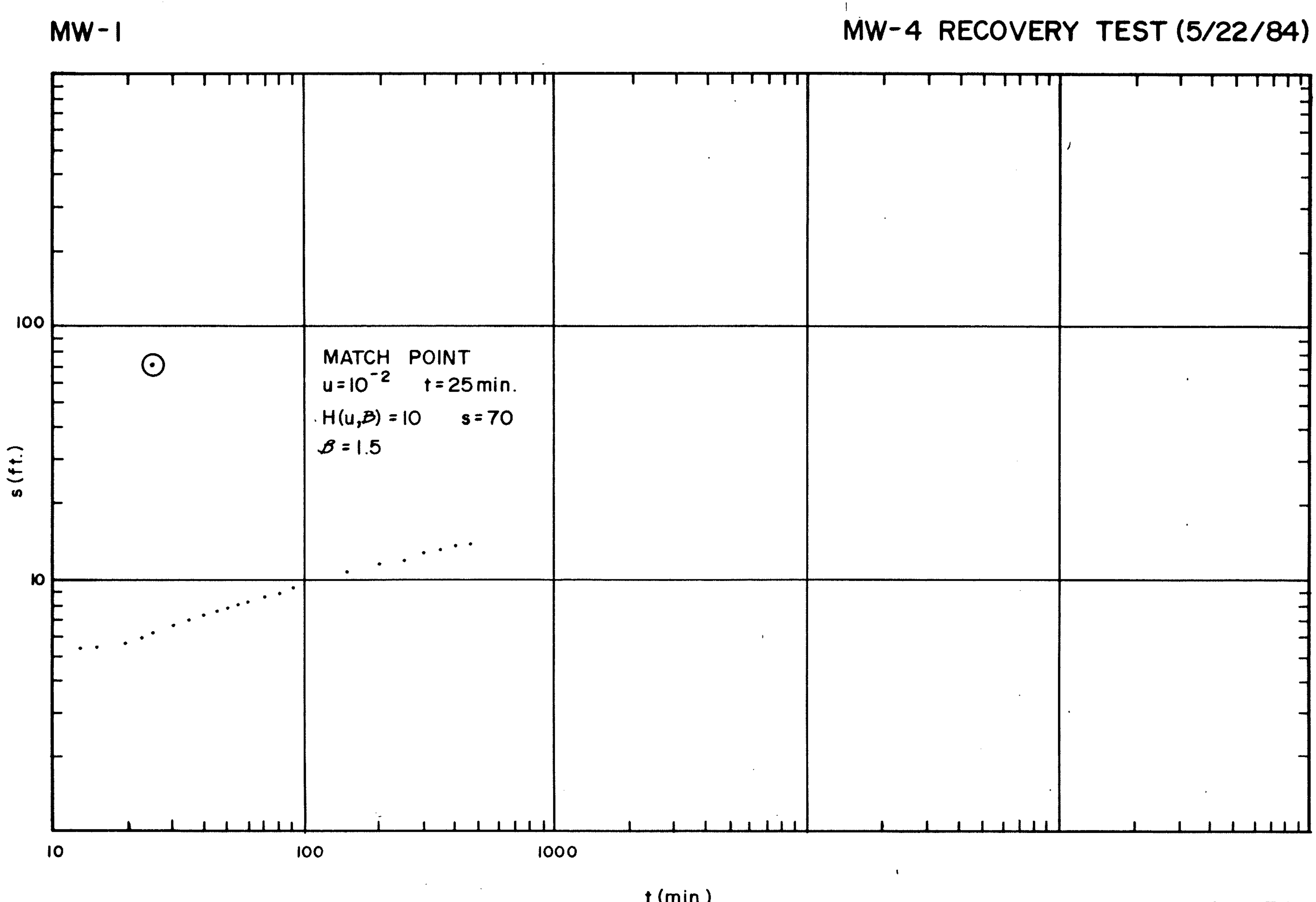
OLVER INCORPORATED

LAUBENSTEIN WELL

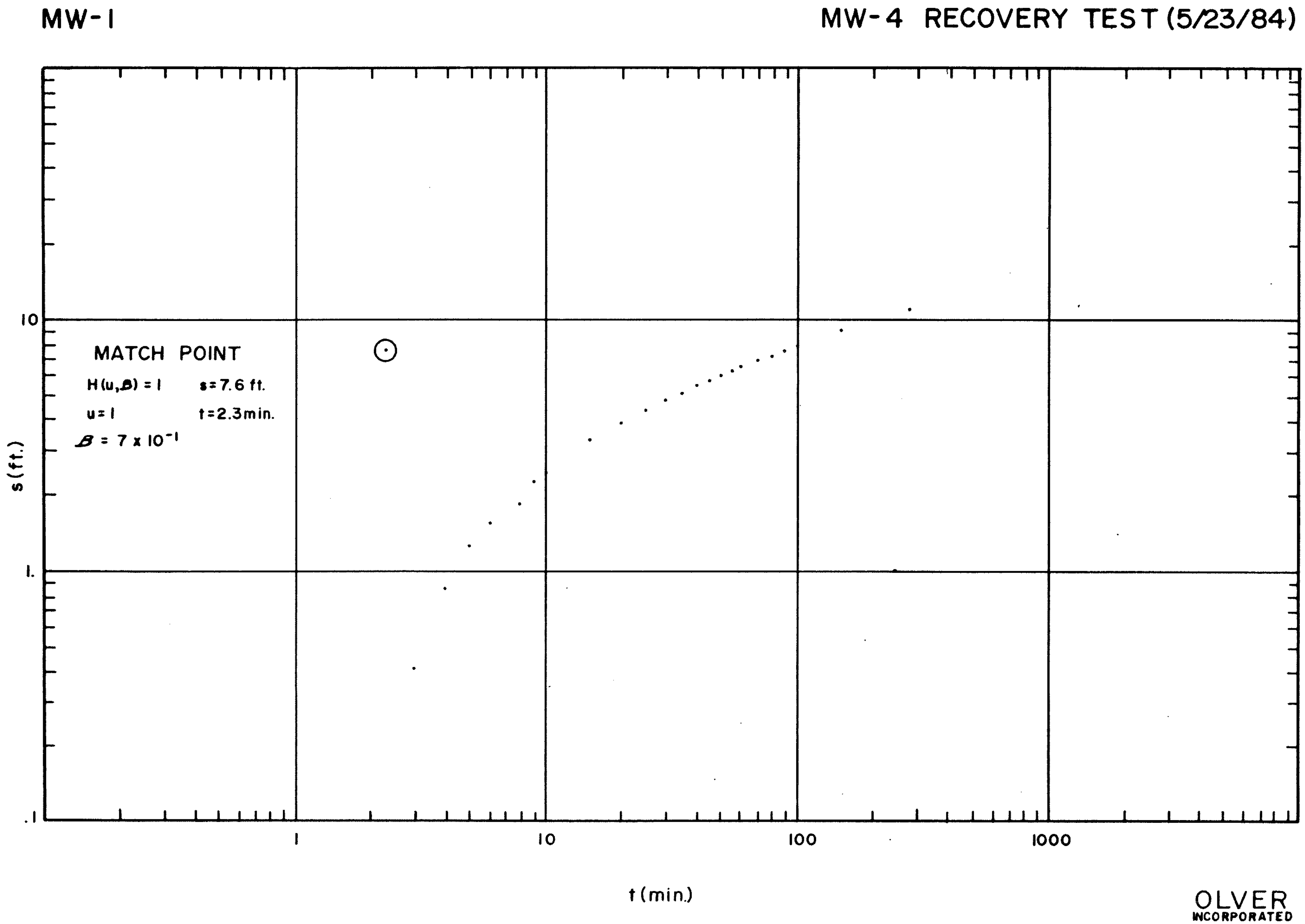
MW-4 RECOVERY TEST (5/23/84)



OLVER INCORPORATED



OLVER INCORPORATED


MW-1
MW-4 RECOVERY TEST (5/23/84)
MATCH POINT
H(u,β) = 1
s=7.6 ft.
u=1
t=2.3 min.
β = 7 x 10⁻¹
s(ft.)
t(min.)
10
1.
.1
1
10
100
1000
OLVER
INCORPORATED

APPENDIX IV

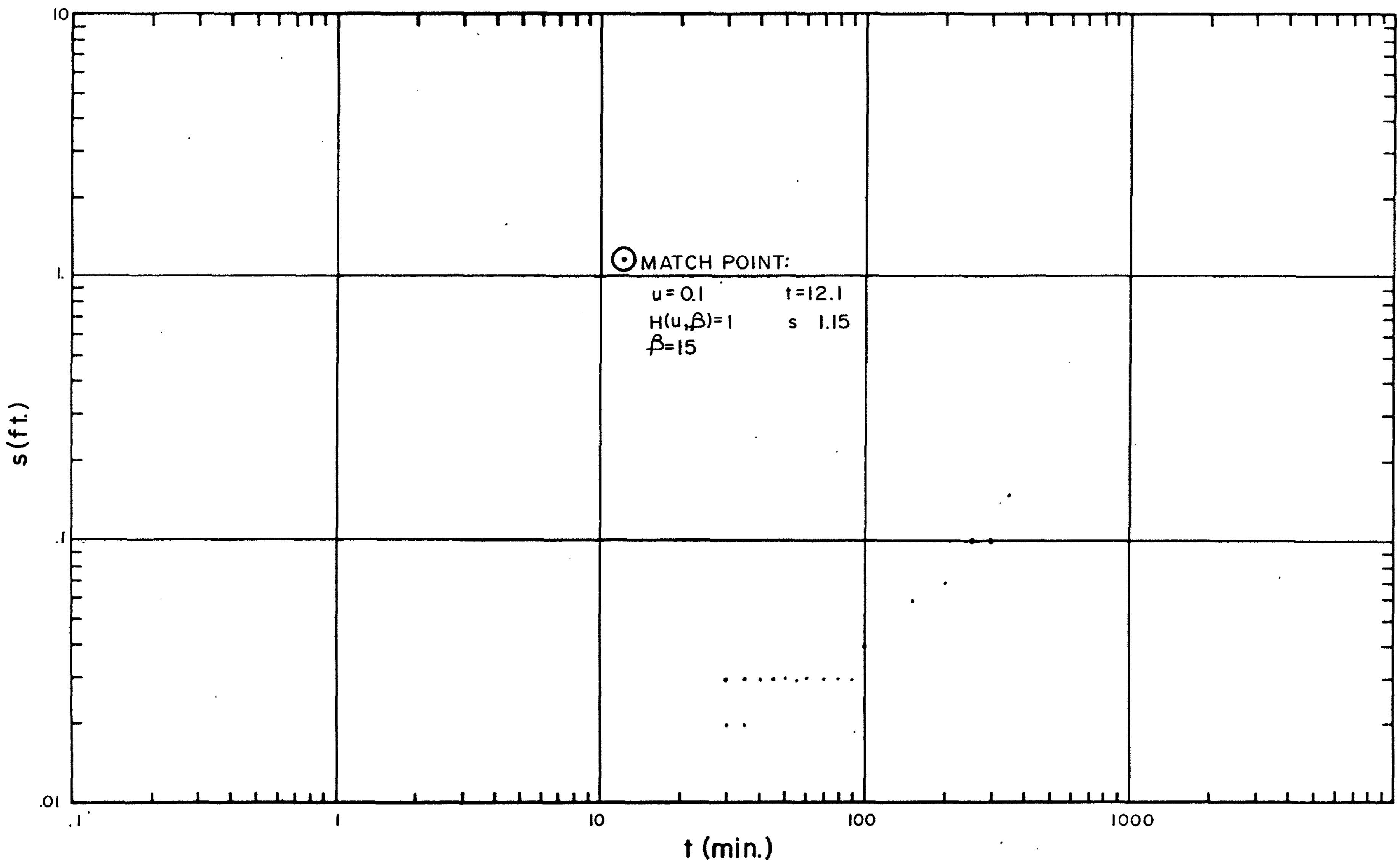
GEOPHYSICAL SURVEYS

APPENDIX V

LAUBENSTEIN WELL PACKER PUMP TEST DATA PLOTS

LAUBENSTEIN WELL PACKER PUMP TEST
ZONE: < 140 FT

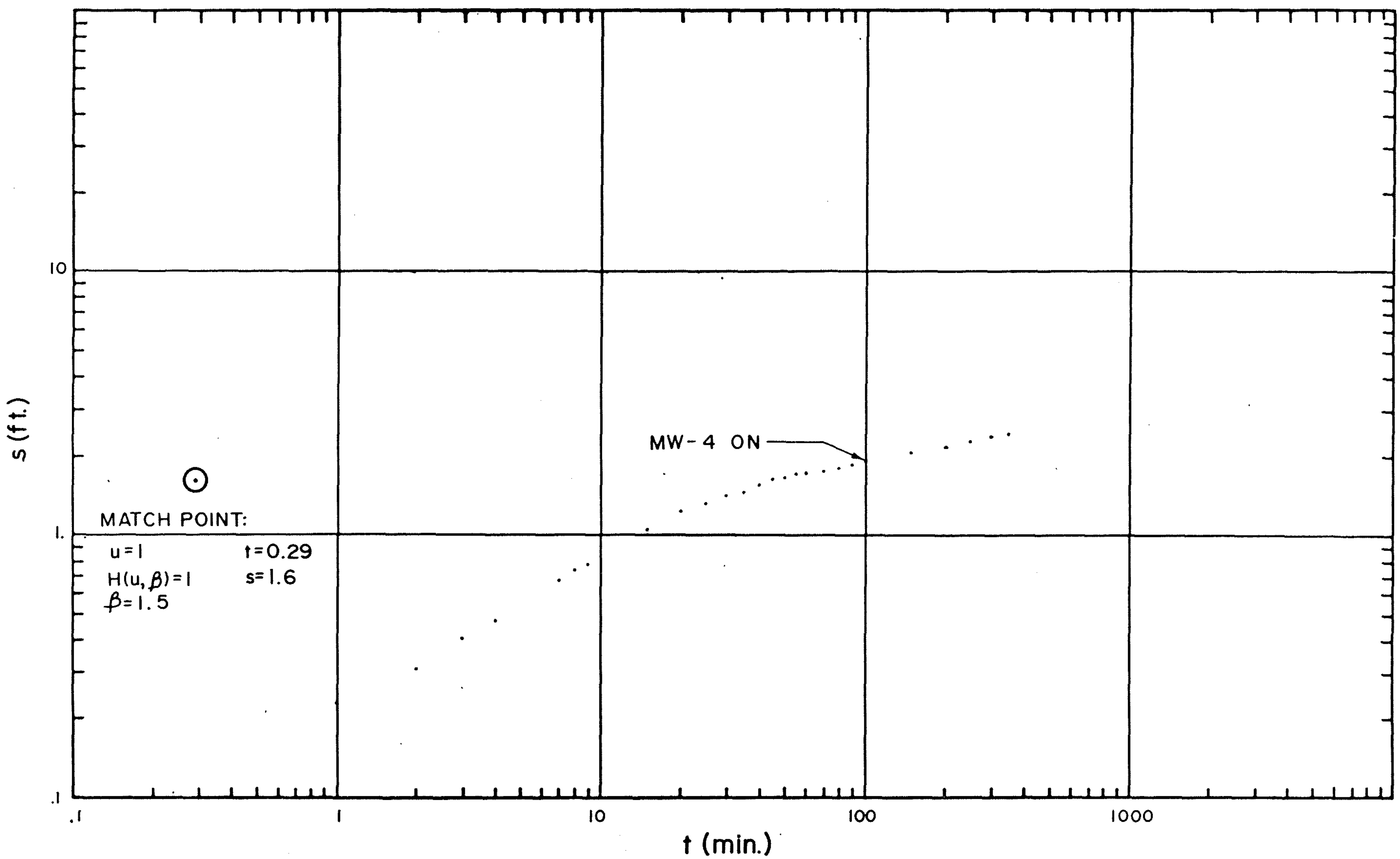
PZ-6



OLVER INCORPORATED

LAUBENSTEIN WELL PACKER PUMP TEST
ZONE: 270 – 320 FT.

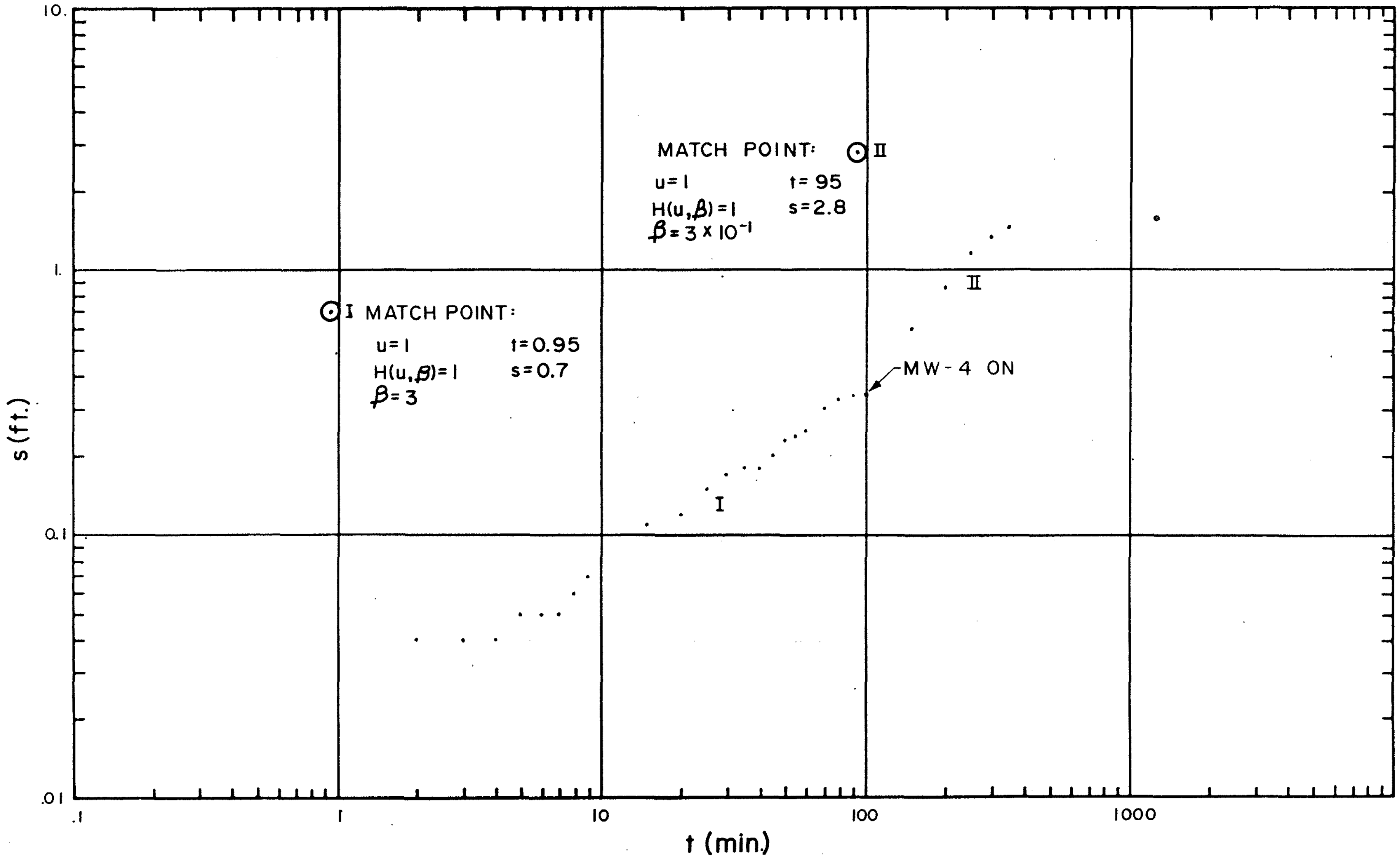
MW-1



OLVER INCORPORATED

MW-2

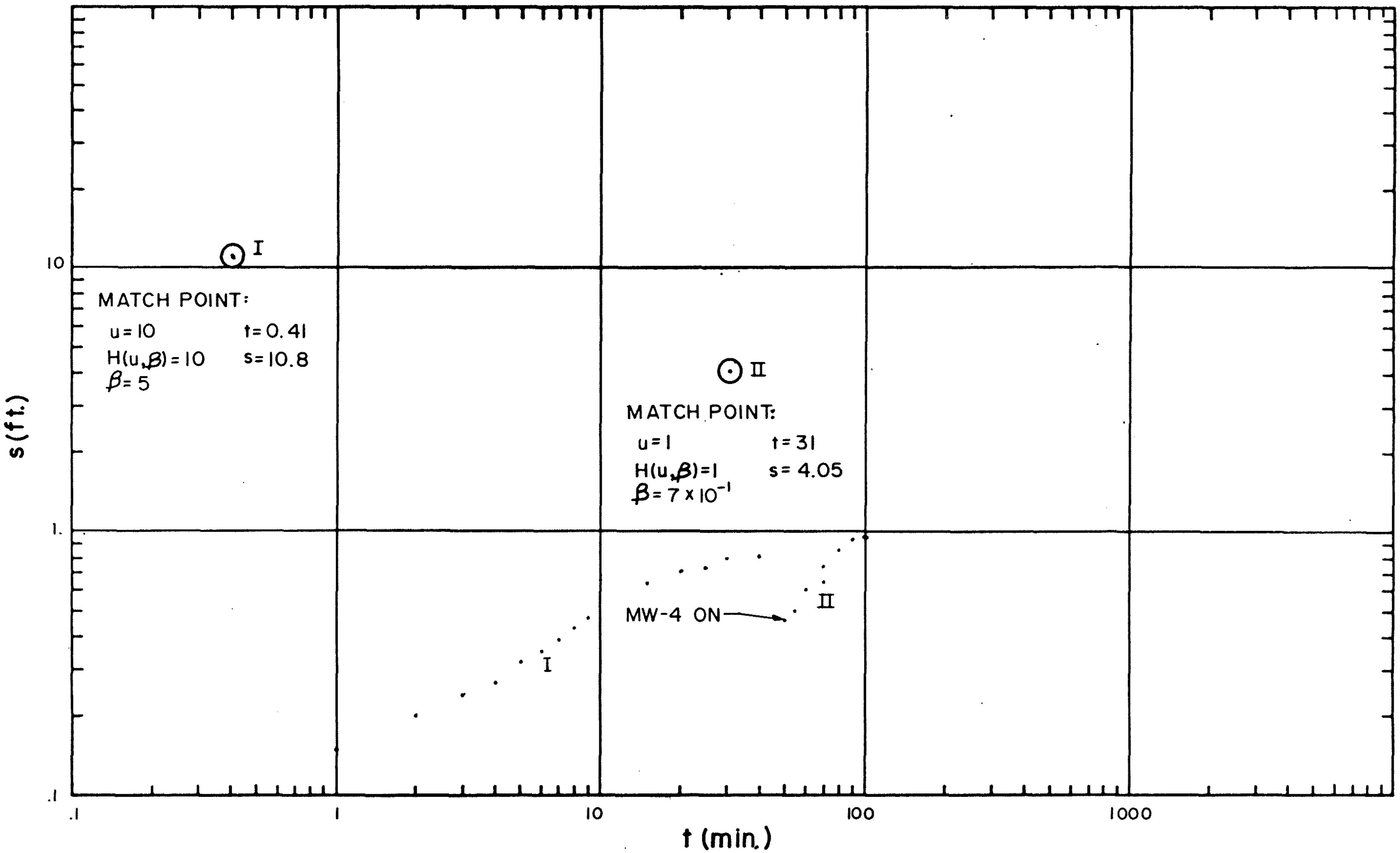
LAUBENSTEIN WELL PACKER PUMP TEST
ZONE: 270 - 320 FT



OLVER INCORPORATED

MW-1

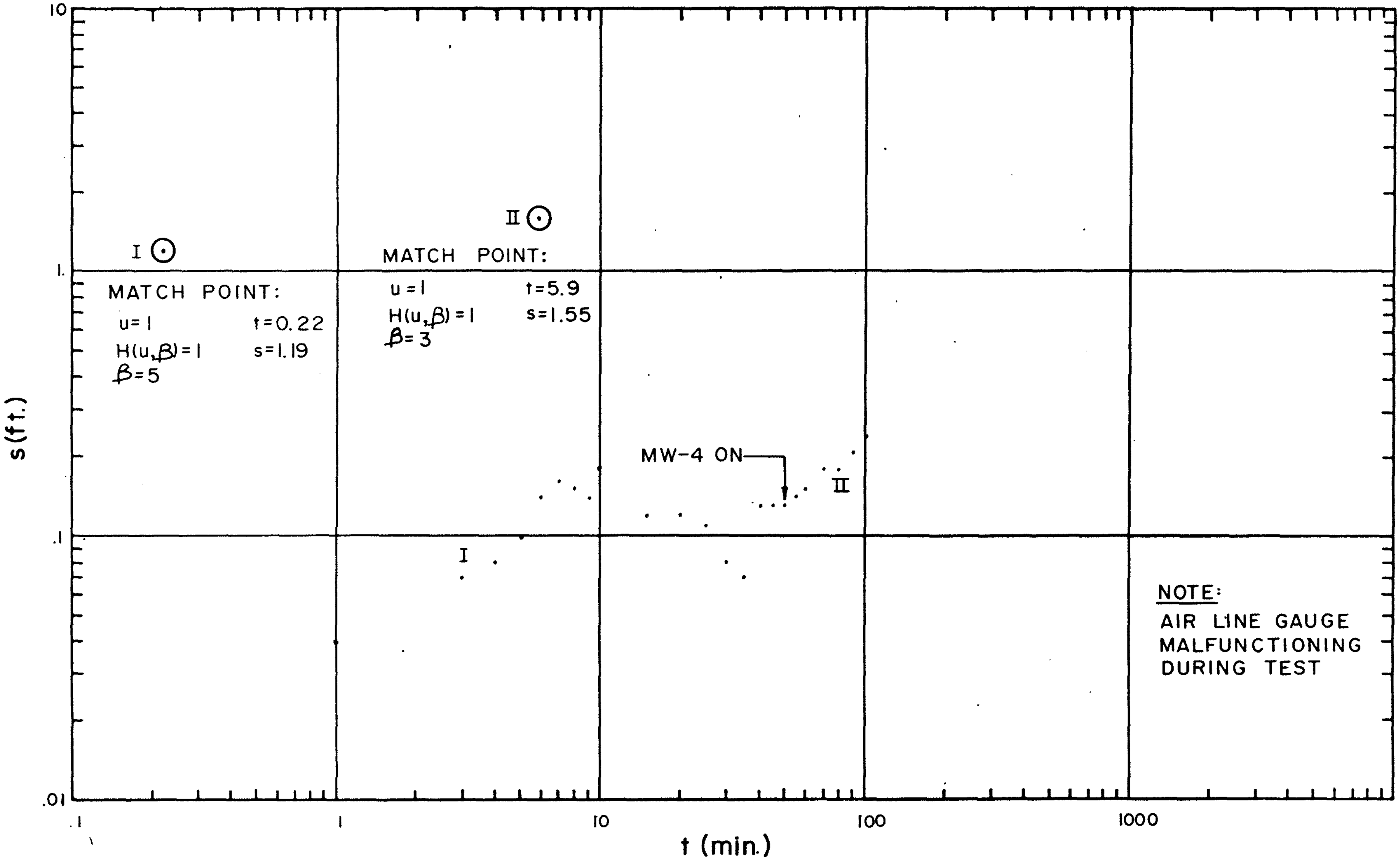
LAUBENSTEIN WELL PACKER PUMP TEST
ZONE: 280 – 330 FT.



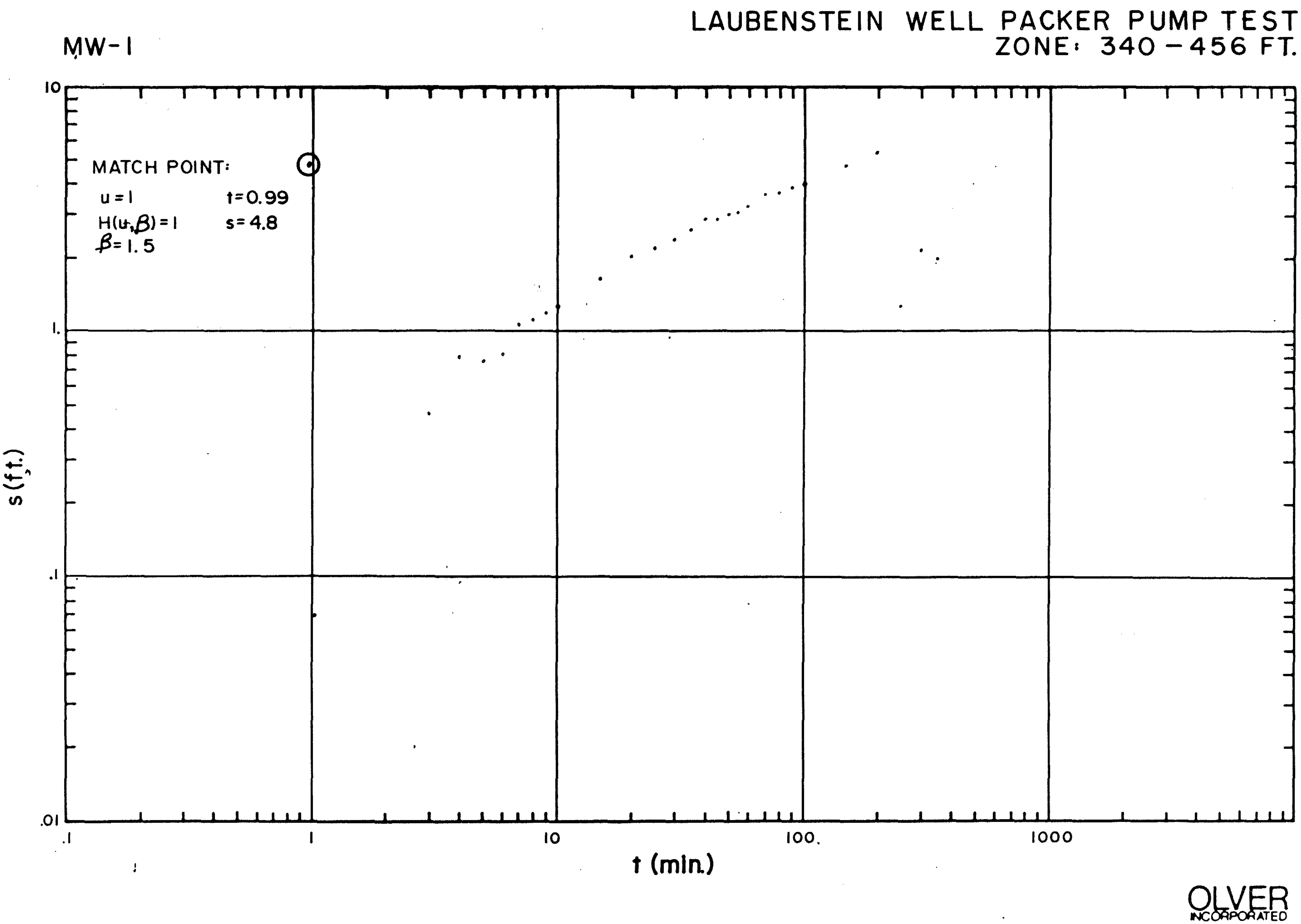
OLVER INCORPORATED

LAUBENSTEIN WELL PACKER PUMP TEST
ZONE: 280 – 330 FT.

MW-2



OLVER INCORPORATED


LAUBENSTEIN WELL PACKER PUMP TEST
ZONE: 340 – 456 FT.
MW-1
MATCH POINT:
u = 1
t = 0.99
H(u, β) = 1
s = 4.8
β = 1.5
s (ft.)
10
1.
.1
.01
.1
1
10
100.
1000
t (min.)
OLVER INCORPORATED

APPENDIX VI

LAUBENSTEIN WELL PACKER PUMP TEST
GROUND WATER QUALITY ANALYSES

NOTE ON ANALYTICAL RESULTS

Olver Incorporated performs organic analyses using Hewlett-Packard Models 5730A and 5790A gas chromatographs, and a Model 7675 purge and trap sampler. Due to the characteristics of this equipment, trichlorethylene and trans-1,2-dichlorethylene exhibit the same retention times. Consequently, it should be recognized that trans-1,2-dichloroethylene may be present, even though the analyses report trichloroethylene concentrations.

OLVER INCORPORATED Consulting Engineers • Environmental Laboratories
1531 North Main Street Blacksburg, Virginia 24060 (703) 552-5548

Client Sheet No. 4615 Job No. 30519

Date August 16, 1984 Date Received 7/20/84 - 7/26/84

Client Freeman Chemical Corporation

Source Laubenstien Packer Pump Test

Shipping Information Delivered to Olver Incorporated by Federal Express

Sample No.:	17089	17090
Time Collected:	9:26 a.m.	9:54 a.m.
Date Collected:	7/16/84	7/16/84
Description:	Depth: 340 Feet-Bottom	Depth: 340 Feet-Bottom

Analysis:

pH	7.0	7.3
Chemical Oxygen Demand	12 mg/l	<5 mg/l
Trichloroethylene	25 ppb	28 ppb
Benzene	44 ppb	78 ppb
Ethyl Benzene	26 ppb	17 ppb
Toluene	<1 ppb	<1 ppb
Styrene	<1 ppb	1 ppb
Total Xylene	2 ppb	1 ppb

All tests according to Standard Methods for the Examination of Water and Wastewater, 15th Edition and Methods for the Chemical Analysis of Water and Wastes, EPA.

By: Elizabeth Smiley
Elizabeth B. Smiley
Laboratory Director

Revised 1/10/85

EBS/glh

Unless otherwise indicated, this report sets forth the results of our analysis of samples delivered to our laboratory and shall not be construed to be a representation by Olver Incorporated as to the source or method of procuring such samples. All reports are submitted as the confidential property of clients and authorization for publication of any statements contained in our reports is reserved pending our written approval.

OLVER
INCORPORATED

Client Sheet No.	4615
Page	Page Two
Client	Freeman Chemical Corporation
Date	August 16, 1984

Sample No.:	17092	17094
Time Collected:	11:01 a.m.	1:21 p.m.
Date Collected:	7/16/84	7/16/84
Description:	Depth: 340 Feet-Bottom	Depth: 340 Feet-Bottom

Analysis:

pH	7.4	7.5
Chemical Oxygen Demand	8 mg/l	<5 mg/l
Trichloroethylene	23 ppb	23 ppb
Benzene	46 ppb	50 ppb
Ethyl Benzene	7 ppb	4 ppb
Toluene	<1 ppb	<1 ppb
Styrene	3 ppb	3 ppb
Total Xylene	<1 ppb	2 ppb

Sample No.:	17096	17097
Time Collected:	2:58 p.m.	2:50 p.m.
Date Collected:	7/16/84	7/16/84
Description:	Depth: 340 Feet-Bottom	Saukville Feeds N.W. Tank Pit

Analysis:

pH	7.6	7.5
Chemical Oxygen Demand	<5 mg/l	38 mg/l
Trichloroethylene	18 ppb	20 ppb
Benzene	40 ppb	1 ppb
Ethyl Benzene	3 ppb	<1 ppb
Toluene	<1 ppb	<1 ppb
Styrene	<1 ppb	<1 ppb
Total Xylene	2 ppb	9 ppb

OLVER
INCORPORATED

Client Sheet No. 4615
Page Page Three
Client Freeman Chemical Corporation
Date August 16, 1984

Sample No.:	17122*	17123*
Time Collected:	12:00 p.m.	12:15 p.m.
Date Collected:	7/18/84	7/18/84
Description:	Depth: 270 Feet-320 Feet	Depth: 270 Feet-320 Feet

Analysis:

pH	7.5	7.7
Chemical Oxygen Demand	<5 mg/l	33 mg/l
Trichloroethylene	73 ppb	62 ppb
Benzene	73 ppb	80 ppb
Ethyl Benzene	20 ppb	40 ppb
Toluene	7 ppb	<1 ppb
Styrene	2 ppb	3 ppb
Total Xylene	7 ppb	2 ppb

*Air bubbles were present in sample vial.

Sample No.:	17124*	17125
Time Collected:	12:30 p.m.	12:45 p.m.
Date Collected:	7/18/84	7/18/84
Description:	Depth: 270 Feet-320 Feet	Depth: 270 Feet-320 Feet

Analysis:

pH	7.8	7.7
Chemical Oxygen Demand	21 mg/l	16 mg/l
Trichloroethylene	59 ppb	40 ppb
Benzene	86 ppb	62 ppb
Ethyl Benzene	23 ppb	11 ppb
Toluene	2 ppb	1 ppb
Styrene	<1 ppb	1 ppb
Total Xylene	<1 ppb	<1 ppb

OLVER
INCORPORATED

Client Sheet No.	4615
Page	Page Four
Client	Freeman Chemical Corporation
Date	August 16, 1984

Sample No.:	17127	17129*
Time Collected:	1:45 p.m.	2:45 p.m.
Date Collected:	7/18/84	7/18/84
Description:	Depth: 270 Feet-320 Feet	Depth: 270 Feet-320 Feet

Analysis:

pH	7.7	7.6
Chemical Oxygen Demand	23 mg/l	14 mg/l
Trichloroethylene	76 ppb	61 ppb
Benzene	94 ppb	111 ppb
Ethyl Benzene	14 ppb	18 ppb
Toluene	<1 ppb	<1 ppb
Styrene	<1 ppb	3 ppb
Total Xylene	1 ppb	<1 ppb

Sample No.:		
Time Collected:	17131	17133*
Date Collected:	3:45 p.m.	4:45 p.m.
Description:	7/18/84 Depth: 270 Feet-320 Feet	7/18/84 Depth: 270 Feet-320 Feet

Analysis:

pH	7.7	7.8
Chemical Oxygen Demand	5 mg/l	5 mg/l
Trichloroethylene	37 ppb	27 ppb
Benzene	78 ppb	32 ppb
Ethyl Benzene	12 ppb	8 ppb
Toluene	1 ppb	5 ppb
Styrene	2 ppb	<1 ppb
Total Xylene	<1 ppb	4 ppb

OLVER
INCORPORATED

Client Sheet No.	4615
Page	Page Five
Client	Freeman Chemical Corporation
Date	August 16, 1984

Sample No.:	17135*	17190
Time Collected:	5:45 p.m.	8:45 a.m.
Date Collected:	7/18/84	7/24/84
Description:	Depth: 270 Feet- 320 Feet	Depth: <140 Feet

Analysis:

pH	7.9	7.8
Chemical Oxygen Demand	<5 mg/l	31 mg/l
Trichloroethylene	28 ppb	36 ppb
Benzene	28 ppb	119 ppb
Ethyl Benzene	32 ppb	122 ppb
Toluene	30 ppb	22 ppb
Styrene	<1 ppb	<1 ppb
Total Xylene	<1 ppb	1 ppb

Sample No.:	17191	17192
Time Collected:	9:00 a.m.	9:15 a.m.
Date Collected:	7/24/84	7/24/84
Description:	Depth: <140 Feet	Depth: <140 Feet

Analysis:

pH	7.7	7.7
Chemical Oxygen Demand	29 mg/l	25 mg/l
Trichloroethylene	57 ppb	31 ppb
Benzene	189 ppb	78 ppb
Ethyl Benzene	96 ppb	140 ppb
Toluene	20 ppb	12 ppb
Styrene	<1 ppb	<1 ppb
Total Xylene	20 ppb	38 ppb

OLVER
INCORPORATED

Client Sheet No.	4615
Page	Page Six
Client	Freeman Chemical Corporation
Date	August 16, 1984

Sample No.:	17201	17203
Time Collected:	1:30 p.m.	2:30 p.m.
Date Collected:	7/24/84	7/24/84
Description:	Depth: <140 Feet	Depth: <140 Feet

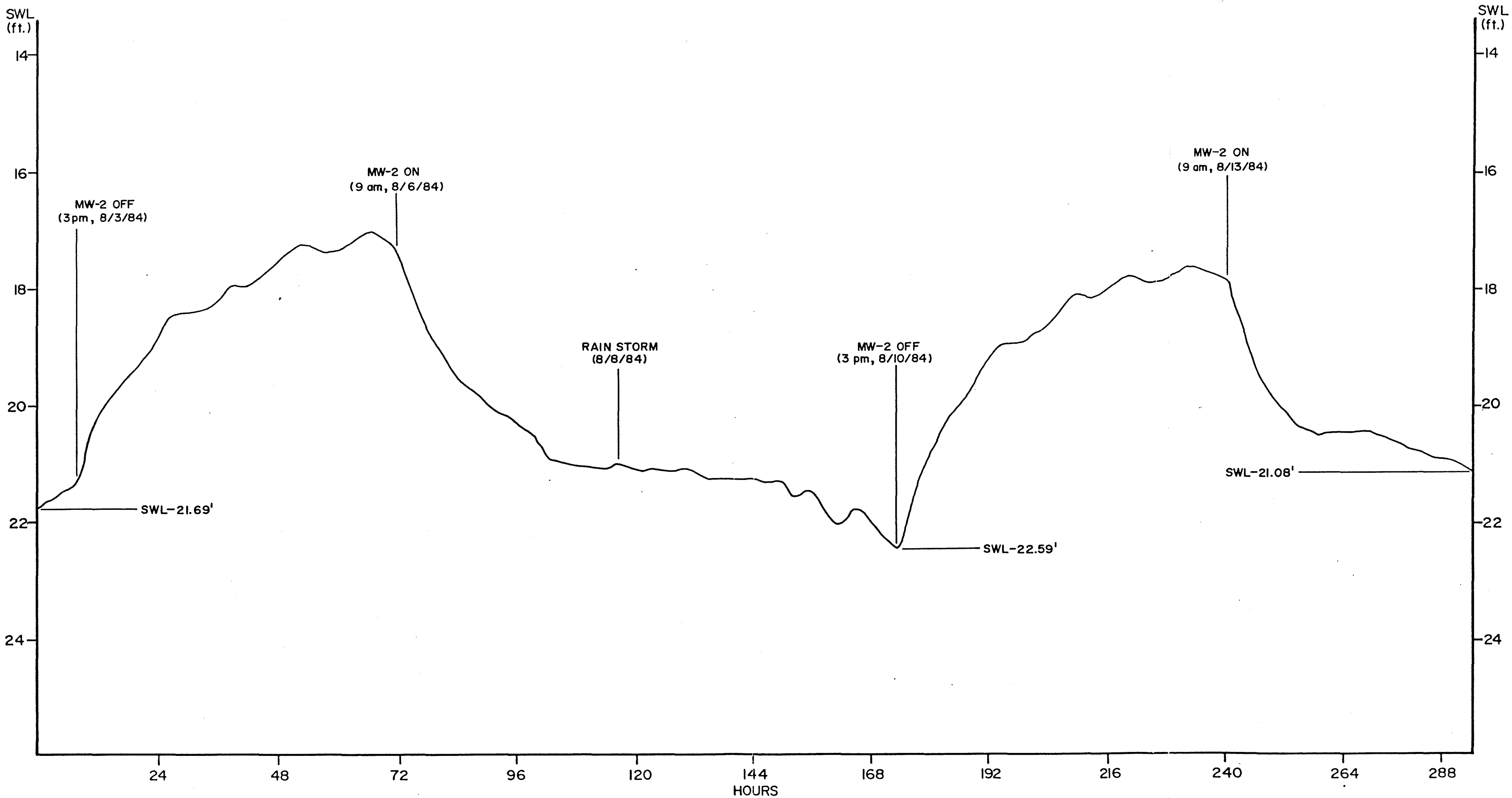
Analysis:

pH	7.7	7.7
Chemical Oxygen Demand	21 mg/l	10 mg/l
Trichloroethylene	37 ppb	37 ppb
Benzene	127 ppb	127 ppb
Ethyl Benzene	121 ppb	126 ppb
Toluene	4 ppb	3 ppb
Styrene	<1 ppb	<1 ppb
Total Xylene	27 ppb	24 ppb

APPENDIX VII

WATER LEVEL FLUCTUATIONS IN LAUBENSTEIN WELL
AFTER INSTALLATION OF PNEUMATIC PACKER

OLVER
INCORPORATED



OLVER INCORPORATED Consulting Engineers • Environmental Laboratories 1531 NORTH MAIN STREET BLACKSBURG, VIRGINIA 24060 (703) 552-5548	Designed: JWD Drawn: TLM Checked: JWD	Scale: SHOWN Job No.: 10519 Date: 7/17/84	HYDROGEOLOGIC ASSESSMENT AT SAUKVILLE, WISCONSIN	Rev.	Description	Date	By	LAUBENSTEIN WELL WATER LEVEL RECORD (PNEUMATIC PACKER AT 80 FT)	Drawing No.

APPENDIX VIII

VERIFICATION OF AQUIFER CHARACTERISTICS

VERIFICATION OF AQUIFER CHARACTERISTICS
FROM DRAWDOWN DATA IN THE LAUBENSTEIN WELL (6/11/84)

GOVERNING EQUATIONS

$$T = \frac{QH(u,\beta)}{4\pi s} \qquad S = \frac{4Ttu}{r^2}$$

CALCULATIONS

MW-4:

$T = 950\ ft^2/day$
$S = 1.4 \times 10^{-7}$
$Q = 167,800\ ft^2/day$
$t = 2$ hours $= 8.3 \times 10^{-2}$ days (from chart)
$r = 3600$ ft
$\beta = 20$

$$1.4 \times 10^{-7} = \frac{4(950)(8.3x10-2)}{3600^2} u \Rightarrow u = 5.75 \times 10^{-3} \Rightarrow H(u,\beta) = 4.4 \times 10^{-2}$$

$$950 = \frac{167,800(4.4 \times 10^{-2})}{4\ s_t} \Rightarrow s_t = 0.62 \text{ ft}$$

where, s_t = theoretical drawdown

MW-2:

$T = 520\ ft^2/day$
$S = 5 \times 10^{-7}$
$Q = 38,800\ ft^3/day$
$\beta = 7$
$r = 760$ ft
$t = 5.5$ hrs $= 0.46$ days (from chart)

$$5 \times 10^{-7} = \frac{4(520)(0.46)}{760^2} u \Rightarrow u = 3.02 \times 10^{-4} \Rightarrow H(u,\beta) = 1.0$$

$$520 = \frac{38,800(1)}{4\pi s_t} \Rightarrow s_t = 5.94 \text{ ft}$$

TOTAL OBSERVED DRAWDOWN

MW-4: $s_o = 0.30$ ft
MW-2: $s_o = 6.35$ ft

$s_{to} = 6.65$ ft

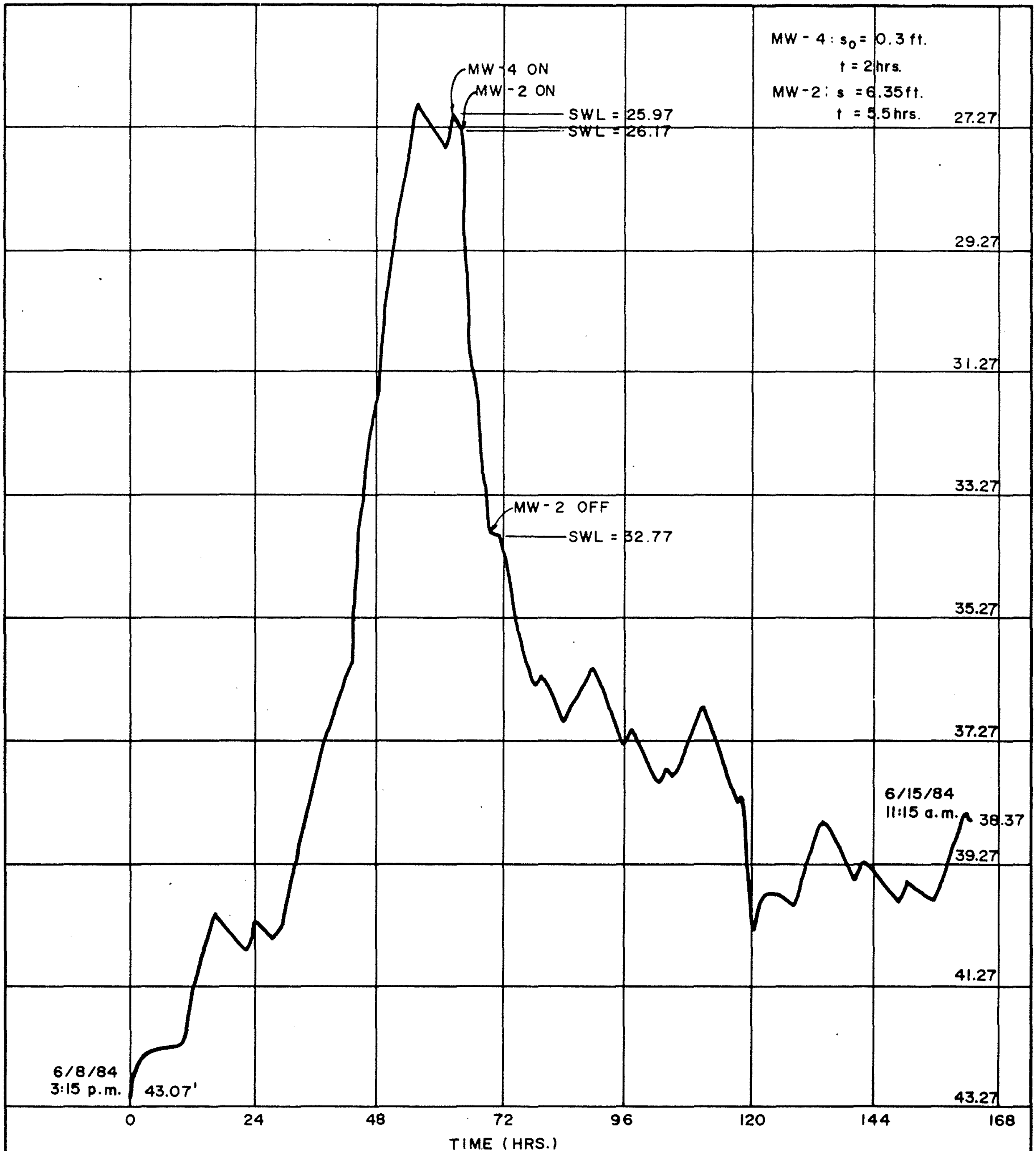
where, s_o = observed drawdown
s_{to} = total observed drawdown

THEORETICAL DRAWDOWN

MW-4: s_t = 0.62 ft
MW-2: s_t = 5.94 ft

s_{tt} = 6.56 ft where, s_{tt} = total theoretical drawdown

Difference between theoretical and observed drawdowns is 0.09 ft (1.08 in) which is within the range of instrumentation error.



HYDROGEOLOGIC ASSESSMENT AT SAUKVILLE, WISCONSIN

LAUBENSTEIN WELL CONTINUOUS WATER LEVEL RECORD

(6/8-15/84)