RESPONSE OF RRGE-1 TO 298 GPM ARTESIAN

TEST BEGINNING FEBRUARY 3, 1982

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CONTENTS

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DISCHARGE RATE

This is basically a 7110.33 min duration 298 gpm artesian flow test. Prior to beginning the test, a 15 gpm freeze prevention and wellbore heatup discharge was maintained for several days. The 298 gpm flow was initiated at 20:00:00 on February 3, 1982. The discharge rate for the initial 11 min is somewhat uncertain since the strip chart recorder failed but appears to be between 290 and 298 gpm. For the interval $11 \leq t \leq 14$ min the discharge rate was 290 gpm. For the period $14 \leq t$ 17 min, the discharge rate was 299 gpm. The discharge rate declined to 297 gpm at $t = 18.5$ min and remained at 297 gpm until $t = 43$ min when the discharge rate increased to 298 gpm which was maintained until well shut-in at $t = 7110.33$ min. The excellent discharge control for $t \geq 17$ min resulted in good quality data suitable for defining the well productivity and reservoir characteristics.

WELLHEAD TEMPERATURE

The wellhead resistance thermometer device (RTD) temperature at the beginning of the test was approximately 270.5°F. The temperature gradually increased to 274°F at $t = 75$ min. The temperature remained between 273.5 and 274.0°F during the remainder of the test. The mercury thermometer indicated a temperature between 274.1 and 274.8°F for the period $75 \leq t \leq 7110.33$ min. It is concluded that the wellhead temperature during this test was approximately 274°F.

ANNULUS WELLHEAD AND BUBBLER PRESSURES

Drawdown

Early Time

Pressure data were collected in the annulus between the pump column and the well casing using both a Digiquartz system and Heise gauge at the wellhead and a Digiquartz system and Heise gauge connected to a bubbler tube. Figure 1 is a semilogarithmic plot of annulus wellhead Heise pressure and annulus bubbler Heise pressure during drawdown. Figure 2 is a semilogarithmic plot of annulus wellhead Digiquartz pressure during drawdown. Essentially no Digiquartz bubbler pressure data were collected during drawdown. In Figure 1, the Heise wellhead data indicate an apparent recharge type boundary affected the data for t ≥ 10.8 min. The initial data where 0.5 ≤ t ≤ 7 min has a Δs of 13.4 psi/log cycle and a Q/Δs of 22.2 gpm/psi/log cycle. These data are entered in Table 1 which lists the pertinent hydrologic data obtained during this test. The kh which is the reservoir intrinsic transmissivity (k is the permeability coefficient and h is the reservoir thickness) has an estimated value of 22317 md-ft while the ϕch which is the reservoir storativity (ϕ is the reservoir effective porosity and c is the reservoir compressibility) has an estimated value of 0.0148 ft/psi. The transmissivity and storage coefficient are estimated to be 2362 gpd/ft and 0.00597 respectively (Table 1). Because of uncertainty in the discharge rate for the initial 11 min of the test, these estimates for the reservoir parameters could have significant errors associated with them. The Heise bubbler pressure drawdown in Figure 1 did not follow a credible linear trend for the period prior to 21 min. Thus, an estimate for kh and ϕch is not possible using these data. The Digiquartz wellhead pressure data in Figure 2 has a Δs and a Q/Δs of 17.2 psi/log cycle and 17.3 gpm/psi/log cycle respectively for the period where 0.83 ≤ t ≤ 4.0 min. An apparent recharge boundary affects the data after t = 7.3 min. The estimates for kh and ϕch are 17386 md-ft and 0.0446 ft/psi respectively. The transmissivity and storage coefficient are 1840 gpd/ft and 0.0179 respectively. The reason for the large discrepancies between the wellhead Heise and Digiquartz data is not known although the Digiquartz data are probably more reliable. These "early" time data strongly suggest that an apparent recharge boundary affects the drawdown data perhaps as late as 10.8 min after initiating pumping.

Late Time

The late time data where t > 10.8 min have significantly different slopes than the early time data. The wellhead pressure data are affected by nitrogen gas accumulation in the annulus for the period beginning perhaps as early as 1300 min. The nitrogen gas was introduced into the annulus when purging the bubbler tube. This problem was overcome by bleeding the gas from the annulus just prior to decreasing the discharge rate to 15 gpm at t = 7110.33 min. The data points collected just prior to the discharge rate change plot on the projected late time linear trends that developed prior to t = 1300 min, thus indicating no additional boundary effects during the period $1300 \leq t \leq 7110.33$ min.

The late time wellhead data were also affected by frozen gauge lines. Freezing appears to have affected the Heise data during the interval $1860 \leq t \leq 3660$ min (Figure 1) and the Digiquartz data during the intervals $1860 \leq t \leq 2280$ and $3120 \leq t \leq 3660$ min (Figure 2). Fortunately, the loss of the data during these intervals was not crucial since no additional apparent hydrologic boundaries affected the data and since the bubbler data were not affected by freezing.

The Heise wellhead data plotted in Figure 1 has a Δs and a $Q/\Delta s$ of 8.18 psi/log cycle and 36.4 gpm/psi/log cycle respectively for the interval $18 \leq t$ 7110.33 min. The ratio of the early to late time Δs values is 1.64 for the Heise wellhead data. This low value for the ratio relative to the recovery data, Table 1, and the similarity the late time Δs value to others, Table 1, strongly suggests that the early time wellhead Heise data are invalid.

The wellhead Digiquartz data in Figure 2 for the interval $18 \leq t \leq 7110.33$ min have a Δs and a $Q/\Delta s$ of 8.10 psi/log cycle and

36.8 gpm/psi/log cycle respectively. The ratio of the early to late time Δs values is 2.12, Table 1. This value for the ratio appears to be somewhat low compared to recovery values in Table 1, thus suggesting all early time drawdown data are probably invalid. The rapidly changing wellbore fluid temperature and thus wellbore fluid density as well as the unknown discharge rate probably all contribute to the apparent errors in the early time drawdown data.

The late time Heise bubbler pressure data in Figure 1 have a Δs and a Q/Δs of 7.10 psi/log cycle and 42.0 gpm/psi/log cycle respectively for the interval $21 \le t \le 7110.33$ min. The bubbler data fluctuate more about the linear trend than do the wellhead pressure data as expected, but the reason for the 3 psi drift between the bubbler and wellhead data during the interval $21 \le t \le 7110.33$ min is not known.

For the late time drawdown data, the mean Δs and Q/Δs are 7.79 psi/log cycle and 38.4 gpm/psi/log cycle respectively.

Recovery

Early Time

The only extensive early time recovery data collected were obtained using the Digiquartz monitoring the wellhead pressure, Figure 3. During the period $0.33 \le t' \le 1.67$ min, the linear regression has a Δs of 19.6 psi/log cycle and a Q/Δs of 15.2 gpm/psi/log cycle. The kh is 15257 md-ft and the T is 1615 gpd/ft. The ϕch and S cannot be calculated directly from the data in Figure 3.

Calculated wellhead recovery data, s', are plotted in Figure 4. The calculated wellhead recovery values are obtained by subtracting the estimated wellhead pressures after shut-in to 15 gpm by projecting the late time linear regression in Figure 2 from the observed wellhead pressures after shut-in. The early time data in Figure 4 result in a Δs and a Q/Δs of 20.6 psi/log cycle and 14.5 gpm/psi/log cycle respectively. The calculated kh is 14517 md-ft and the ϕch is 0.0415 ft/psi. The transmissivity is 1537 gpd/ft and the S is 0.0167.

The early time recovery data can be expected to provide better estimates for the reservoir parameters than the early time drawdown data when the quality of the data are strongly affected by variations in well discharge and wellbore fluid density. The mean Δs value, Table 1, of 20.1 psi/log cycle for the recovery data is greater than the Δs values obtained from the drawdown data. Similarly, the mean early time Q/Δs, kh, and T values are less for the recovery data than for the early time drawdown data, Table 1. Although there is only one estimate for ϕch and S during recovery, they are very close to the value obtained from the drawdown wellhead Digiquartz data. Since it is unlikely that additional early boundaries affect the data prior to 0.33 min, the early time recovery data are presumed to provide the best estimates for the reservoir parameters kh, ϕch, T, and S. These estimates for the reservoir parameters must be used with caution since a nonideal relationship will be demonstrated to exist between the late time Q/Δs and Q. This strongly implies that a nonideal relationship also exists between Q/Δs and Q for the early time data. Thus it is likely that no singular values can be used to define the reservoir parameters.

Late Time

Late time recovery data are plotted in Figures 3, 4, and 5. In Figure 3, a linear data trend developed for the interval $8.0 \leq t' \leq 229.67$ min. The data during the period $229.67 < t' \leq 2629.67$ min are displaced above the preceeding trend by approximately 1 psi. This is believed to result because of a slight decrease in the rate of discharge from the wellhead. The Δs and the Q/Δs values for the period $8.0 \leq t' \leq 2629.67$ min with the data where $229.67 \leq t' \leq 2629.67$ min transposed 1 psi downward are 7.10 psi/log cycle and 42.0 gpm/psi/log cycle respectively. The late time calculated wellhead recovery data in Figure 4 have a Δs and a Q/Δs of 7.03 psi/log cycle and 42.4 gpm/psi/log cycle respectively for the interval $8.0 \leq t' \leq 229.67$ min. As expected, these values are very similar to those for the late time data in Figure 3.

Figure 5 contains recovery plots for the bubbler Heise and Digiquartz data as well as the wellhead Heise data. The bubbler Heise data do not follow an obviously linear trend somewhat parallel to the other data in Figure 5 during the period where $7.67 \leq t' \leq 229.67$ min. The reasons for the nonlinearity of the data is not known. The bubbler Heise data cannot be used to estimate the Δs and $Q/\Delta s$ parameters with a high degree of confidence.

The bubbler Digiquartz data in Figure 5 plot as a linear trend during the period $7.67 \leq t' \leq 229.67$ min. The Δs and $Q/\Delta s$ during this period are 7.40 psi/log cycle and 40.3 gpm/psi/log cycle respectively. The Heise (wellhead) data in Figure 5 have a Δs and a $Q/\Delta s$ of 7.00 psi/log cycle and 42.6 gpm/psi/log cycle respectively during the interval $5.67 \leq t' \leq 229.67$ min.

The recovery Δs values, Table 1, range from 7.00 to 7.40 psi/log cycle which are below the mean of 7.42 psi/log cycle. The mean Δs for the drawdown data is 7.79 psi/log cycle. It is not readily apparent whether there is a significant difference between the recovery and drawdown Δs values and thus $Q/\Delta s$ values.

The ratios of the early to late Δs values for the wellhead Digiquartz data are 2.76 and 2.93 (Table 1) with a mean of 2.85. Thus, the drawdown/recovery Δs for the late time data is approximately 1/3 that of the early time data. This can be interpreted as indicating that after approximately 3 min of drawdown/recovery, the "cone" encounters a zone with a greater transmissivity or storage coefficient than the zone adjacent to the wellbore.

The intersections of the early and late recovery Digiquartz data occur at 3.31 and 3.00 min, Table 1 with a mean of 3.16 min. This appearance of apparent boundary effects so soon after drawdown/recovery is initiated implies that the zone(s) with greater apparent transmissivity or storage coefficient is relatively close to the wellbore.

Fully Recovered Pressures

The late time recovery data can be projected to $t/t' = 1$ to provide an estimate of the wellhead or bubbler pressure at theoretical full recovery. This assumes that the recovery curve is not displaced due to either an aquifer of limited extent, or an aquifer recharged by induced leakage, or an aquifer with spatial variations in S or ϕch, or wellbore fluid density effects, or well interference, or depressed pressures due to low preheat flow rates from the well, etc. The recovery data in Figures 3 and 4 suggest at least a 1 psi lowered displacement of the data where $t' \leq 229.67$ min probably due to a slight decrease in the discharge rate at $t' = 229.67$ min. A density displacement of the wellhead data can also be expected relative to high rate discharge tests. During this test, the wellhead temperature was aproximately 274°F. During the 10/20/81 and 10/28/81 tests, the wellhead temperature was approximately 277.5°F. Density correcting the wellhead pressure from 274°F to 277.5°F would result in a 1.3 psi increase in pressure. This density correction was also assumed to apply to the bubbler data, although the correction would probably be less. Table 2 lists the estimated pressures when $t/t' = 1$. To provide additional estimates for the fully recovered displacement and density corrected pressures, the observed or estimated differences between bubbler Digiquartz (BQ), bubbler Heise (BH), wellhead Digiquartz (WQ), and wellhead Heise (WH) pressures at t = 1000 min were used to provide adjusted values for the displacement and density corrected pressures at $t/t' = 1$ listed in Column 5 Table 2. These additional estimated values are listed in Column 6 Table 2. This procedure was also used for $t' = 1000$ min data. These values are listed in Column 7 Table 2. The close agreement between the values in Columns 5 to 7 in Table 2 indicate that the observed differences between the values in Column 5 Table 2 are probably fairly accurate (e.g. ±1 psi). However, the absolute values in Columns 2 and 5 to 8 inclusive may be in error due to phenomena affecting the recovery data for this particular test such as low wellhead pressures due to keep warm flows, etc. The best estimates for the fully recovered pressure at $t/t' = 1$ corrected for a 1 psi displacement are 554.2 psia 541.5 psig, 169.4 psia and 156.7 psig for BQ, BH, WQ, and WH data respectively.

Estimates for the fully recovered wellhead pressures for the tests beginning 10/20/81 and 10/28/81 are 555 psig and 542 psig for BH data respectively. These values compare favorably with the observed 541.5 psig calculated for the 02/03/82 test.

CALCULATED DRAWDOWN/RECOVERY PRESSURES

Calculated drawdown and recovery data for the 02/03/82, 10/20/81 and 10/28/81 tests suggest that the estimate for hot shut-in pressures are reasonably accurate. Table 3 lists drawdown/recovery data at t and t' values of 10, 100, 1000, and 10,000 min. The drawdown values for the 02/03/82 test were calculated by subtracting the observed pressures from the appropriate data type shut-in pressures listed in Column 9 of Table 2. For the 10/20/81 and 10/28/81 tests, the drawdowns were calculated by subtracting the observed pressures from the appropriate data type shut-in pressures listed in Column 8 Table 2. The recovery pressures for the 02/03/82 test were calculated by subtracting the estimated pressures had the pumping continued from the observed pressures. The estimated pressures assuming the continued pumping of the well were obtained by extrapolating the linear data trends for $t \geq 10.8$ min in Figures 1 and 2. A displacement value of 1 psi was added to the raw calculated recovery data. A similar procedure was used for the 10/20/81 and 10/28/81 tests. The drawdown data for the 11/07/75 test were obtained from a report by T. N. Narasimhan and P. A. Witherspoon (Reservoir Evaluation tests on RRGE-1 and RRGE-2, Raft River Geothermal Project, Idaho, LBL 5958, May 1977). The recovery data for the 11/07/75 test were estimated assuming a downhole shut-in pressure of 2081.3 psia.

For the 02/03/82 test, the mean drawdown and recovery pressures, at each drawdown/recovery time are in close agreement (Table 3). The greatest difference of 2.7 psi resulted for the 10 min data with the drawdown mean being less than the recovery mean. If large well losses had occurred, the drawdown means would be much larger than the recovery means. The data implies negligible well losses at a 298 gpm discharge rate. However, if the estimated shut-in pressures are too low due to well keep warm discharges during recovery, the well losses would be underestimated. In the section on skin factor it will be demonstrated that well losses are low. This suggests that the estimated shut-in pressures are reasonably accurate. The small differences between drawdown and recovery data suggest negligible well losses while discharging the well at 298 gpm.

The calculated drawdown and recovery data for drawdown and recovery times of 10, 100, 1000, and 10,000 min for the 02/03/82 test are plotted in Figure 6. Bracketed data are estimates. Additional data listed in Table 3 for the tests beginning 10/20/81, 10/28/81, and 11/07/75 are also plotted in Figure 6. During the 10/20/81 and 10/28/81 tests, Figures 7 and 8 respectively, the drawdown bubbler pressure data at high pumpage rates do not plot on extensive linear regressions until $t \geq 200$ min. If the drawdown/recovery can be predicted at a convenient time, e.g., 1000 min before any additional boundaries affect the data and the Δs or $Q/\Delta s$ of the data for t and/or $t' \geq 200$ min can be predicted, then the drawdown and/or recovery at any time beyond 200 min can be predicted provided there is no well interference and no additional apparent hydrologic boundaries affect the data. The best fitting power curve through the t and t' data for 1000 min versus Q is plotted in Figure 6. Because of the rather sparse data, the predicted value for drawdown/recovery should be used with caution.

CALCULATED Δs AND $Q/\Delta s$ VALUES

The Δs and $Q/\Delta s$ values for all available data to date have been tabulated in Table 4. Mean values for drawdown/recovery have been used where appropriate, e.g., 02/03/82 test. The Δs values versus Q have been plotted in Figure 9. The best fitting power curve is also plotted. Some data with obvious errors (bracketed values) were eliminated when fitting the power curve. However, the relatively poor fit of the power curve to the data where $Q \geq 900$ gpm is undesireable. The linear regression fitted to the data where $900 \leq Q \leq 1100$ appears to define the data within this range better than the power curve. However, until additional data become available, the power curve will be used to define the relationship between Δs and Q. This best fit power curve was used to calculate the relationship between Q/Ds and Q in Figure 10. Since the best fitting curve does not have a slope of zero, the apparent transmissivity which is related to Q/Δs by the following equation

$$T = \frac{264\ Q}{\Delta s} \qquad (1)$$

where

T = transmissivity in gpd/ft

Q = discharge rate in gpm

Δs = drawdown per log cycle in ft

does not have a unique value for the data obtained from RRGE-1. However, the drawdown/recovery for t and/or t' ≥ 200 min can be calculated using the following equation:

$$D/R = 0.0068573\ Q^{1.579632} + (0.0017957411\ Q^{1.455905584})\ (\log t)-3) \qquad (2)$$

where

D/R = drawdown and/or recovery for t and/or t' ≥ 200 min in psi

Q = discharge rate in gpm

t = time since pumping began/ended in minutes.

Equation (2) was used to calculate appropriate pressures using assumed hot shut-in pressures listed at the bottom of Table 3. Calculated pressures during drawdown for both wellhead and drawdown data are plotted in Figures 1, 2, and 4. Equation (2) appears to underestimate the drawdown by 2 to 3 psi and also underestimates Δs. Although Equation (2) was intended to predict drawdown/recovery values for t and t' values greater than 200 min, at a discharge rate of 298 gpm, Equation (2) provides reasonable estimates for the drawdown/recovery at times as early as 8 min (Figure 4). Since the drawdown and recovery data listed in Table 3 are very similar, no additional apparent hydrologic boundaries were encountered during recovery. Based on the data for the 02/03/82 test, Equation (2) is valid for the interval from as early as 8 min to 9740 min after initiating pumping/recovery. Data for the 8/18/80 test suggest Equation (2) is probably valid for at least 55,000 min. For a discharge rate of 298 gpm, Equation (2) provides drawdown/recovery estimates within approximately 4% of the observed values with Equation (2) probably being valid for at least 55,000 min (38 days).

Equation (2) was also used to calculate appropriate bubbler pressures for the tests beginning 10/20/81 and 10/28/81. These calculated bubbler pressures are plotted in Figures 7 and 8 respectively. Equation (2) overestimates the drawdown (437 psi) by as much as 15 psi at t = 1000 min, a 3.4% error. Equation (2) provides reasonable estimates of the drawdown when pumping at 1100 gpm as early as 100 min after pumping began, Figure 7. The much greater time required for Equation (2) to yield valid estimates when pumping at 1100 gpm as compared to pumping at 298 gpm probably results due to wellbore storage effects and the poor hydraulic connection between the wellbore below the pump and the annulus above the pump due to the tight fitting pump. At high pumping rates, Equation (2) may provide reasonably accurate drawdown/recovery estimates as early as 100 min.

SPECIFIC CAPACITY

The specific capacity was determined for the test data listed in Table 3 for which sufficient data are available to permit a drawdown/recovery pressure to be calculated. These specific capacity data at times of 10, 100, 1000, and 10,000 min are plotted in Figure 11 as a function of the discharge rate. The specific capacities for each drawdown/recovery time are strongly dependent on the discharge rate. The specific capacity at 1100 gpm is approximately half that at 298 gpm. The specific capacities should be independent of the discharge rate per the following equation:

$$\frac{Q}{s} = \frac{T}{264 \log \dfrac{Tt}{2693\, r_w^{2}\, S} - 65.5} \; \frac{144}{\gamma} \qquad (3)$$

where

Q/s	=	specific capacity in gpm/psi
Q	=	discharge rate in gpm
s	=	drawdown in psi
T	=	transmissivity in gpd/ft
S	=	storage coefficient dimensionless
r_w	=	nominal radius of well in ft
t	=	time after pumping started in minutes

γ = specific gravity of fluid in lb/ft^3.

This equation assumes that the well losses are as negligible at a discharge rate of 1100 gpm as they are at 298 gpm. These specific capacity data provide only approximate estimates of the well performance.

SKIN FACTOR

Abnormally high head losses have been observed to occur near wellbores due to formation plugging as a result of drilling muds, cement, drill cuttings etc. Conversely, head losses near the wellbore may be abnormally low due to fracturing or acidizing. This zone of reduced or increased permeability immediately surrounding the wellbore is called a "skin" with the resulting effect called "skin effect." The calculated skin factor, s, after 2 min of recovery is 0.0345 for the recovery data plotted in Figures 3 and 4. The calculated skin pressure loss is only 0.59 psi which is negligible considering that the wellbore radius is quite variable. This low skin factor and skin pressure loss when discharging at 298 gpm suggests that there is negligible wellbore damage and fracture enlargement near the wellbore.

CONCLUSIONS

1. RRGE-1 was permitted for discharge at a rate of 298 gpm for 7110.33 min at a wellhead temperature of approximately 274°F. Recovery data were collected for 2629.67 min.

2. The best estimates for kh and T are 14887 md ft and 1576 gal/d/ft respectively for a discharge rate of 298 gpm. The ϕch and S are 0.0415 ft/psi and 0.0167 respectively.

3. An apparent hydrologic recharge type boundary after 3 to 10.8 min decreases the drawdown slope on a semilogarithmic plot to approximately 1/3 of the early time value.

4. The estimated hot shut-in pressures for the bubbler Digiquartz, bubbler Heise, wellhead Digiquartz, and wellhead Heise gauges are 554.2 psia, 541.5 psig, 169.4 psia, and 156.7 psig respectively.

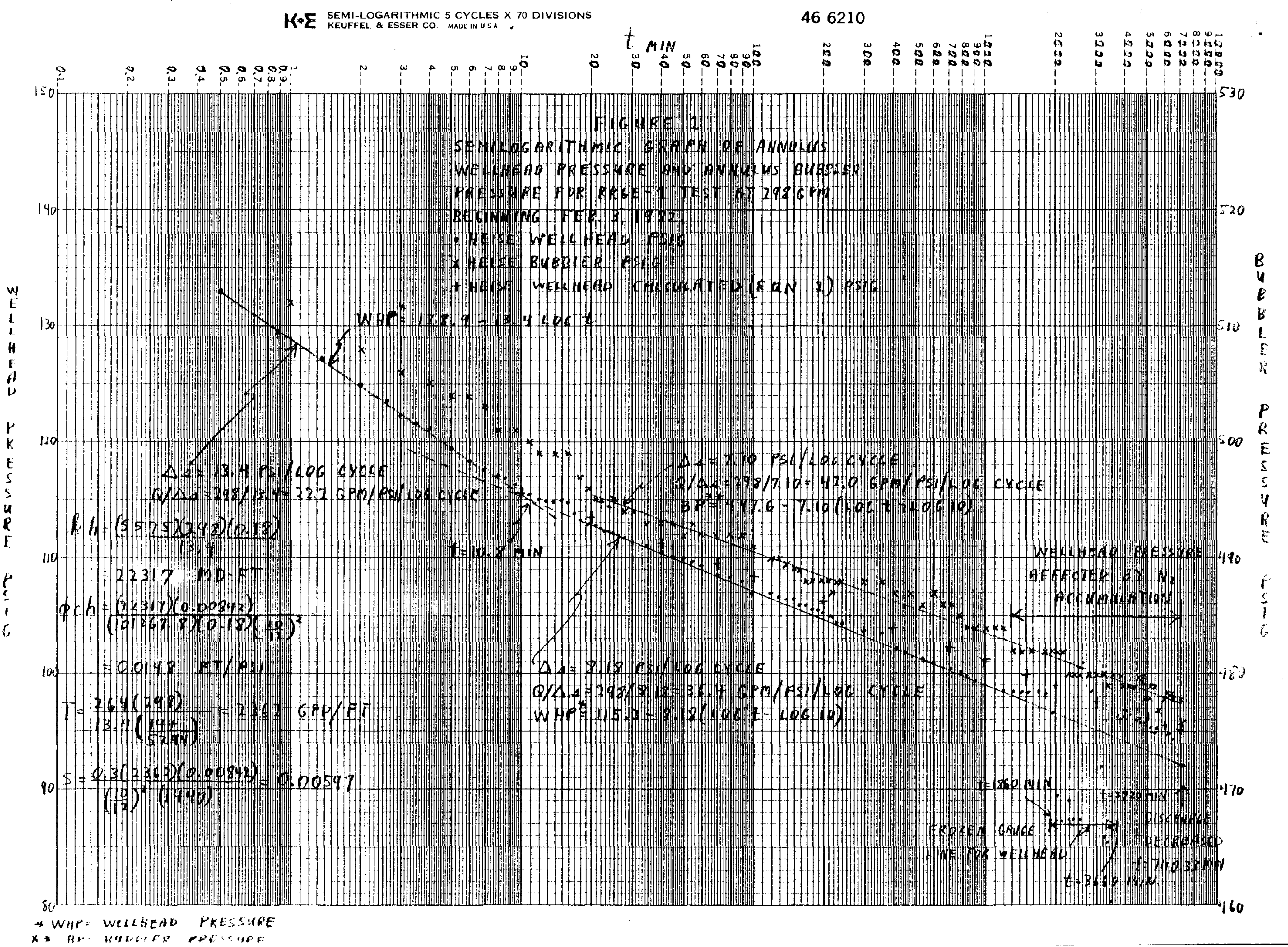
5. The following equation can be used to estimate drawdown/recovery pressures as early as 8 min and probably extending to at least 55,000 min (38 days).

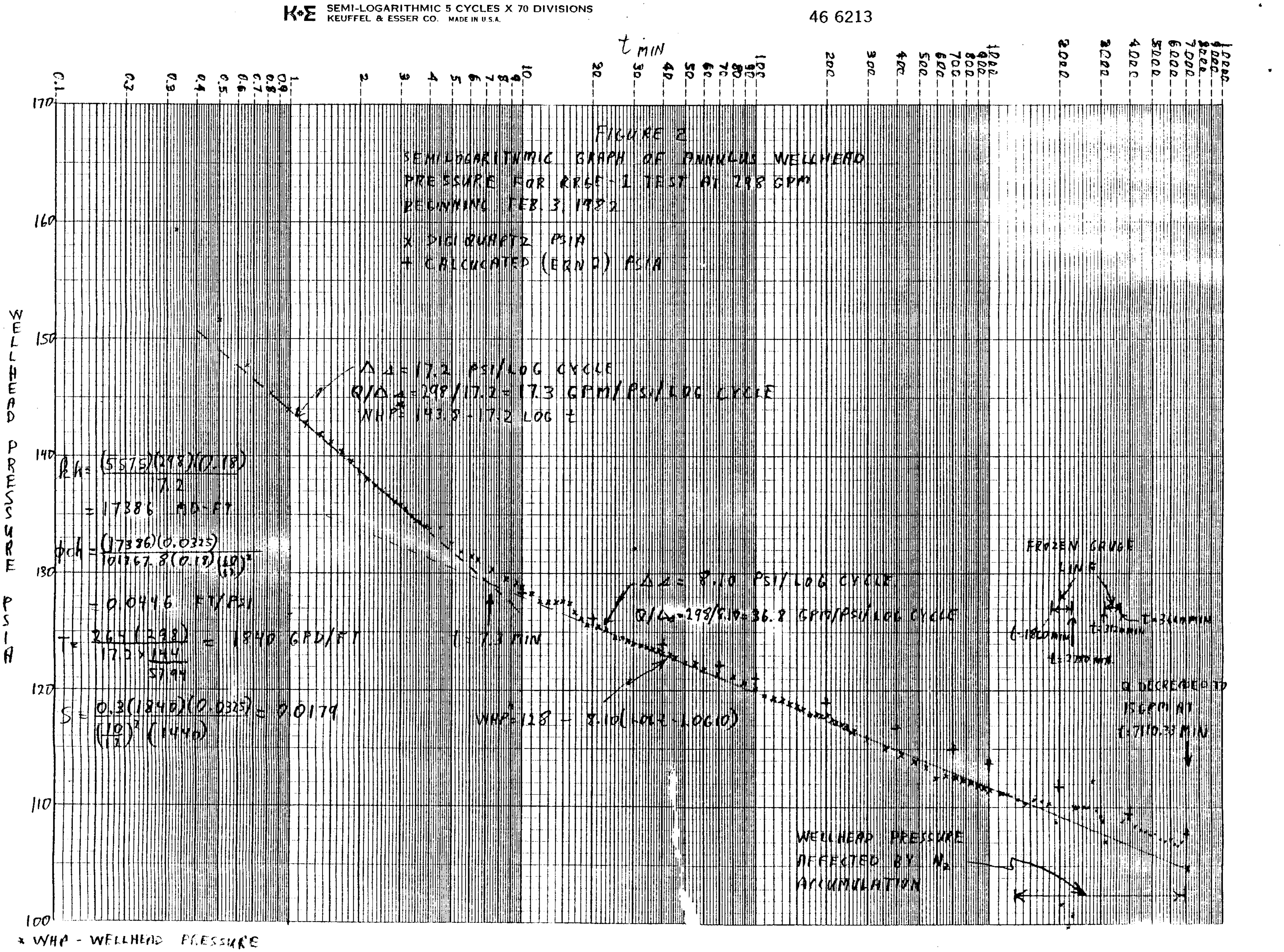
$$D/R = 0.0068573\ Q^{1.579632} + (0.0017957411\ Q^{1.45590})^{5584}\ (\log t)\text{-}3)$$

where

D/R	=	drawdown/recovery for t and/or t' ≥ 200 min, psi
Q	=	discharge rate, gpm
t	=	time since pumping began/ended, min.

6. The skin factor (0.0345) suggests that well losses are negligible at 298 gpm with no significant fracture enlargement near the wellbore.

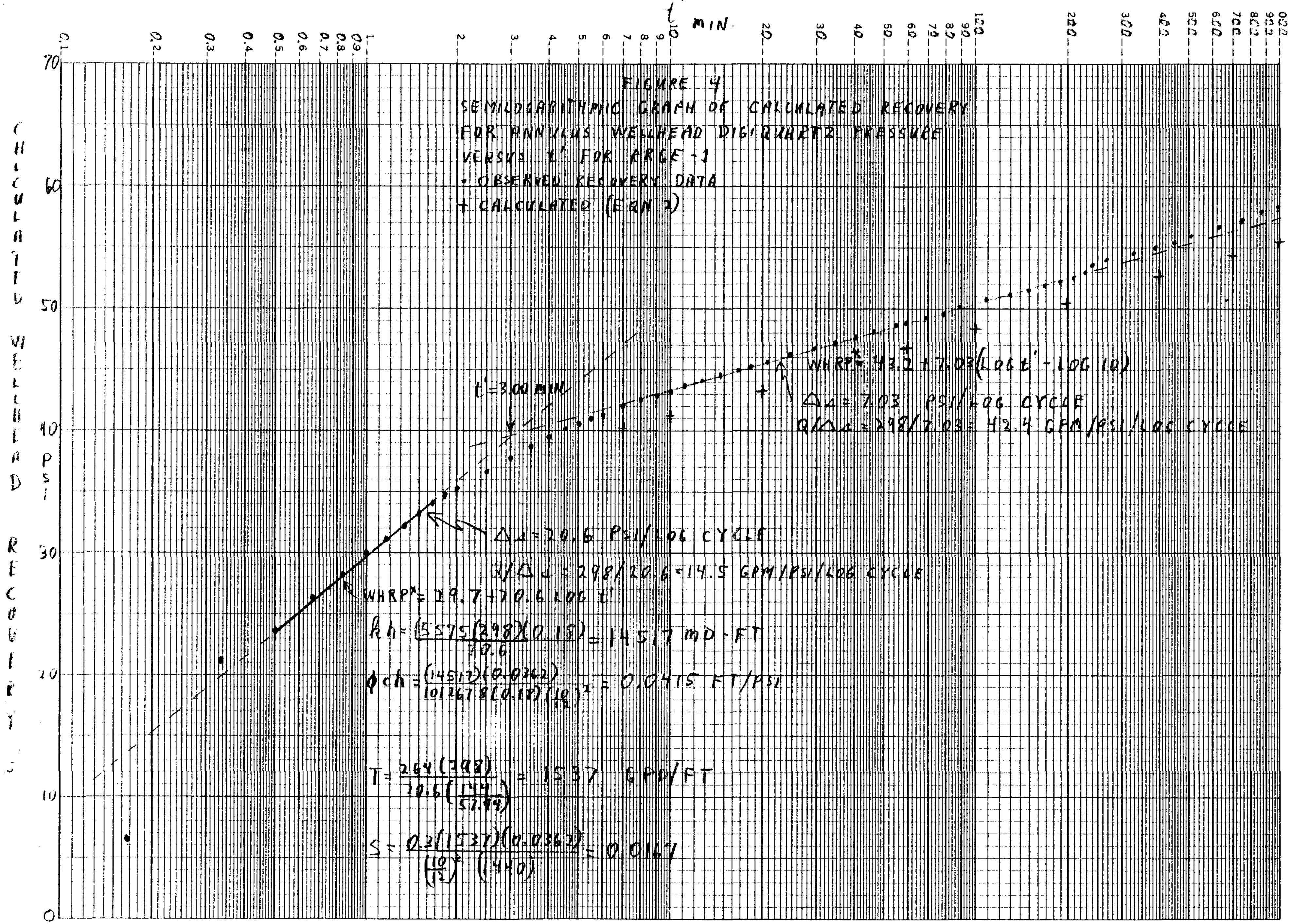

K•E SEMI-LOGARITHMIC 5 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 6210
t MIN
FIGURE 1
SEMILOGARITHMIC GRAPH OF ANNULUS WELLHEAD PRESSURE AND ANNULUS BUBBLER PRESSURE FOR RRGE-1 TEST AT 298 GPM BEGINNING FEB. 3, 1982.
• HEISE WELLHEAD PSIG
x HEISE BUBBLER PSIG
+ HEISE WELLHEAD CALCULATED (EQN 2) PSIG
WHP = 128.9 - 13.4 LOG t
Δ = 13.4 PSI/LOG CYCLE
Q/Δ = 298/13.4 = 22.2 GPM/PSI/LOG CYCLE
kh = (5575)(298)(0.18) / 13.4
= 22317 MD-FT
φch = (22317)(0.00842) / (101267.8)(0.18)(10/12)²
= 0.0148 FT/PSI
T = 264(298) / 13.4(1440/5794) = 2362 GPD/FT
S = 0.3(2362)(0.00842) / (10/12)² (1440) = 0.00547
t = 10.8 MIN
Δ = 7.10 PSI/LOG CYCLE
Q/Δ = 298/7.10 = 42.0 GPM/PSI/LOG CYCLE
BP = 497.6 - 7.10 (LOG t - LOG 10)
Δ = 8.18 PSI/LOG CYCLE
Q/Δ = 298/8.12 = 36.4 GPM/PSI/LOG CYCLE
WHP = 115.3 - 8.12 (LOG t - LOG 10)
WELLHEAD PRESSURE AFFECTED BY N₂ ACCUMULATION
t = 860 MIN
FROZEN GAUGE LINE FOR WELLHEAD
t = 3660 MIN
t = 3720 MIN
DISCHARGE DECREASED
t = 7110.33 MIN
WELLHEAD PRESSURE PSIG
BUBBLER PRESSURE PSIG
* WHP = WELLHEAD PRESSURE
x* BP = BUBBLER PRESSURE



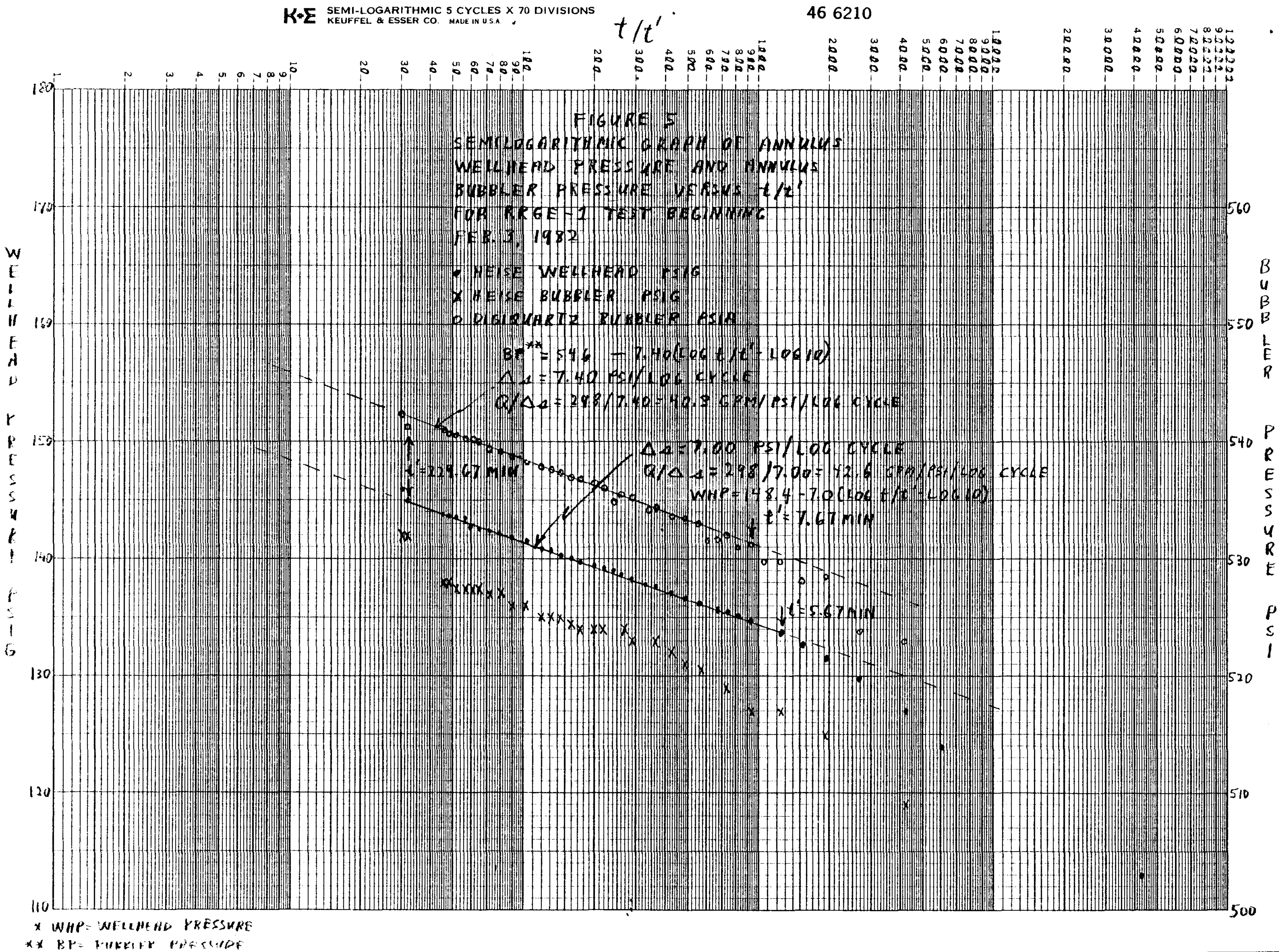
K+E SEMI-LOGARITHMIC 5 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 6213
t MIN
FIGURE 2
SEMILOGARITHMIC GRAPH OF ANNULUS WELLHEAD PRESSURE FOR RRGE-1 TEST AT 298 GPM BEGINNING FEB. 3, 1982
x DIGIQUARTZ PSIA
+ CALCULATED (ERN A) PSIA
WELLHEAD PRESSURE PSIA
Δ = 17.2 PSI/LOG CYCLE
Q/Δ = 298/17.2 = 17.3 GPM/PSI/LOG CYCLE
WHP* = 143.8 - 17.2 LOG t
kh = (5575)(298)(0.18) / 7.2
= 17386 MD-FT
φch = (17386)(0.0325) / 101767.8(0.18)(10/12)²
= 0.0446 FT/PSI
T = 264(298) / 17.2 × 144/5794 = 1840 GPD/FT
S = 0.3(1840)(0.0325) / (10/12)²(1440) = 0.0179
t = 7.3 MIN
Δ = 8.10 PSI/LOG CYCLE
Q/Δ = 298/8.10 = 36.8 GPM/PSI/LOG CYCLE
WHP* = 128 - 8.10(LOG t - LOG 10)
FROZEN CRUDE LINE
t = 1800 MIN
t = 2200 MIN
t = 3100 MIN
t = 3600 MIN
Q DECREASED TO 15 GPM AT t = 7110.33 MIN
WELLHEAD PRESSURE AFFECTED BY N₂ ACCUMULATION
* WHP - WELLHEAD PRESSURE

K•Σ SEMI-LOGARITHMIC 4 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.

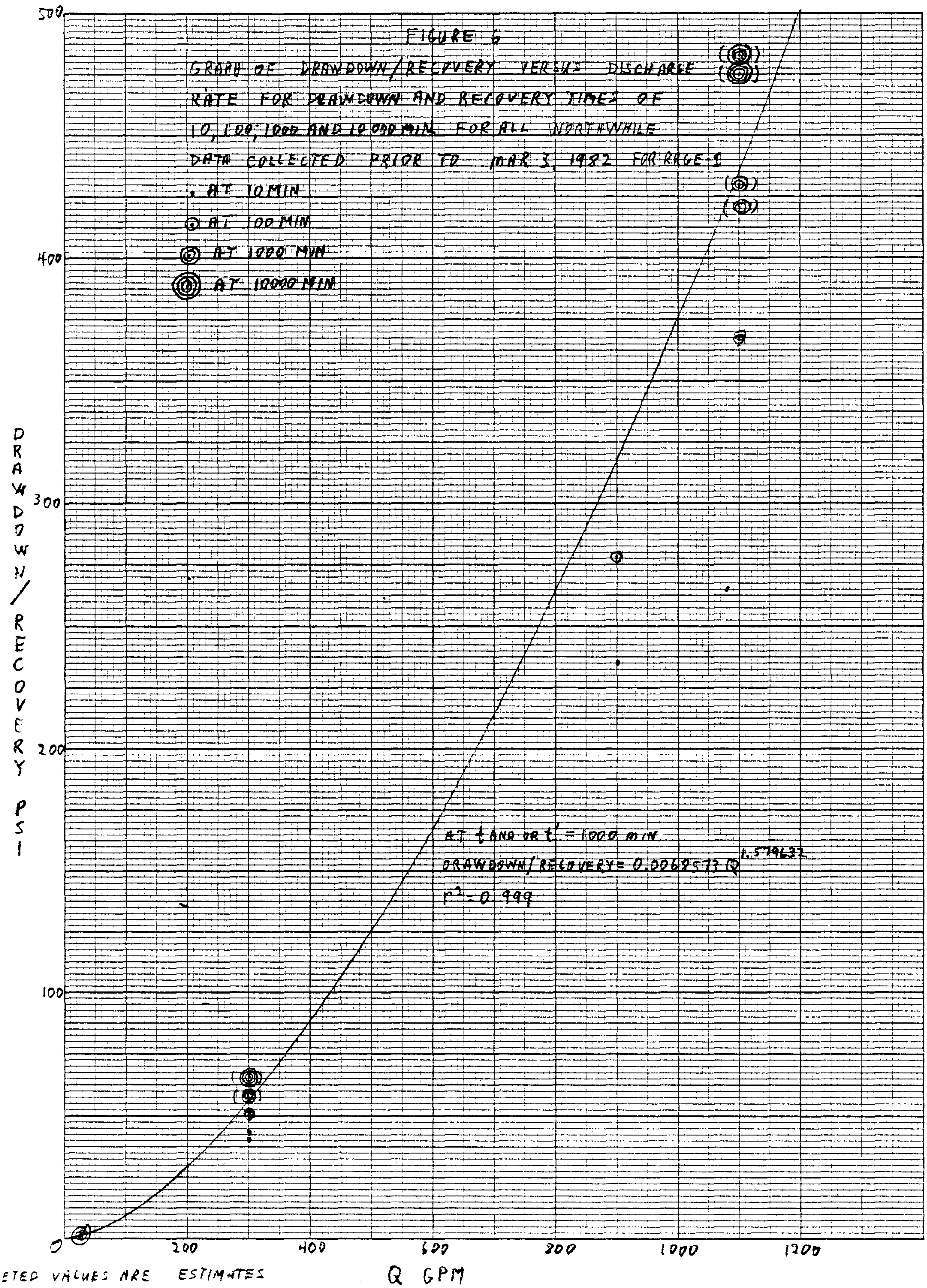
46 6010



* WHRP = WELLHEAD RECOVERY PRESSURE



K•E SEMI-LOGARITHMIC 5 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 6210
t/t'
FIGURE 5
SEMILOGARITHMIC GRAPH OF ANNULUS WELLHEAD PRESSURE AND ANNULUS BUBBLER PRESSURE VERSUS t/t' FOR RRGE-1 TEST BEGINNING FEB. 3, 1982
• HEISE WELLHEAD PSIG
x HEISE BUBBLER PSIG
o DIGIQUARTZ BUBBLER PSIA
BP** = 546 − 7.40(LOG t/t' − LOG 10)
Δ = 7.40 PSI/LOG CYCLE
Q/Δ = 298/7.40 = 40.3 GPM/PSI/LOG CYCLE
Δ = 7.00 PSI/LOG CYCLE
Q/Δ = 298/7.00 = 42.6 GPM/PSI/LOG CYCLE
WHP* = 148.4 − 7.0(LOG t/t' − LOG 10)
t' = 7.67 MIN
t' = 229.67 MIN
t' = 5.67 MIN
WELLHEAD PRESSURE PSIG
BUBBLER PRESSURE PSI
* WHP = WELLHEAD PRESSURE
** BP = BUBBLER PRESSURE



BRACKETED VALUES ARE ESTIMATES

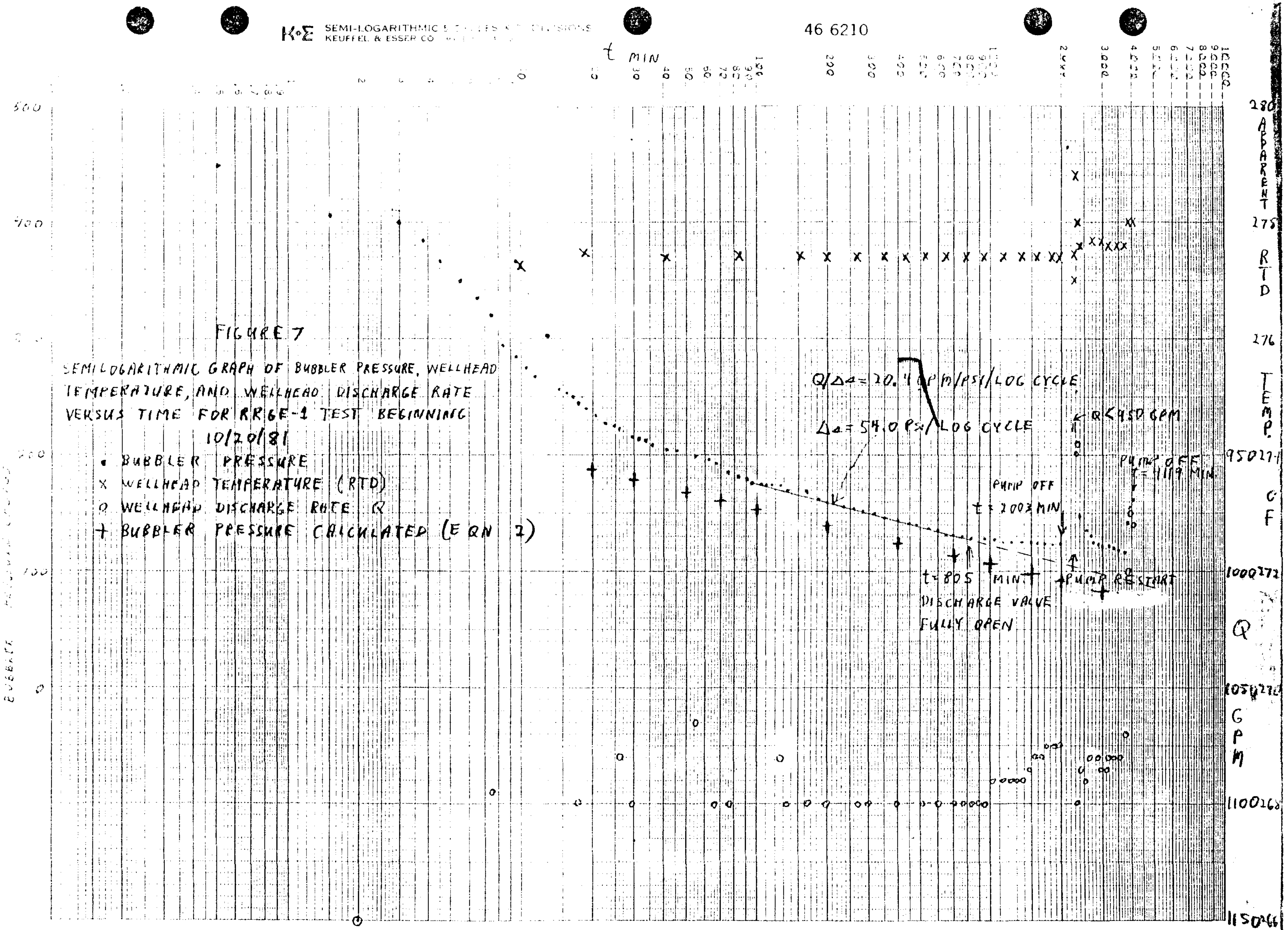
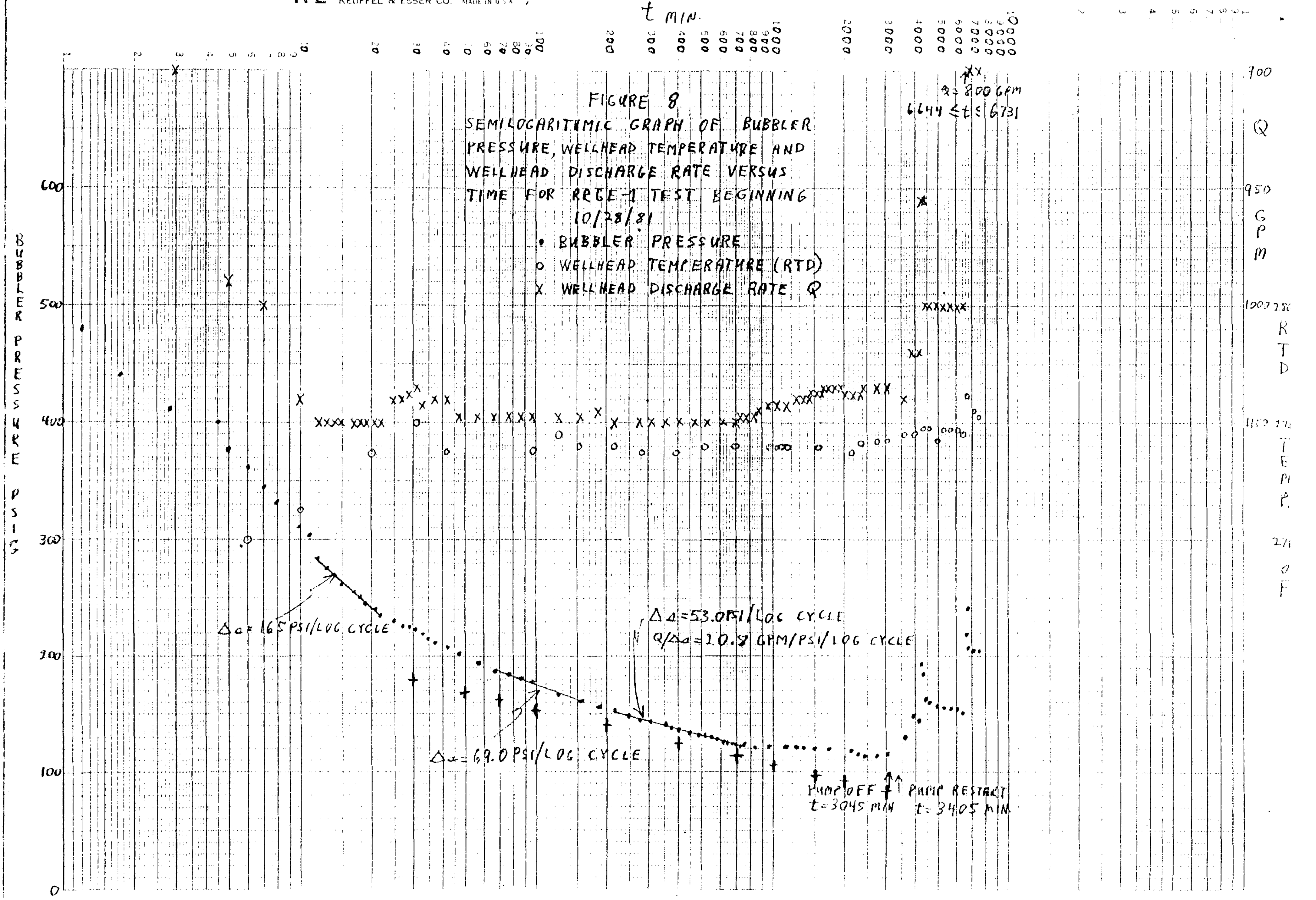


FIGURE 7

SEMILOGARITHMIC GRAPH OF BUBBLER PRESSURE, WELLHEAD TEMPERATURE, AND WELLHEAD DISCHARGE RATE VERSUS TIME FOR RRGE-1 TEST BEGINNING 10/20/81

- • BUBBLER PRESSURE
- x WELLHEAD TEMPERATURE (RTD)
- o WELLHEAD DISCHARGE RATE Q
- + BUBBLER PRESSURE CALCULATED (EQN 7)


t MIN.
FIGURE 8
SEMILOGARITHMIC GRAPH OF BUBBLER PRESSURE, WELLHEAD TEMPERATURE AND WELLHEAD DISCHARGE RATE VERSUS TIME FOR RRGE-1 TEST BEGINNING 10/28/81
• BUBBLER PRESSURE
o WELLHEAD TEMPERATURE (RTD)
X WELLHEAD DISCHARGE RATE Q
Q = 800 GPM
6644 ≤ t ≤ 6731
BUBBLER PRESSURE PSIG
Q GPM
RTD TEMP. °F
Δ = 165 PSI/LOG CYCLE
Δ = 69.0 PSI/LOG CYCLE
Δ = 53.0 PSI/LOG CYCLE
Q/Δ = 10.8 GPM/PSI/LOG CYCLE
PUMP OFF t = 3045 MIN
PUMP RESTART t = 3405 MIN
0
100
200
300
400
500
600
700
950
1000
1100

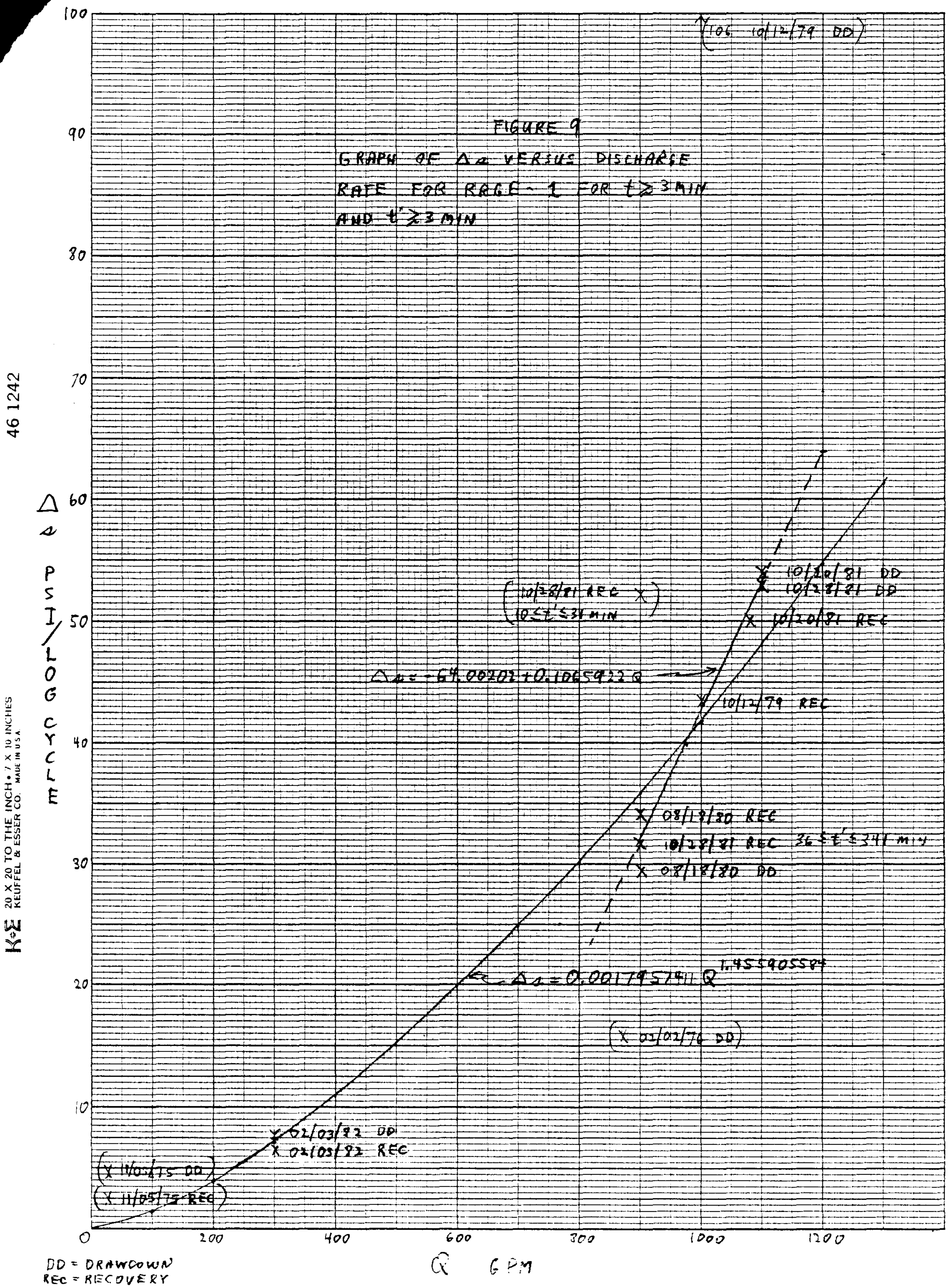


FIGURE 9

GRAPH OF Δs VERSUS DISCHARGE RATE FOR RRGE-1 FOR t ≥ 3 MIN AND t' ≥ 3 MIN

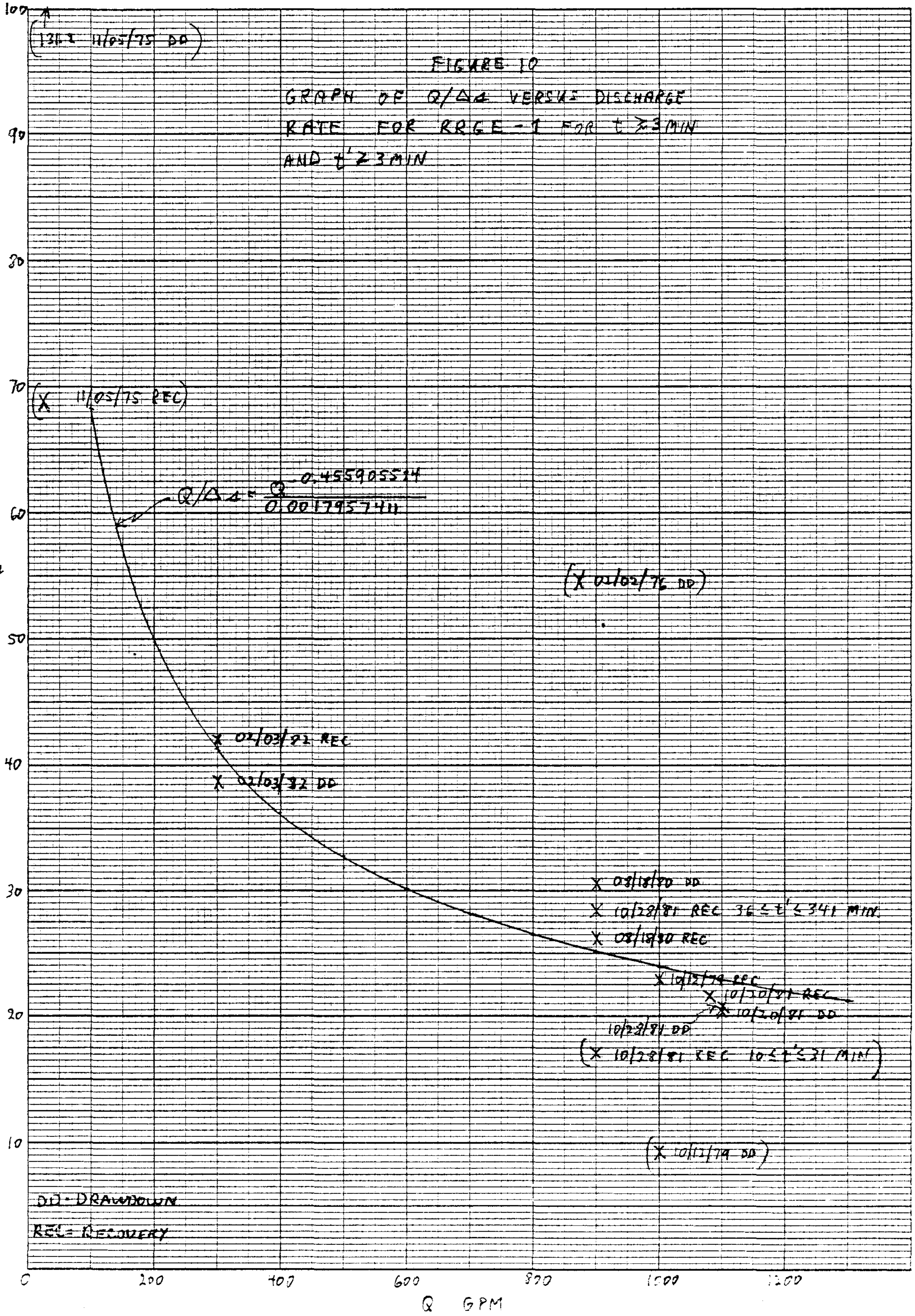
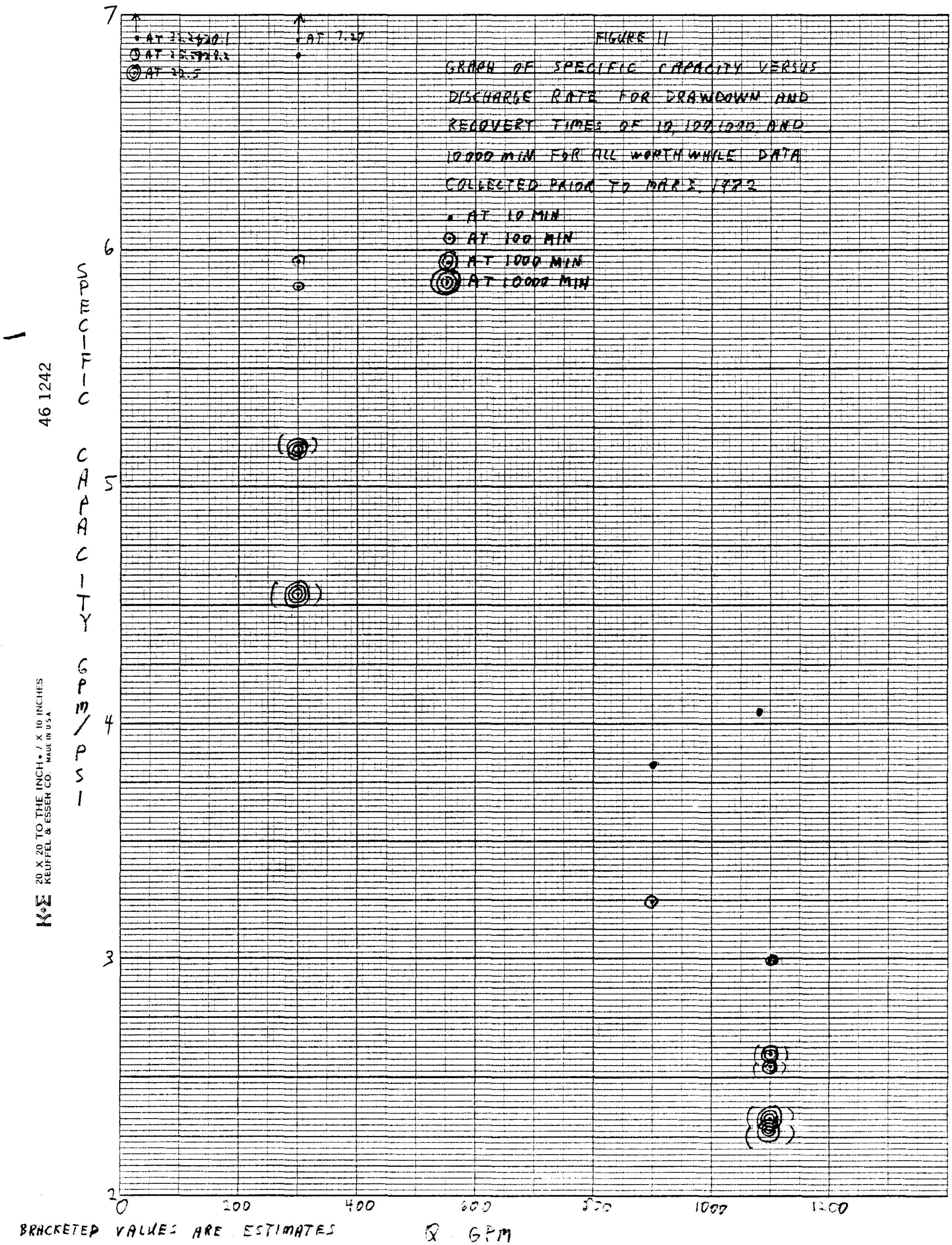


FIGURE 10
GRAPH OF Q/Δs VERSUS DISCHARGE RATE FOR RRGE-1 FOR t ≥ 3 MIN AND t' ≥ 3 MIN
(↑ 136.2 11/05/75 DD)
(X 11/05/75 REC)
Q/Δs = Q^-0.455905514 / 0.001795741
X 02/03/82 REC
X 02/03/82 DD
(X 02/02/76 DD)
X 08/18/80 DD
X 10/28/81 REC 36 ≤ t' ≤ 341 MIN
X 08/18/80 REC
X 10/12/79 REC
X 10/20/81 REC
X 10/20/81 DD
10/28/81 DD
(X 10/28/81 REC 10 ≤ t' ≤ 31 MIN)
(X 10/12/79 DD)
DD = DRAWDOWN
REC = RECOVERY
Q/Δs GPM/PSI/LOG CYCLE
Q GPM



BRACKETED VALUES ARE ESTIMATES

TABLE 1. HYDROLOGIC DATA FOR RRGE-1 TEST AT 298 GPM BEGINNING FEBRUARY 3, 1982

Interval (min)		Δs (psi/log cycle)		Δs Ratio	Figure	Q/Δs (gpm/psi/log cycle)		kh	T	ϕch		t_o or t'_o	Intersection of Early/Late	Pressure at t/t' = 1	
From	To	Early	Late	Early/Late	Number	Early	Late	(md/ft)	(gal/D/ft)	(ft/psi)	S	(min)	(min)	(psi)	Data Type[a]
0.5	7	13.4[b]	--	1.64[b]	1	22.2[b]		22,317[b]	2362[b]	0.0148[b]	0.00597[b]	0.00842	10.8[b]	--	DWH
18	7110.33	--	8.18	--	1	--	36.4	--	--	--	--	--	--	--	DWH
21	7110.33	--	7.10	--	1	--	42.0	--	--	--	--	--	--	--	DBH
0.83	4.0	17.2[b]	--	2.12[b]	2	17.3[b]	--	17,386[b]	1840[b]	0.0446[b]	0.0179[b]	0.0325	7.3[b]	--	DWQ
18	7110.33	--	8.10	--	2	--	36.8	--	--	--	--	--	--	--	DWQ
0.33	1.67	19.6	--	2.76	3	15.2	--	15,257	1615	--	--	--	3.31	--	RWQ
8.0	2629.67	--	7.10	--	3	--	42.0	--	--	--	--	--	--	--	RWQ
0.50	1.67	20.6	--	--	4	14.5	--	14,517	1537	0.0415	0.0167	0.0362	3.00	--	RCWQ
8.0	229.67	--	7.03	2.93	4	--	42.4	--	--	--	--	--	--	168.0	RCWQ
5.67	229.67	--	7.00	--	5	--	42.6	--	--	--	--	--	--	155.4	RWH
7.67	229.67	--	7.40	--	5	--	40.3	--	--	--	--	--	--	553.4	RBQ
Mean		20.1	7.42	2.85		14.9	40.4	14,887	1576	0.0415	0.0167	--	3.16		
Ratio															

a. Legend: D = Drawdown, C = Calculated, B = Bubbler, Q = Digiquartz, R = Recovery, W = Wellhead, H = Heise

b. Values not used to calculate means.

TABLE 2. ESTIMATED PRESSURES WHEN t/t' = 1

Data Type[a]	Calculated Pressure at t/t' = 1 Using Data t' < 229.67 Min (psia/psig)	Correction for Observed Displacement of Data t' < 229.67 (psi)	Density Correction from 274.0 to 277.5°F (psi)	Displacement and Density Corrected Pressure at t/t' = 1 (psia/psig)	Estimated Displacement and Density Corrected Pressure Using Observed and Estimated Pressure Differences			Average Estimated Displacement Corrected Pressures Using Observed and Estimated Pressure Differences (psia/psig)
					t = 1000 min (psia/psig)	t' = 1000 min (psia/psig)	Average (psia/psig)	
BQ	553.4	1	1.3	555.7	555.4	555.6	555.5	554.2
BH	540.8[b]	1	1.3	543.1[b]	542.6[b]	543.0[b]	542.8[b]	541.5
WQ	168.0	1	1.3	170.3	170.9	170.5	170.7	169.4
WH	155.4	1	1.3	157.9	158.1	157.9	158.0	156.7

a. Legend: B = Bubbler, Q = Digiquartz, H = Heise, W = Wellhead

b. Values are estimates.

TABLE 3. RRGE-1 DRAWDOWN, RECOVERY, AND SPECIFIC CAPACITY AT t AND t' EQUAL TO 10, 100, 1000 AND 10,000 MIN

Date Test	Q (gpm)	Data Type[a]	Well Drawdown/Recovery[b] (psi)				Specific Capacity at Various Drawdown/Recovery Times (gpm/psi)			
			10 min	100 min	1000 min	10,000 min	10 min	100 min	1000 min	10,000 min
02/03/82	298	DWH	41.2	49.7	57.7	65.7[c]	--	--	--	--
	298	DBH	41.5	51.0	58.0	65.3[c]	--	--	--	--
	298	DWQ	40.4	49.4	57.9	66.0[c]	--	--	--	--
	298	DMEAN	41.0	50.0	57.9	65.7[c]	7.27	5.96	5.15	4.54[c]
	298	RWH	44.4	51.5	57.2[c]	--	--	--	--	--
	298	RBH	42.5	50.5	--	--	--	--	--	--
	298	RWQ	44.0	51.2	58.0[c]	--	--	--	--	--
	298	RCWQ	44.2	51.2	58.3[c]	--	--	--	--	--
	298	RBQ	43.2	50.8	57.5[c]	--	--	--	--	--
	298	RMEAN	43.7	51.0	57.8[c]	--	6.82	5.84	5.16[c]	--
	398	RMEAN-RMEAN (MEAN DD)	-2.7	-1.0	+0.1	--	--	--	--	--
10/20/81	1100	DRH	--	368	421[c]	475[c]	--	2.99	2.61[c]	2.32[c]
	1080	RBH	226	--	--	--	4.06	--	--	--
10/28/81	1100	DBH	--	368	430[c]	483[c]	--	2.99	2.56[c]	2.28[c]
	900	RBH	235	278	--	--	3.83	3.24	--	--
11/07/75	26.5	DXQ	0.824	1.04[d]	1.18[d]	--	32.2	25.5[d]	25.5[d]	--
	26.5	RXQ	0.88	0.94[d]	--	--	30.1	28.2[d]	--	--

a. Legend: D = Drawdown; W = Wellhead; H = Heise; X = Downhole; R = Recovery; B = Bubbler; Q = Digiquartz; C = Calculated

b. Assumed hot (274.0°F) shut-in pressures for 02/03/82 data: WH = 156.7 psig; WQ = 169.4 psia; BQ = 554.2 psia; BH = 541.5 psig. Data for 10/20/81 and 10/28/81 assume pressures are 1.3 psi greater than 02/03/82 values.

c. Values are estimates.

d. Data significantly affected by earth tides.

TABLE 1. HYDROLOGIC DATA FOR RRGE-1 TEST AT 298 GPM BEGINNING FEBRUARY 3, 1982

Interval (min)		Δs (psi/log cycle)		Δs Ratio	Figure	Q/Δs (gpm/psi/log cycle)		kh	T	ϕch		t_o or t'_o	Intersection of Early/Late	Pressure at $t/t' = 1$	
From	To	Early	Late	Early/Late	Number	Early	Late	(md/ft)	(gal/D/ft)	(ft/psi)	S	(min)	(min)	(psi)	Data Type[a]
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21	7110.33	--	7.10	--	1	--	42.0	--	--	--	--	--	--	--	DBH
0.83	4.0	17.2[b]	--	2.12[b]	2	17.3[b]	--	17,386[b]	1840[b]	0.0446[b]	0.0179[b]	0.0325	7.3[b]	--	DWQ
18	7110.33	--	8.10	--	2	--	36.8	--	--	--	--	--	--	--	DWQ
0.33	1.67	19.6	--	2.76	3	15.2	--	15,257	1615	--	--	--	3.31	--	RWQ
8.0	2629.67	--	7.10	--	3	--	42.0	--	--	--	--	--	--	--	RWQ
0.50	1.67	20.6	--	--	4	14.5	--	14,517	1537	0.0415	0.0167	0.0362	3.00	--	RCWQ
8.0	229.67	--	7.03	2.93	4	--	42.4	--	--	--	--	--	--	168.0	RCWQ
5.67	229.67	--	7.00	--	5	--	42.6	--	--	--	--	--	--	155.4	RWH
7.67	229.67	--	7.40	--	5	--	40.3	--	--	--	--	--	--	553.4	RBQ
Mean		20.1	7.42	2.85		14.9	40.4	14,887	1576	0.0415	0.0167	--	3.16		
Ratio															

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BQ	553.4	1	1.3	555.7	555.4	555.6	555.5	554.2
BH	540.8[b]	1	1.3	543.1[b]	542.6[b]	543.0[b]	542.8[b]	541.5
WQ	168.0	1	1.3	170.3	170.9	170.5	170.7	169.4
WH	155.4	1	1.3	157.9	158.1	157.9	158.0	156.7

a. Legend: B = Bubbler H = Heise
Q = Digiquartz W = Wellhead

b. Values are estimates.

TABLE 3. RRGE-1 DRAWDOWN, RECOVERY, AND SPECIFIC CAPACITY AT t AND t' EQUAL TO 10, 100, 1000 AND 10,000 MIN

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	298	DBH	41.5	51.0	58.0	65.3[c]	--	--	--	--
	298	DWQ	40.4	49.4	57.9	66.0[c]	--	--	--	--
	298	DMEAN	41.0	50.0	57.9	65.7[c]	7.27	5.96	5.15	4.54[c]
	298	RWH	44.4	51.5	57.2[c]	--	--	--	--	--
	298	RBH	42.5	50.5	--	--	--	--	--	--
	298	RWQ	44.0	51.2	58.0[c]	--	--	--	--	--
	298	RCWQ	44.2	51.2	58.3[c]	--	--	--	--	--
	298	RBQ	43.2	50.8	57.5[c]	--	--	--	--	--
	298	RMEAN	43.7	51.0	57.8[c]	--	6.82	5.84	5.16[c]	--
	398	RMEAN-RMEAN (MEAN DD)	-2.7	-1.0	+0.1	--	--	--	--	--
10/20/81	1100	DRH	--	368	421[c]	475[c]	--	2.99	2.61[c]	2.32[c]
	1080	RBH	226	--	--	--	4.06	--	--	--
10/28/81	1100	DBH	--	368	430[c]	483[c]	--	2.99	2.56[c]	2.28[c]
	900	RBH	235	278	--	--	3.83	3.24	--	--
11/07/75	26.5	DXQ	0.824	1.04[d]	1.18[d]	--	32.2	25.5[d]	25.5[d]	--
	26.5	RXQ	0.88	0.94[d]	--	--	30.1	28.2[d]	--	--

a. Legend: D = Drawdown, W = Wellhead, H = Heise, X = Downhole, R = Recovery, B = Bubbler, Q = Digiquartz, C = Calculated

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