ANALYSIS OF RECOVERY DATA FROM 5/97 PUMPING TEST AT WALLACE COUNTY TEST WELL

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ABSTRACT

A 24-hour pumping test was performed by the Kansas Geological Survey at a test well in Wallace County, Kansas in May of 1997. This test was designed to obtain information about the aqueous geochemistry and average hydraulic conductivity (K) of the sand units comprising the Dakota aquifer in the Wallace County area. Significant pumping rate variations in the early portions of the test, coupled with leakage-dominated responses at large times, made it difficult to estimate K using the drawdown during the pumping period. Since the residual drawdown during the recovery period are much less sensitive to rate variations, recovery data were employed in the analysis. The average K of the Dakota sands at this site most likely lies in the range of 0.32 ft/day to 0.50 ft/day (0.22-0.34 ft/day for pure water at 15.6 deg. C). These values are on the low end of the range of K estimates obtained from well tests performed by Kansas Geological Survey personnel in support of the Dakota Aquifer Program.

INTRODUCTION

A 24-hour pumping test was performed by the Kansas Geological Survey (KGS) at a test well in Wallace County, Kansas in early May of 1997. This work was done as part of the final stages of the Dakota Aquifer Program, a multi-year research effort directed at developing an understanding of the hydrologic, water-quality, and water-resources-management ramifications of increased utilization of the Dakota aquifer in central and western Kansas (Macfarlane et al., 1990). This project, which was funded as part of the Kansas Water Plan, has been coordinated by P. Allen Macfarlane of the Geohydrology Section of the KGS.

The site of the test well is in Wallace County, approximately six miles northeast of Sharon Springs, Kansas (see Figure 1a). The well was drilled in July of 1996, with the primary purpose of obtaining more information about the aqueous geochemistry and hydraulic properties of the Dakota aquifer in the Wallace County area. This particular site was chosen after extensive review of geophysical well logs from nearby petroleum wells, considering both lithologic and geochemical indicators. A borehole, 0.656 feet in diameter, was drilled through the Dakota sand units to a total depth of 1504 ft below land surface (lsf). Well completion involved two steps. First, steel casing, 5.56 inches (0.464 ft) in outer diameter (5.00 inches (0.417 ft) in inner diameter) and open at both ends, was suspended above the bottom of the borehole and cement grout was pumped into the casing. A swabbing tool (rubber cementing plug) was used to push the grout out of the casing and into the annulus. This process continued until the annulus was filled with grout to the surface. A portion of the grout remained in the bottom of the casing and served as a bottom cap on the well. After the cement had hardened, the casing and cement-filled annulus were perforated at two intervals using downhole explosive devices. Pairs of perforations, oriented approximately 180 degrees apart, were created at each level. Figure 1b displays the natural gamma log through the Dakota sand units. As shown in the figure, perforations were created in the interval from 1386-1402 ft below lsf (1.9 perforations/ft) and from 1416-1426 ft below lsf (3 perforations/ft). Upon completion, the well was moderately developed with a bailer. Note that this well was plugged shortly after the pumping test described in this report.

PUMPING TEST

A pumping test was performed at the Wallace County test well May 3-4, 1997 (total duration 24 hours and 1 minute) in conjunction with geochemical sampling. The Wallace County well was used as both the pumping and observation well for this test. Figures 2 and 3 are linear and semilog plots of drawdown versus time. As shown in the figures, drawdown stabilizes about 300 minutes after the start of pumping. This stabilization is undoubtedly a product of leakage from the shales in which the Dakota sands are embedded. The pumping rate variations in the first 70 minutes of the test coupled with the skin effects associated with the casing perforations, additional head losses due to partial penetration, and the leakage-dominated response at large times made analysis of the drawdown during the pumping period difficult. Since recovery data are much less sensitive to rate variations (Streltsova, 1988) and recovery analyses can be performed to remove the impact of skin effects and partial penetration (e.g., Butler and Healey, 1998), the residual drawdown data became the focus of the analysis. Table 1 provides a record of the residual drawdown data collected during the recovery period. Changes in water level were measured at one minute intervals during both the pumping and recovery periods using a pressure transducer (an In-Situ PXD-260 series 0-50 psig transducer) connected to a data logger (Campbell Scientific 21X data logger). The pumping rate was measured periodically by timing the filling of a calibrated bucket. The pumping rate was approximately 5 gallons per minute (gpm) in the interval on Figure 2 from "Throttled back on discharge" to "Position of hoses changed". The rate was nearly 6 gpm in the intervals on Figure 2 from "Added hose and valve to discharge line" to "Throttled back on discharge" and from "Position of hoses changed" to "Hose added and started sampling". No measurements of flow rate were obtained for the interval on Figure 2 from "Hose added and started sampling" to "Pump shut off". However, the drawdown data on Figure 2 indicate that the pumping rate during this period was clearly less than 5 gpm.

The standard approach for estimation of transmissivity (T) from recovery data is to use a superposition-based, semilog-plot method (Theis, 1935; Kruseman and de Ridder, 1989). This method involves the following three steps: 1) the residual drawdown data are plotted versus the log of the ratio of the total time since pumping began over the time since the pump was cut off (column 4 of Table 1); 2) the slope of a straight line fit to the semilog residual drawdown plot at small values of the time ratio is computed; and 3) an estimate of the transmissivity is calculated using equation (1),

$$T = \frac{2.3Q}{4\pi\Delta s} \qquad \textbf{(1)}$$

where

Q = pumping rate;

Δs = change in residual drawdown over one log cycle of the time ratio.

Figure 4 displays a complete record of the residual drawdown data in the semilog format required for the recovery method, while Figure 5 is a closeup of the interval of analysis. In order to calculate T from eqn. (1), Δs and Q must be estimated. A Δs value of 14.424 ft was computed for the best-fit line on Figure 5. The pumping rate varied from 5-6 gpm during most of the test, so an average rate of 5.3 gpm (1020.3 ft^3/day) was used for Q. As shown in Figure 4, the residual drawdown curve approaches the best-fit line from below. This was thought to be a product of the lower pumping rate used in the last hour of the test for the collection of water samples. Note that the extension of the best-fit line to a time ratio of one, which should theoretically correspond to a residual drawdown of zero (Streltsova, 1988), would, in this case, correspond to a residual drawdown of -3.1 ft. This negative residual drawdown at a time ratio of one is an indication that leakage plays a very significant role in the later stages of the recovery period. If data collection had continued, the residual drawdown plot would have eventually taken on a pronounced concave-upward curvature as a result of the increasing contribution of leakage. The absence of a concave-upward curvature to the plot of Figure 5 is an indication that leakage is not a significant mechanism during the period of the analysis.

Given the estimates for Δs and Q, a transmissivity of 12.9 ft^2/day was calculated from eqn. (1). Since one of the purposes of this test was to obtain an estimate of the average hydraulic conductivity of the Dakota sands, the transmissivity estimated from the recovery data must be converted into an average K. In order to make this conversion, some estimate of the thickness of the interval contributing flow to the well (henceforth designated as the flow interval) is needed. At least two approaches are possible at the Wallace County site. First, the length of the perforated interval (26 ft) can be used for the thickness of the flow interval. If this approach is used, a K estimate of 0.50 ft/day is calculated. A second approach is to use the length of the relatively clean sand interval, the interval from 1386-1426 ft (40 ft), for the thickness of the flow interval. In this case, a K estimate of 0.32 ft/day is calculated. Thus, the average K for the Wallace County site most likely lies between 0.32-0.50 ft/day.

Note that the storage coefficient cannot be estimated from a recovery analysis (Kruseman and de Ridder, 1989), so no information about the storage properties of the Dakota sands could be obtained from this analysis.

In order to compare the K estimates from the Wallace County site with values obtained at other sites in the Dakota aquifer, the Wallace estimates must be converted to either permeability estimates or to the standard laboratory conditions for reporting hydraulic conductivity values (pure water at 15.6 deg. C (Fetter, 1994)). Since most other Dakota estimates are reported as hydraulic conductivity values, the latter approach was used here. The water temperature and the total-dissolved-solids concentration measured during the pumping test were 33.0 deg. C and 3300. mg/l, respectively. Considering only the temperature correction, the 0.32-0.50 ft/day range converts to a K range of 0.22-0.34 ft/day. Laboratory data detailing viscosity and density changes as a function of sodium chloride concentration (Weast, 1976) indicate that a correction for salinity would change K values less than one percent at this site. Thus, a salinity correction was not deemed necessary.

Note that the analysis approach used here ignores the effect of wellbore storage. However, in aquifers of moderate or lower hydraulic conductivity, such as the interval tested at the Wallace County well, wellbore storage effects cannot necessarily be ignored. Papadopulos and Cooper (1967) present an analytical solution that can be used to assess the impact of wellbore storage effects on the residual drawdown. Since a drop pipe was used in the pumping test, the effective radius (r_c) of the Wallace County well was 0.183 ft. The Papadopulos and Cooper solution can be used to show that if the time since the pump was cut off is greater than $12.5\, r_c^2/T$, the relative difference between residual drawdown calculated with and without wellbore storage is less than 4%. Since this criterion corresponds to a time ratio of 29.6 in the Wallace County recovery data (i.e. a time before the interval at which the recovery analysis was applied), wellbore storage effects can be assumed negligible for the purposes of this test.

SUMMARY OF WALLACE COUNTY PUMPING TEST

A 24-hour pumping test was carried out at a Kansas Geological Survey test well in Wallace County, Kansas in May of 1997. The primary purpose of this test was to obtain water samples from and an estimate of the average hydraulic conductivity for the sand units comprising the Dakota aquifer in the Wallace County region. An analysis of the recovery data from the pumping test found that the average hydraulic conductivity at this site most likely lies in the range of 0.32-0.50 ft/day (0.22-0.34 ft/day for pure water at 15.6 deg. C). The K estimates at this site are at the low end of the range of values obtained from well tests in the Dakota aquifer in Kansas (Macfarlane et al., 1990).

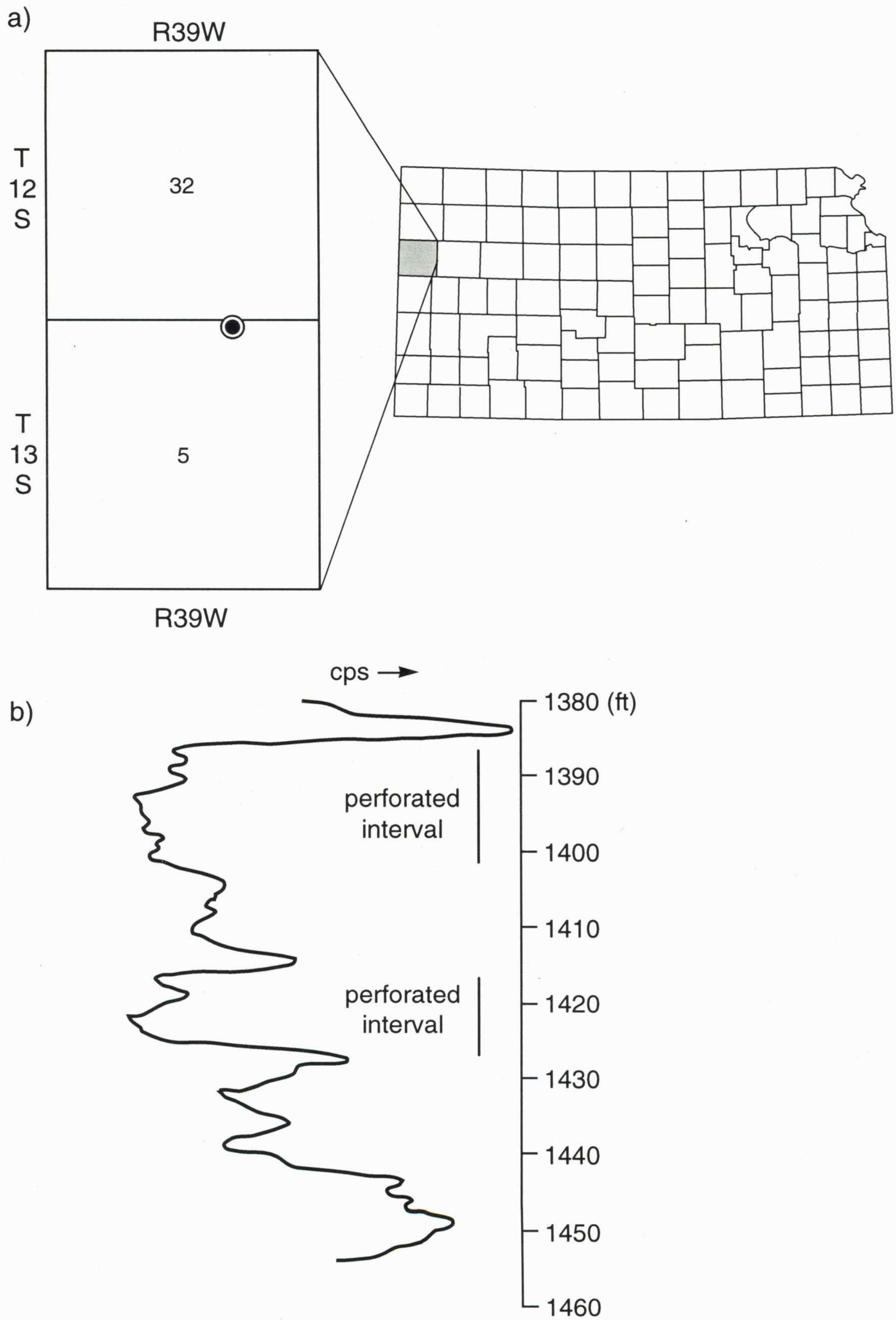

Figure 1. Location map (a) and natural gamma log (b) for Wallace County site.

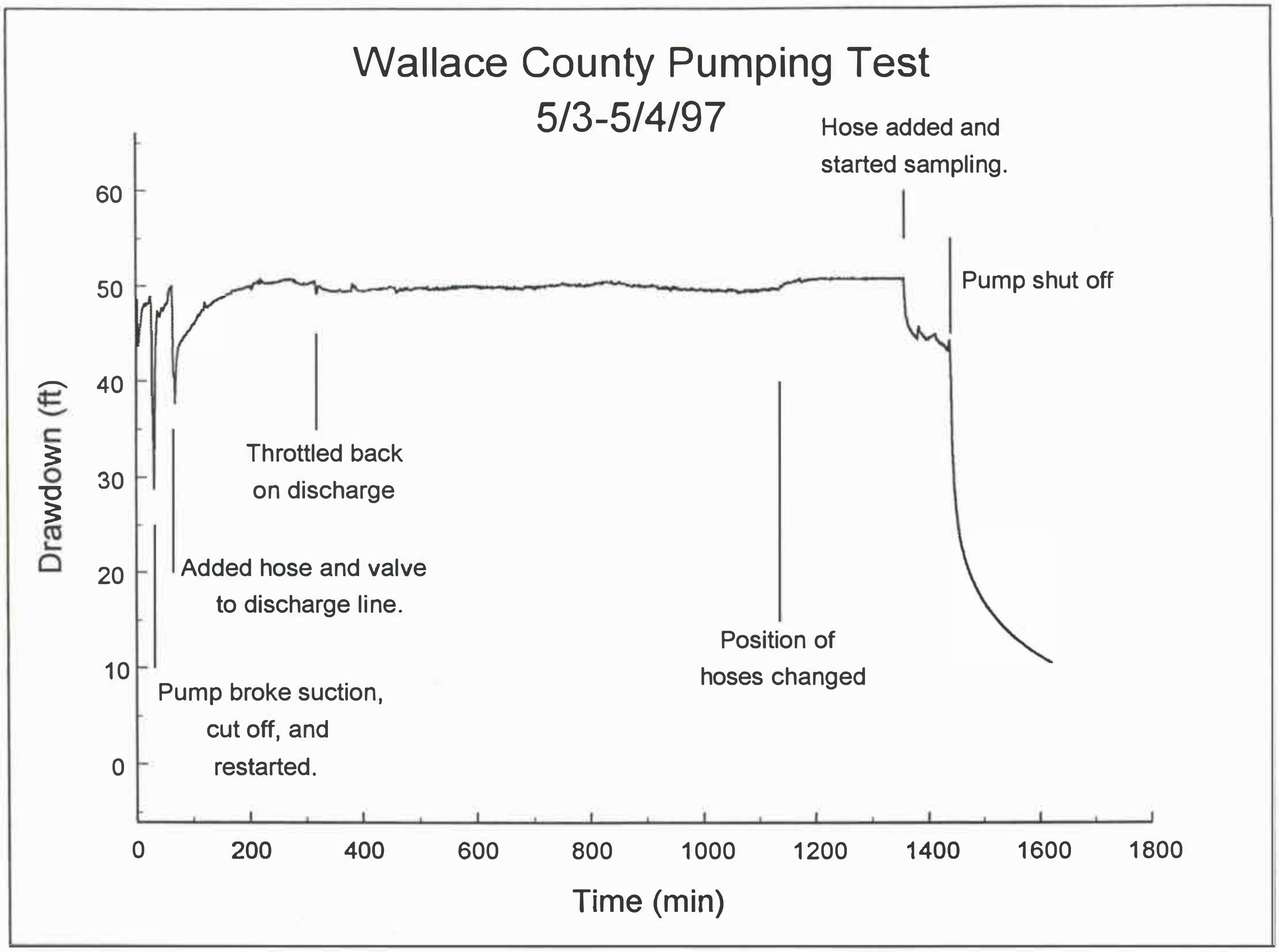

FIGURE 2 - PLOT OF DRAWDOWN VERSUS THE TIME SINCE PUMPING BEGAN.

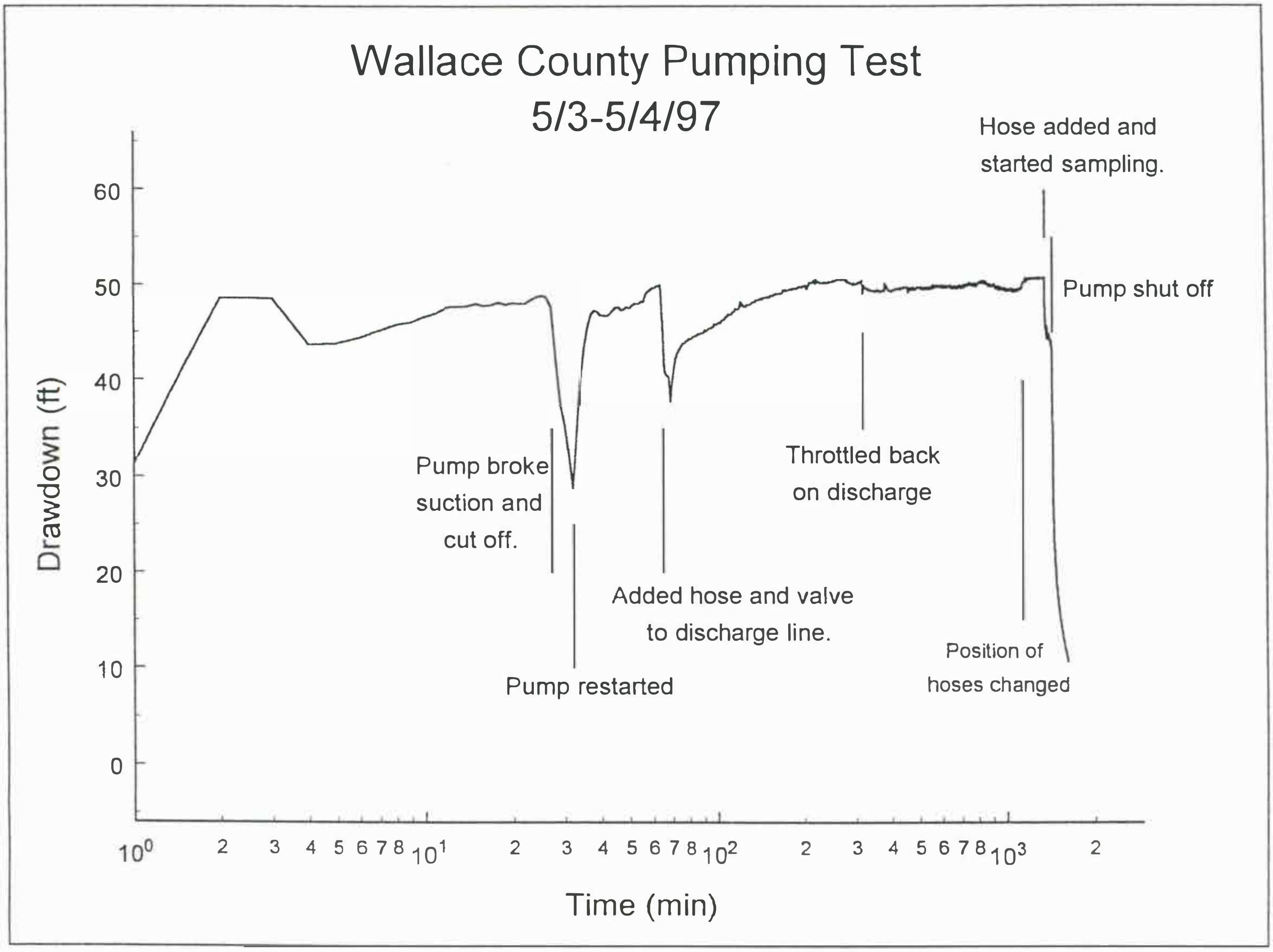

FIGURE 3 - PLOT OF DRAWDOWN VERSUS THE LOG OF TIME SINCE PUMPING BEGAN.

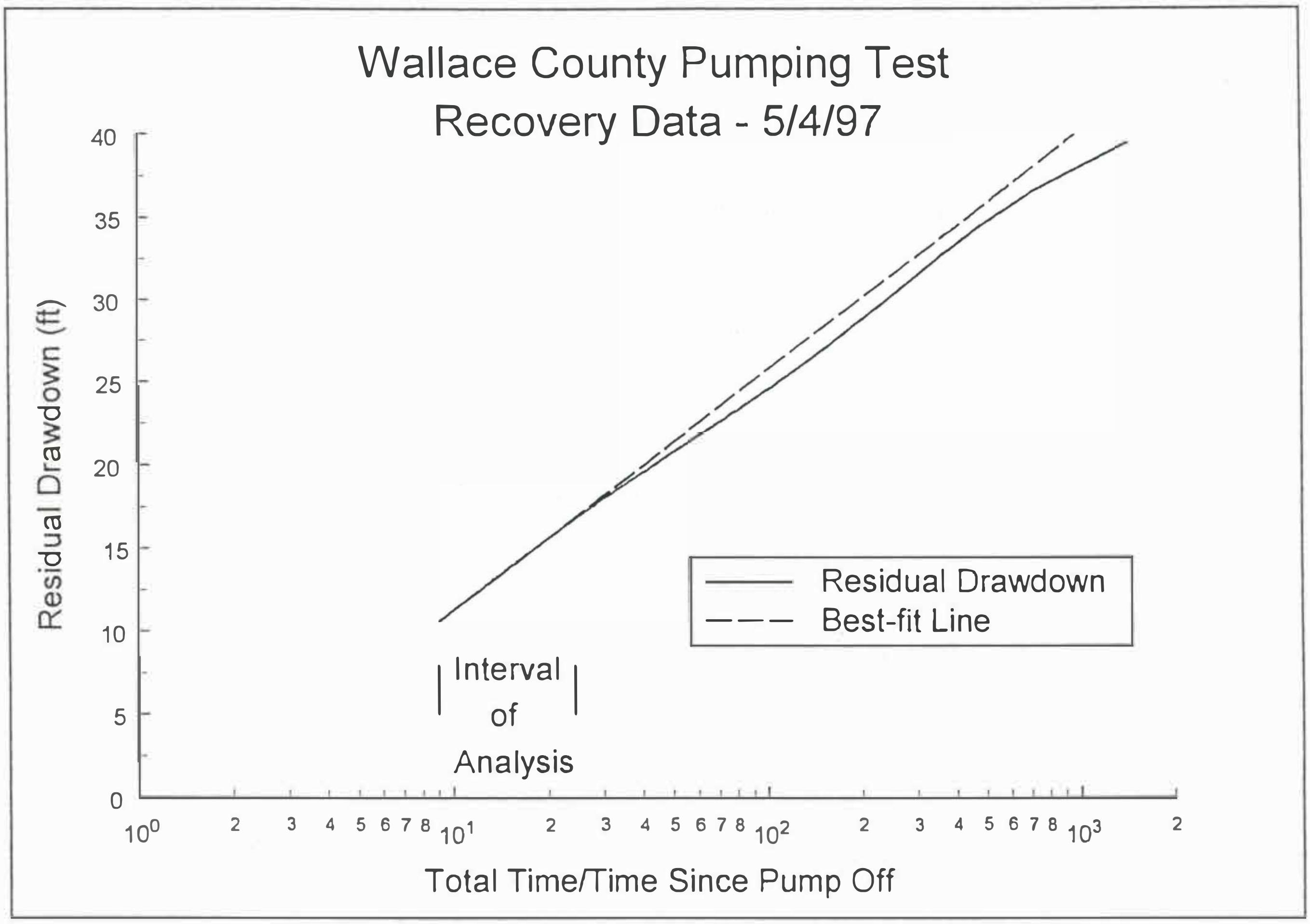

FIGURE 4 - PLOT OF RESIDUAL DRAWDOWN VERSUS THE LOG OF THE RATIO OF THE TOTAL TIME SINCE PUMPING BEGAN OVER THE TIME SINCE PUMP WAS CUT OFF

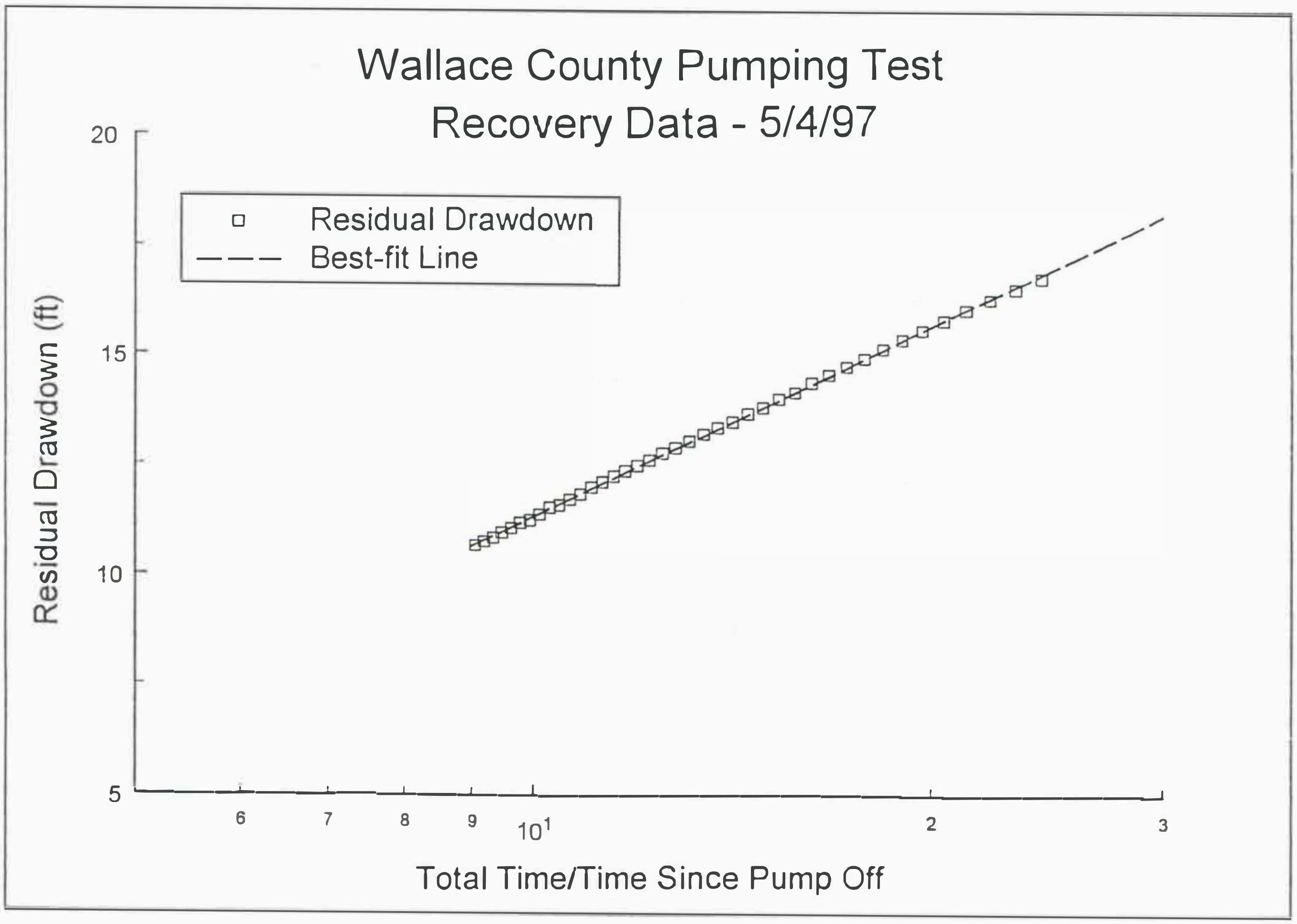

FIGURE 5 - RESIDUAL DRAWDOWN PLOT AND THE BEST-FIT STRAIGHT LINE FOR THE INTERVAL EMPLOYED IN THE RECOVERY ANALYSIS (EVERY THIRD MEASUREMENT PLOTTED).

TABLE 1 - RECOVERY DATA FROM WALLACE COUNTY PUMPING TEST

Time Since Pump Cut Off (min)	Residual Drawdown (ft)	Time Since Start of Pumping (min)	Time Ratio[1]
1.00	39.47	1442.00	1442.00
2.00	36.68	1443.00	721.50
3.00	34.49	1444.00	481.33
4.00	32.70	1445.00	361.25
5.00	31.21	1446.00	289.20
6.00	29.98	1447.00	241.17
7.00	28.96	1448.00	206.86
8.00	28.09	1449.00	181.13
9.00	27.35	1450.00	161.11
10.00	26.70	1451.00	145.10
11.00	26.11	1452.00	132.00
12.00	25.62	1453.00	121.08
13.00	25.16	1454.00	111.85
14.00	24.72	1455.00	103.93
15.00	24.35	1456.00	97.07
16.00	23.98	1457.00	91.06
17.00	23.67	1458.00	85.77
18.00	23.33	1459.00	81.06
19.00	23.09	1460.00	76.84
20.00	22.78	1461.00	73.05
21.00	22.53	1462.00	69.62
22.00	22.28	1463.00	66.50
23.00	22.07	1464.00	63.65
24.00	21.85	1465.00	61.04
25.00	21.63	1466.00	58.64
26.00	21.42	1467.00	56.42
27.00	21.26	1468.00	54.37
28.00	21.05	1469.00	52.46
29.00	20.86	1470.00	50.69
30.00	20.71	1471.00	49.03
31.00	20.52	1472.00	47.48
32.00	20.37	1473.00	46.03
33.00	20.18	1474.00	44.67
34.00	20.03	1475.00	43.38
35.00	19.90	1476.00	42.17
36.00	19.72	1477.00	41.03
37.00	19.59	1478.00	39.95
38.00	19.44	1479.00	38.92
39.00	19.32	1480.00	37.95
40.00	19.19	1481.00	37.02
41.00	19.07	1482.00	36.15
42.00	18.91	1483.00	35.31
43.00	18.82	1484.00	34.51

44.00	18.67	1485.00	33.75
45.00	18.54	1486.00	33.02
46.00	18.42	1487.00	32.33
47.00	18.33	1488.00	31.66
48.00	18.20	1489.00	31.02
49.00	18.08	1490.00	30.41
50.00	17.99	1491.00	29.82
51.00	17.86	1492.00	29.25
52.00	17.77	1493.00	28.71
53.00	17.65	1494.00	28.19
54.00	17.55	1495.00	27.68
55.00	17.46	1496.00	27.20
56.00	17.37	1497.00	26.73
57.00	17.28	1498.00	26.28
58.00	17.18	1499.00	25.84
59.00	17.06	1500.00	25.42
60.00	17.00	1501.00	25.02
61.00	16.87	1502.00	24.62
62.00	16.78	1503.00	24.24
63.00	16.72	1504.00	23.87
64.00	16.60	1505.00	23.52
65.00	16.53	1506.00	23.17
66.00	16.44	1507.00	22.83
67.00	16.35	1508.00	22.51
68.00	16.29	1509.00	22.19
69.00	16.19	1510.00	21.88
70.00	16.10	1511.00	21.59
71.00	16.04	1512.00	21.30
72.00	15.95	1513.00	21.01
73.00	15.85	1514.00	20.74
74.00	15.79	1515.00	20.47
75.00	15.73	1516.00	20.21
76.00	15.64	1517.00	19.96
77.00	15.58	1518.00	19.71
78.00	15.51	1519.00	19.47
79.00	15.42	1520.00	19.24
80.00	15.36	1521.00	19.01
81.00	15.27	1522.00	18.79
82.00	15.21	1523.00	18.57
83.00	15.14	1524.00	18.36
84.00	15.08	1525.00	18.16
85.00	15.02	1526.00	17.95
86.00	14.93	1527.00	17.76
87.00	14.87	1528.00	17.56
88.00	14.80	1529.00	17.38
89.00	14.74	1530.00	17.19
90.00	14.68	1531.00	17.01
91.00	14.62	1532.00	16.84
92.00	14.56	1533.00	16.66
93.00	14.49	1534.00	16.50
94.00	14.40	1535.00	16.33
95.00	14.37	1536.00	16.17

96.00	14.31	1537.00	16.01
97.00	14.25	1538.00	15.86
98.00	14.15	1539.00	15.70
99.00	14.12	1540.00	15.56
100.00	14.09	1541.00	15.41
101.00	14.00	1542.00	15.27
102.00	13.97	1543.00	15.13
103.00	13.91	1544.00	14.99
104.00	13.81	1545.00	14.86
105.00	13.78	1546.00	14.72
106.00	13.75	1547.00	14.59
107.00	13.66	1548.00	14.47
108.00	13.63	1549.00	14.34
109.00	13.57	1550.00	14.22
110.00	13.47	1551.00	14.10
111.00	13.44	1552.00	13.98
112.00	13.41	1553.00	13.87
113.00	13.35	1554.00	13.75
114.00	13.29	1555.00	13.64
115.00	13.23	1556.00	13.53
116.00	13.20	1557.00	13.42
117.00	13.16	1558.00	13.32
118.00	13.07	1559.00	13.21
119.00	13.04	1560.00	13.11
120.00	12.98	1561.00	13.01
121.00	12.95	1562.00	12.91
122.00	12.89	1563.00	12.81
123.00	12.86	1564.00	12.72
124.00	12.82	1565.00	12.62
125.00	12.76	1566.00	12.53
126.00	12.70	1567.00	12.44
127.00	12.64	1568.00	12.35
128.00	12.61	1569.00	12.26
129.00	12.58	1570.00	12.17
130.00	12.52	1571.00	12.09
131.00	12.48	1572.00	12.00
132.00	12.45	1573.00	11.92
133.00	12.39	1574.00	11.84
134.00	12.36	1575.00	11.75
135.00	12.30	1576.00	11.67
136.00	12.27	1577.00	11.60
137.00	12.24	1578.00	11.52
138.00	12.18	1579.00	11.44
139.00	12.15	1580.00	11.37
140.00	12.11	1581.00	11.29
141.00	12.05	1582.00	11.22
142.00	12.02	1583.00	11.15
143.00	11.99	1584.00	11.08
144.00	11.93	1585.00	11.01
145.00	11.90	1586.00	10.94
146.00	11.84	1587.00	10.87
147.00	11.81	1588.00	10.80

148.00	11.77	1589.00	10.74
149.00	11.71	1590.00	10.67
150.00	11.68	1591.00	10.61
151.00	11.65	1592.00	10.54
152.00	11.59	1593.00	10.48
153.00	11.59	1594.00	10.42
154.00	11.53	1595.00	10.36
155.00	11.53	1596.00	10.30
156.00	11.47	1597.00	10.24
157.00	11.43	1598.00	10.18
158.00	11.37	1599.00	10.12
159.00	11.34	1600.00	10.06
160.00	11.31	1601.00	10.01
161.00	11.25	1602.00	9.95
162.00	11.25	1603.00	9.90
163.00	11.22	1604.00	9.84
164.00	11.19	1605.00	9.79
165.00	11.13	1606.00	9.73
166.00	11.10	1607.00	9.68
167.00	11.06	1608.00	9.63
168.00	11.03	1609.00	9.58
169.00	11.00	1610.00	9.53
170.00	10.97	1611.00	9.48
171.00	10.94	1612.00	9.43
172.00	10.88	1613.00	9.38
173.00	10.85	1614.00	9.33
174.00	10.82	1615.00	9.28
175.00	10.82	1616.00	9.23
176.00	10.76	1617.00	9.19
177.00	10.72	1618.00	9.14
178.00	10.69	1619.00	9.10
179.00	10.66	1620.00	9.05
180.00	10.63	1621.00	9.01
181.00	10.60	1622.00	8.96

1 - Column 3 over column 1.