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ANALYSIS OF 1994-95 HYDRAULIC TESTS AT TREGO COUNTY MONITORING SITE

by

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ABSTRACT

A 21.5-hour, constant-rate pumping test and a series of slug tests were performed by the Kansas Geological Survey at a monitoring well in Trego County, Kansas in July of 1994 and October-November of 1995. These tests were designed to obtain information about the average hydraulic conductivity (K) of the sand units comprising the Dakota aquifer. The average K estimate obtained from the pumping test varied considerably depending on what value was used for aquifer thickness. An estimate in the range of 44.-50. ft/day (35.-40. ft/day for pure water at 15.6 deg. C) was considered most reasonable for this site, although the average K could be as high as 71 ft/day (56 ft/day for pure water at 15.6 deg. C). Conductivity estimates obtained from slug tests varied over two orders of magnitude and were strongly affected by a dynamic skin and the apparent buildup of a bacterial/oxyhydroxide mat in the vicinity of the well screen. The highest slug-test K estimate was 22. ft/day (17. ft/day for pure water at 15.6 deg. C). More extensive well development and more elaborate slug-test procedures would be required to obtain a slug-test estimate closer to the average K obtained from the pumping test. The conductivity estimates obtained at this site are relatively high with respect to other values obtained from outside of the Dakota subcrop region.

INTRODUCTION

A series of hydraulic tests were performed by the Kansas Geological Survey (KGS) at a monitoring well in Trego County, Kansas in July of 1994, and October-November of 1995. This work was done as part of the Dakota Aquifer Program, a 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 is funded as part of the Kansas Water Plan, is being coordinated by P. Allen Macfarlane of the Geohydrology Section of the KGS.

The site of the monitoring well is in Trego County, approximately 4 3/4 miles northwest of WaKeeney, Kansas (see Figure 1). The well was drilled in May of 1994, with the primary purpose of obtaining more information about the geochemistry and hydraulic properties of the Dakota aquifer in the Trego County area. This particular site was chosen after extensive review of geophysical well logs from nearby petroleum wells. Figure 2 and Table 1 provide stratigraphy and well construction information for the site. Prior to hydraulic testing, the well was moderately developed with a bailer on June 30, 1994.

JULY 1994 PUMPING TEST

A constant-rate pumping test was performed July 16-17, 1994 (total duration 21 hours and 38 minutes) in conjunction with geochemical sampling. The Trego well was used as both the pumping

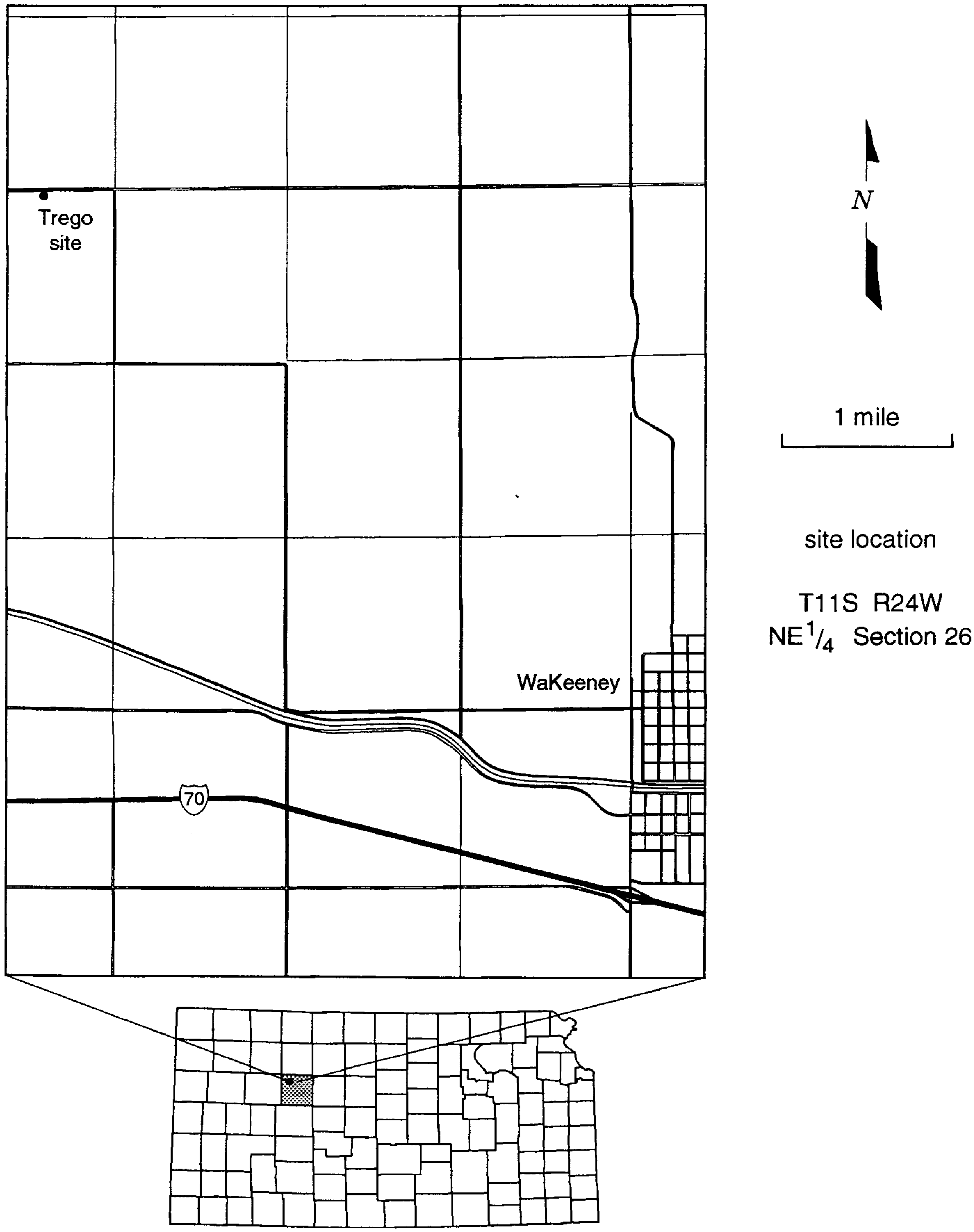

Figure 1. Location map for Trego County site

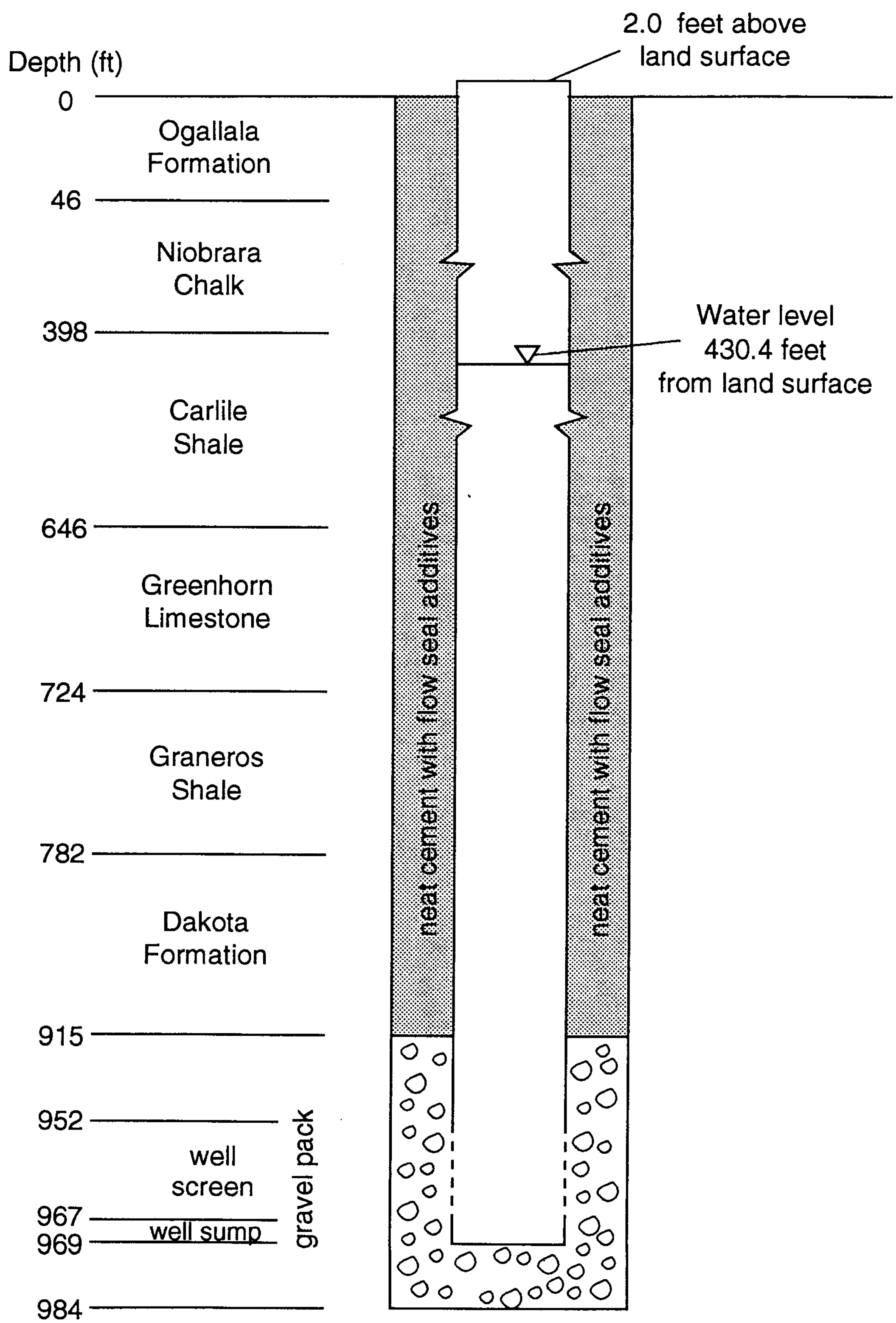

Figure 2. Stratigraphy and well construction at Trego County site.

Well Name	Borehole Radius[1]	Casing Radius[2] (ESR)[3]	Total Depth	NSI (ESL)[4]	Gravel Pack Interval	Grout Interval
Trego	0.3281	0.2083 (0.3281)	984	952-967 (?)	915-984	0-915

1 - Units for information in this and remaining columns are ft. Reference location is land surface.

2 - Casing is standard steel casing, while screen is stainless steel. Both casing and screen are Schedule 40 pipe.

3 - ESR - effective screen radius

4 - NSI - nominal screened interval
ESL - effective screen length

TABLE 1 - WELL CONSTRUCTION INFORMATION FOR TREGO COUNTY SITE

and observation well for this test. Although very little drawdown data were collected during the period of pumping, detailed measurements were taken for the first 30 minutes of recovery after the cessation of pumping. Table 2 provides a record of the residual drawdown data collected during the recovery period. A Solinst electric tape was employed for all water-level measurements.

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) plotting the residual drawdown 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 2); 2) computing the slope of a straight line fit to the semilog residual drawdown plot at small values of the time ratio; and 3) calculating transmissivity using equation (1),

$$T = \frac{2.3Q}{4\pi\Delta s} \tag{1}$$

where

Q = pumping rate;

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

Figure 3 displays a complete record of the residual drawdown data in the semilog format required for the recovery method, while

Time Since Pump Cut Off (sec)	Residual Drawdown (ft)	Time Since Start of Pumping (sec)	Time Ratio[1]
10.00	11.58	77890.00	7789.00
35.00	1.80	77915.00	2226.14
55.00	0.91	77935.00	1417.00
65.00	0.85	77945.00	1199.15
75.00	0.80	77955.00	1039.40
85.00	0.79	77965.00	917.24
95.00	0.75	77975.00	820.79
105.00	0.74	77985.00	742.71
110.00	0.72	77990.00	709.00
115.00	0.71	77995.00	678.22
120.00	0.68	78000.00	650.00
180.00	0.62	78060.00	433.67
240.00	0.59	78120.00	325.50
300.00	0.56	78180.00	260.60
360.00	0.53	78240.00	217.33
420.00	0.51	78300.00	186.43
480.00	0.49	78360.00	163.25
540.00	0.48	78420.00	145.22
600.00	0.46	78480.00	130.80
660.00	0.45	78540.00	119.00
720.00	0.44	78600.00	109.17
780.00	0.43	78660.00	100.85
840.00	0.42	78720.00	93.71
900.00	0.41	78780.00	87.53
960.00	0.40	78840.00	82.13
1020.00	0.39	78900.00	77.35
1080.00	0.39	78960.00	73.11
1140.00	0.38	79020.00	69.32
1200.00	0.38	79080.00	65.90
1260.00	0.37	79140.00	62.81
1320.00	0.37	79200.00	60.00
1380.00	0.36	79260.00	57.43
1440.00	0.36	79320.00	55.08
1500.00	0.35	79380.00	52.92
1560.00	0.35	79440.00	50.92
1620.00	0.34	79500.00	49.07
1680.00	0.34	79560.00	47.36
1740.00	0.34	79620.00	45.76
1800.00	0.33	79680.00	44.27

1 - Column 3 over column 1.

TABLE 2 - RECOVERY DATA FROM TREGO COUNTY PUMPING TEST

Figure 4 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 0.293 ft was computed from Figure 4 for the time-ratio interval between 50 and 500. The pumping rate varied from 51.7-54.5 gallons per minute (gpm) during the test, so an average rate of 53.1 gpm (7.10 ft^3/min) was employed for Q.

Given these estimates, a transmissivity of 6,386. ft^2/day was calculated from eqn. (1). Since the purpose of this test was to obtain an estimate of the average hydraulic conductivity of the Dakota sands, the transmissivity estimated from the recovery data needs to 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. Several approaches are possible. First, the nominal length of the screened interval (15 ft) can be used for the thickness of the flow interval. If this approach is employed, a K estimate of 426. ft/day is calculated; a value that is clearly too high for a semiconsolidated sand unit. A second approach would be to use the length of the gravel pack (69 ft) for the thickness of the flow interval. In this case, a K estimate of 92.5 ft/day is calculated; a value that is still extremely high for a semiconsolidated sand unit. A third approach would be to use geologic or geophysical information to estimate the thickness of the flow interval. Since no cores and only limited cuttings were obtained during drilling, wireline geophysical surveys appear to be the best source of information. Figure 5 displays natural gamma

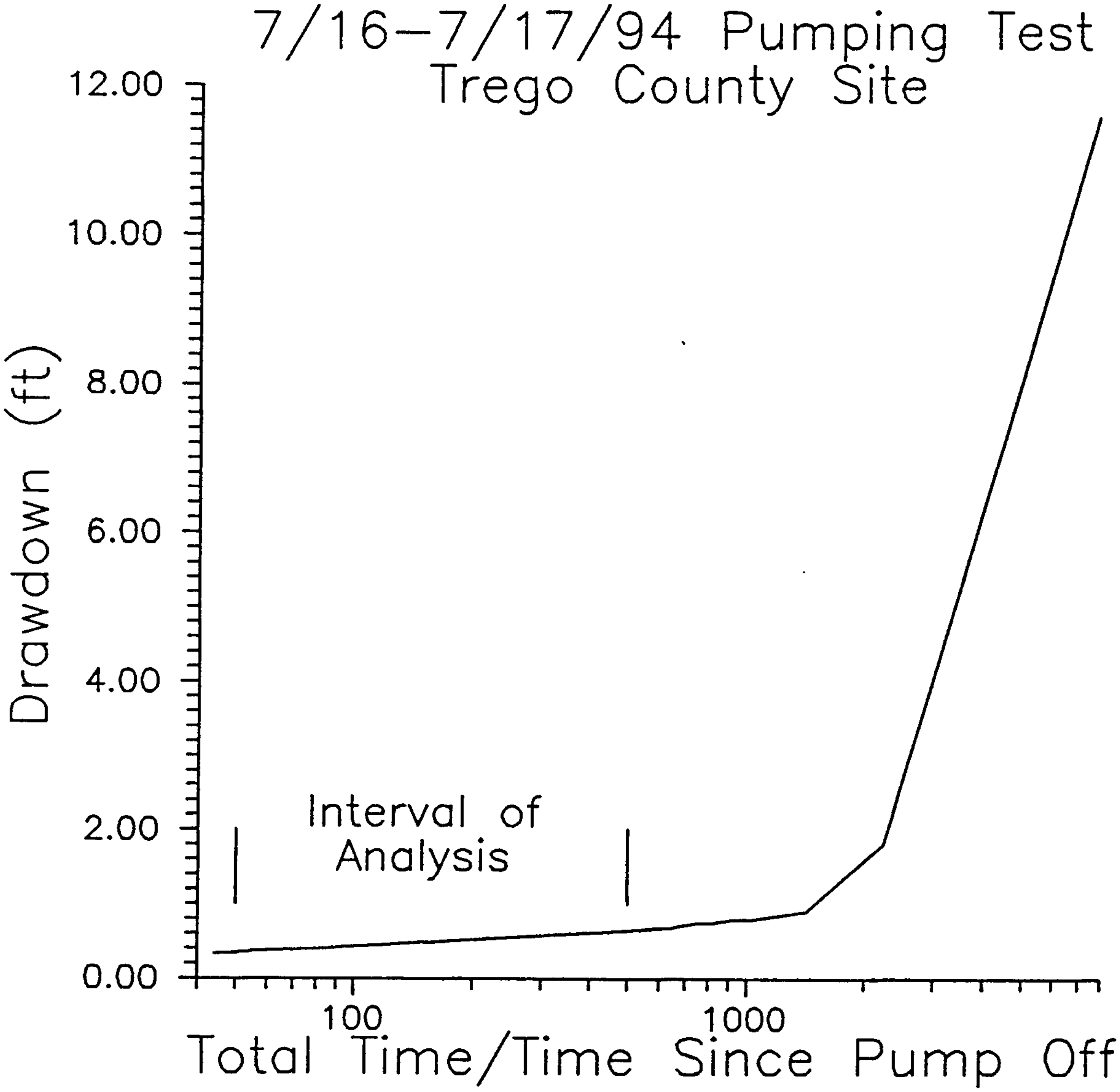

FIGURE 3 - PLOT OF RESIDUAL DRAWDOWN VERSUS THE LOG OF THE RATIO OF THE TOTAL TIME SINCE PUMPING BEGAN OVER THE TIME SINCE PUMP WAS CUT OFF

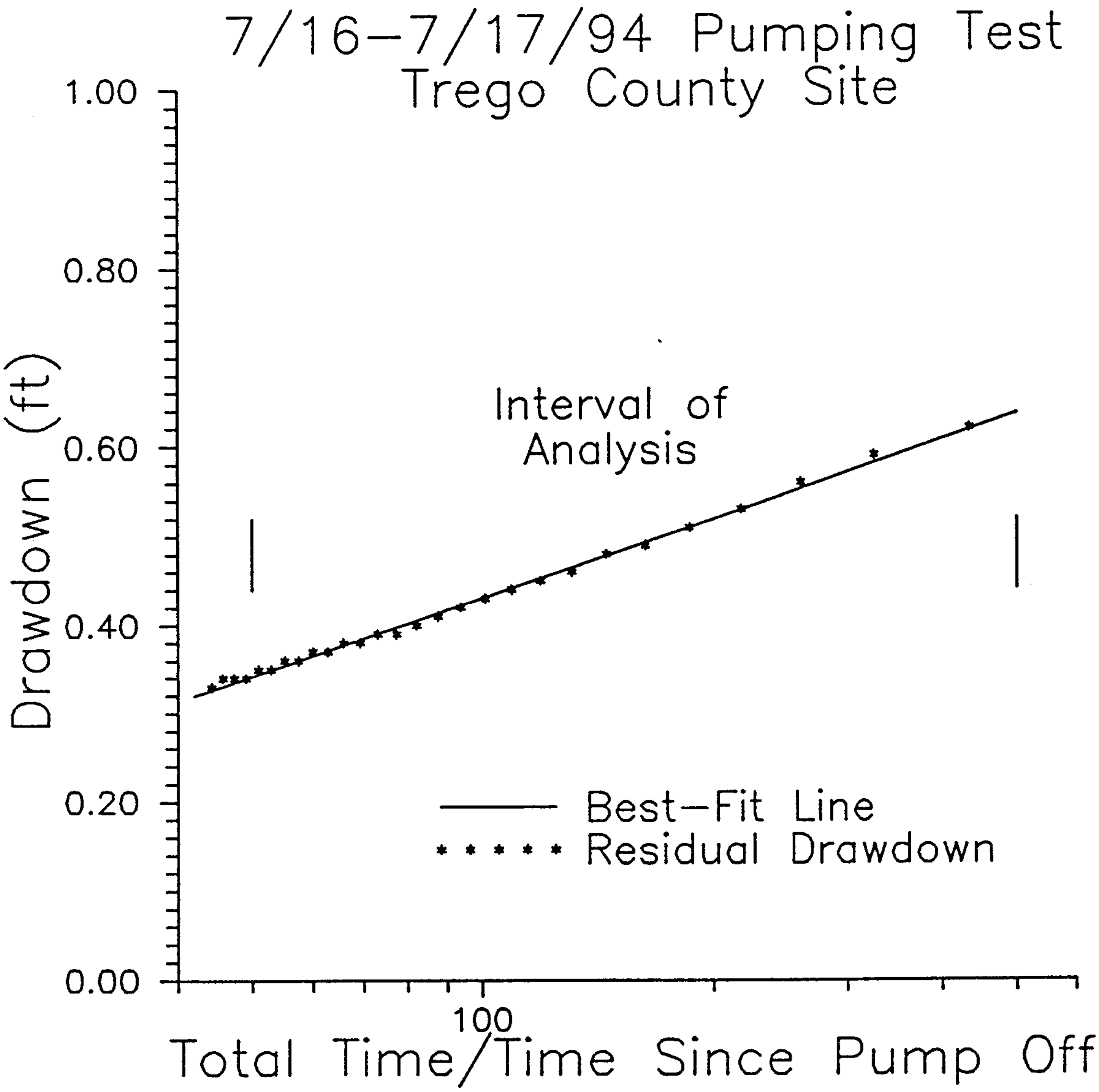

FIGURE 4 - RESIDUAL DRAWDOWN PLOT AND THE BEST-FIT STRAIGHT LINE FOR THE INTERVAL EMPLOYED IN THE RECOVERY ANALYSIS

logs from the Trego monitoring well (labelled "Trego" on figure) and two nearby petroleum wells. Note that the Trego well was installed in the upper portion of the Dakota sands, so it is impossible to estimate sand thickness from this well alone. The logs from the two nearby wells indicate the presence of discontinuous shale lenses in the Dakota sands. If the major shale lens shown in the Conner 1 log is used as the lower boundary of the sand unit (flow-interval thickness of 90 ft), an average K estimate of 71.0 ft/day is obtained; a value that would certainly be on the high end of K estimates obtained for the Dakota sands outside of the Dakota subcrop region (Macfarlane et al., 1990).

If the shale lenses are assumed to be discontinuous, the average thickness of the total sand interval shown on the Conner 1 and Schaus 1 logs (144 ft) can be used for the thickness of the flow interval. In this case, an average K estimate of 44.3 ft/day is calculated. Since there is no sign of leakage in the recovery data, this value should be considered the minimum average K estimate for the Trego site. The average K estimate at this site therefore is undoubtedly in the range of 44.3-71.0 ft/day. Since the logs do not clearly indicate a continuity of shale lenses, we suspect that the actual flow-interval thickness is close to the average sand body thickness of 144 ft. If we assume that a small portion (10 ft would be a reasonable estimate from the logs of Figure 5) of the sand body is occupied by shale, which contributes virtually no flow to the well during the period in which recovery data were collected, then a K estimate of 47.7 ft/day is obtained.

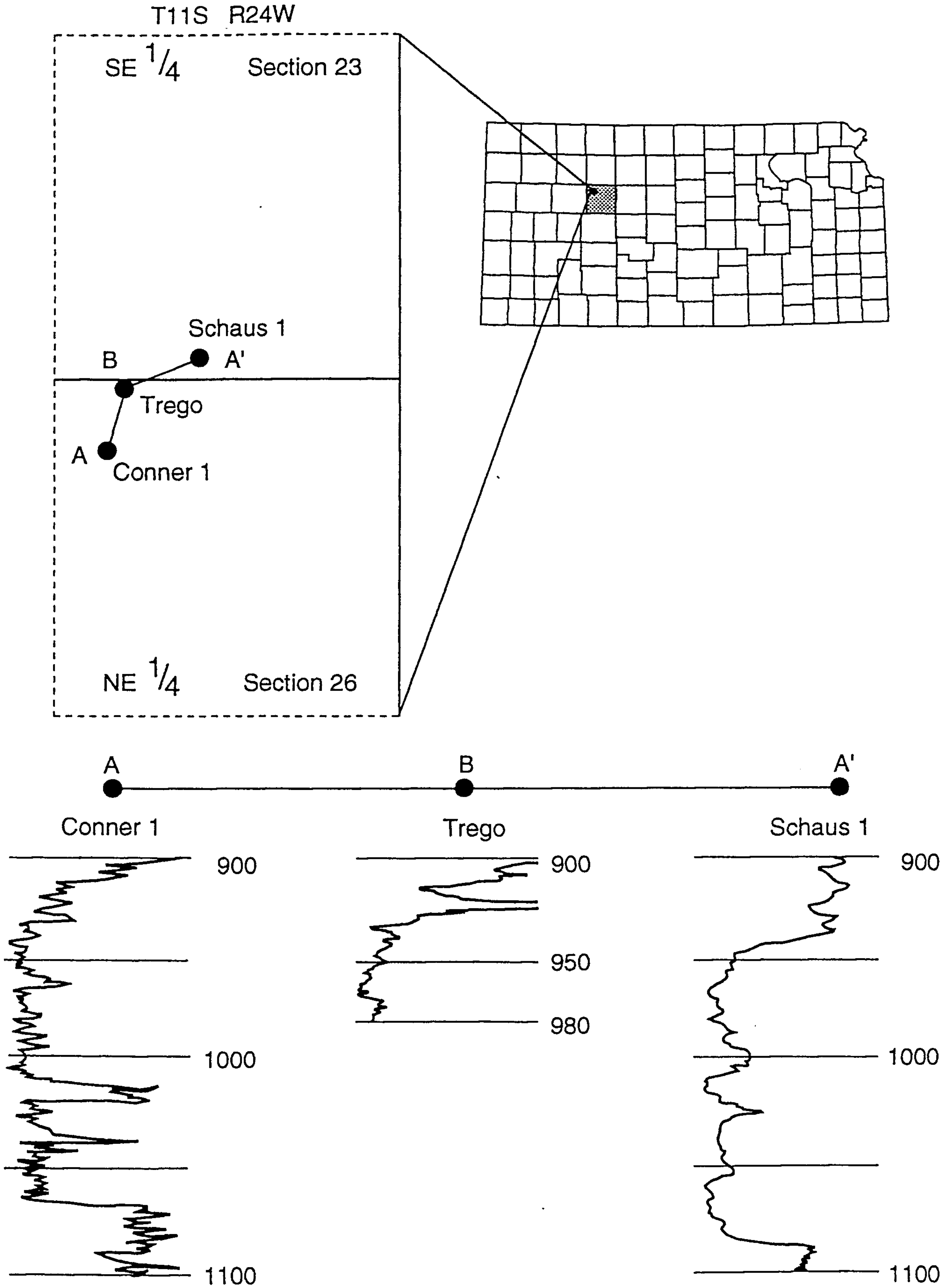

Figure 5. Natural gamma logs from Trego well and two nearby petroleum wells

Given that a small portion of the total thickness of the sand body is occupied by shale, we estimate that the average K for the Trego site most likely lies between 44-50 ft/day, although it could be as high as 71 ft/day. Note that no estimate of the storage properties of the Dakota sands could be obtained from the recovery data.

In order to compare the K estimates from the Trego County site with values obtained at other sites in the Dakota aquifer, the Trego estimates must be converted to 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. The water temperature and the total-dissolved-solids concentration measured during the pumping test were 25.3 deg. C and 2,500 mg/l, respectively. Considering only the temperature correction, the 44-50 ft/day range converts to a K range of 35-40 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 0.2% at this site. Thus, a salinity correction was not deemed necessary.

FALL 1995 SLUG TESTS

A series of slug tests were carried out in October and November of 1995 in an attempt to get further information about the transmissive properties of the Dakota sands (see Table 3 for schedule and details of the tests). These tests were carried out following a recently defined set of guidelines for the performance and analysis of slug tests (Butler et al., 1996), which were the product of a KGS research effort directed at improving slug-test methodology.

Three approaches were employed to initiate the slug tests performed at this site. One approach (henceforth dubbed the "dipper" approach) required the use of a pipe string consisting (starting from the lower end) of a sliding-head inflatable packer, a specially designed check valve that can be opened from the surface via a rope/wireline, and 10-20 ft of PVC casing. This approach involved lowering the pipe string below the static water level in the well until the PVC casing was completely filled with water. The pipe string was then pulled back until the check valve (which was holding the water in the PVC casing) and a pressure transducer (which was placed right above the check valve in the PVC casing) were just below the static water level. The packer would then be inflated and the test would be initiated by opening the check valve from the surface. This procedure would produce a flow of water out of the well in response to the slug-induced disturbance. One important advantage of this approach is that after packer inflation only a relatively short period of time is required for static conditions to be reestablished in the well prior to initiating a test. Once the packer is inflated, the head in the well below the check valve returns to static conditions relatively quickly because only a very small amount of water is required to flow out of/into the well for recovery from the

Date	Test No. and Type[1]	T_0 (sec)	H_0 (ft)[2]	% Recovery[3]	Flow Dir.[4]
10/25/95	1 pneu	21.7	5.11	93.1	in
10/25/95	2 pneu	45.2	4.03	59.0	in
10/25/95	3 pneu	46.9	3.40	41.0	in
10/25/95	4 pneu	54.8	1.02	31.9	in
10/25/95	5 pneu	30.5	7.05	23.8	in
10/26/95	1 pneu	39.7	2.32	100.	in
10/26/95	2 pneu	36.7	2.36	100.	in
11/16/95	1 pneu	77.8	1.63	36.5	in
11/16/95	2a pneu	2112.	5.98	100.	out
11/16/95	2b pneu	41.4	5.88	94.7	in
11/16/95[5]	3 dip	????	??????	100.	out
11/16/95	4 dip	323.7	5.46	100.	out
11/17/95	1 dip	355.4	5.96	100.	out
11/17/95	2 bail	55.5	2.20	94.1	in

1 - pneu - test initiated using the pneumatic method
dip - test initiated using the dipper method
bail - test initiated using the bailer method

2 - H_0 - magnitude of initial displacement (size of slug)

3 - measure of how close well had returned to static conditions prior to test initiation - ratio of actual H_0 (measured at time of test initiation) over expected H_0 if static conditions had been reached (measured by other means such as air-pressure reading)

4 - in - test produces flow into the well
out - test produces flow out of the well

5 - transducer cable caught on line used to open check valve causing transducer movement during test

TABLE 3 - SCHEDULE AND DETAILS OF SLUG TESTS AT TREGO COUNTY SITE

pretest activities (e.g., lowering and raising the pipe string, packer inflation, etc.). Recovery to static conditions following the movement of only a very small volume of water is a result of wellbore storage in this case being the product of the volume of casing and screen below the check valve times the compressibility of water and the packer. In essence, the heads are recovering as if a shut-in slug test had been performed (Bredehoeft and Papadopulos, 1980; Neuzil, 1982).

The second approach (henceforth dubbed the "pneumatic" method) involved pressurization of the air column in a sealed well casing (McLane et al., 1990; Levy and Pannell, 1991). This pressurization produced a depression of the water level in the well as water was driven out of the well in response to the increased air pressure. The water level continued to drop until the magnitude of the total decrease in the pressure head of the water equalled the magnitude of the total increase in the pressure head of the air column. At that point, the well had returned to static conditions and the test could be initiated by a very rapid depressurization of the air column. A pressure disturbance introduced in this manner would produce a flow of water into the well. Note that two procedures were used to seal the well casing in these tests. The approach used in the October series of tests was to seal the casing at the well head. Since the depth to water was greater than 400 ft at this site, a seal at the well head required the pressurization/depressurization of a large volume of well casing. The length of time needed for depressurization of this column potentially could make it difficult to satisfy the instantaneous-introduction assumption required for slug tests (see Butler et al. (1996) for further details). Thus, for the November series of tests, a special down-hole tool was designed and built at the KGS by the second author. This tool consisted (starting from the lower end) of a sliding-head inflatable packer, a specially designed length of pipe through which the transducer cable can pass without compromising the seal, and a specially designed check valve that can be opened from the surface with a rope/wireline. Use of this tool involved lowering the pipe string to a few feet above the static water level, inflating the packer, closing the check valve, and then pressurizing the air column below the tool. When static conditions were reached, the slug-induced disturbance was introduced by opening the check valve. A drawback of the pneumatic method is that one may have to wait a considerable period of time until heads have returned to static conditions. Unlike the dipper approach, wellbore storage in this case is only a function of the cross-sectional area of the casing, resulting in a relatively large volume of water having to move out of the well in the pressurization phase. Note that Shapiro and Greene (1995) suggest a possible approach for analysis of data collected from pneumatic slug tests initiated prior to full recovery to static conditions. That approach, however, has not yet been extensively evaluated in the field, so it was not employed here.

The final approach (henceforth dubbed the "bailer" approach) was only used for one test (11/17/95 test 2). In this approach, a bailer was lowered on a wireline until it was completely submerged below the static water level in the well. After allowing the head in the well to return to static conditions, the bailer was quickly pulled out of the water column, producing a sudden drop in the water level.

For all slug tests, changes in water level were measured using a pressure transducer (an In-Situ PXD-260 series 0-50 psig transducer) connected to a data logger (Campbell Scientific 21X data logger). Air pressures were monitored using a pressure transducer (an Instrumentation Northwest PS9000 series 0-30 psig transducer) and an analog pressure gauge (Davis Instruments Model 1082 series 0-30 psig gauge). Casing pressurization was accomplished using either an air compressor or a tank of compressed nitrogen gas.

October 1995 Tests

The first series of slug tests were performed on October 25-26, 1995. Initially, a test using the dipper approach with 3" PVC casing was attempted. Unfortunately, the pipe string was lodged in the well while being lowered, requiring a great deal of effort and time be spent to remove it. During the removal process, the packer inflation line was severely damaged. Thus, the remaining tests in this series were initiated using the pneumatic approach with the seal at the well head.

A total of seven tests were performed as part of this series. Figures 6 (10/25 tests) and 7 (10/26 tests) display the logarithm of the normalized head (head relative to static normalized by the magnitude of the initial displacement (i.e. the size of the slug)) versus time plots for this series of tests. Table 3 provides details of the 10/25-10/26 slug tests. T_0 is the basic time lag of Hvorslev (1951) and is inversely proportional to K.

The large variation in T_0 between tests performed consecutively on the same day (Figure 6 and Table 3) can be attributed to two factors: 1) the introduction of the slug-induced disturbance causes a mobilization and redistribution of fine material in the near-well portions of the formation (an example of what Butler et al. (1996) term an "evolving" or "dynamic" skin); and 2) the well had not returned to static conditions prior to test initiation. The first factor was considered the most important, although the second factor was also significant for a number of tests. Table 3 indicates that only three tests, 10/25 test 1 and 10/26 tests 1-2, had nearly static conditions prior to test initialization. The large differences between these tests (see Figure 7) is apparently the result of a dynamic skin. The reason that most tests were initiated prior to complete recovery was that it took a very long time for heads to return to static after pressurization of the air column. For some reason, the time required for recovery after pressurization of the air column was much longer than the time required for recovery after column depressurization. Unfortunately, as a result of the damage to the packer inflation line, the reason for this difference in recovery times could not be thoroughly investigated in this series of tests.

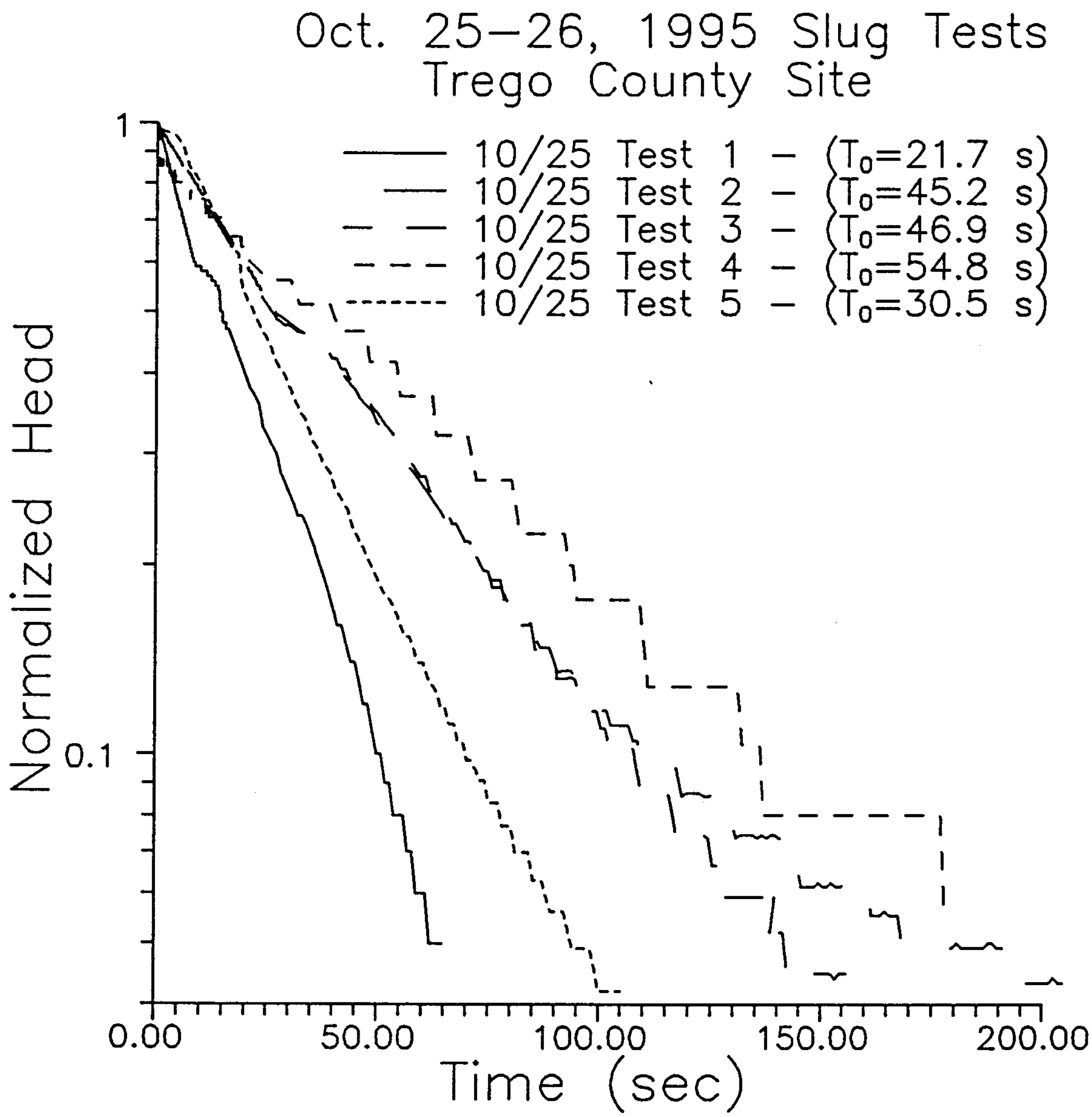

FIGURE 6 - LOG NORMALIZED HEAD VERSUS TIME PLOTS OF 10/25/95 SLUG TESTS.

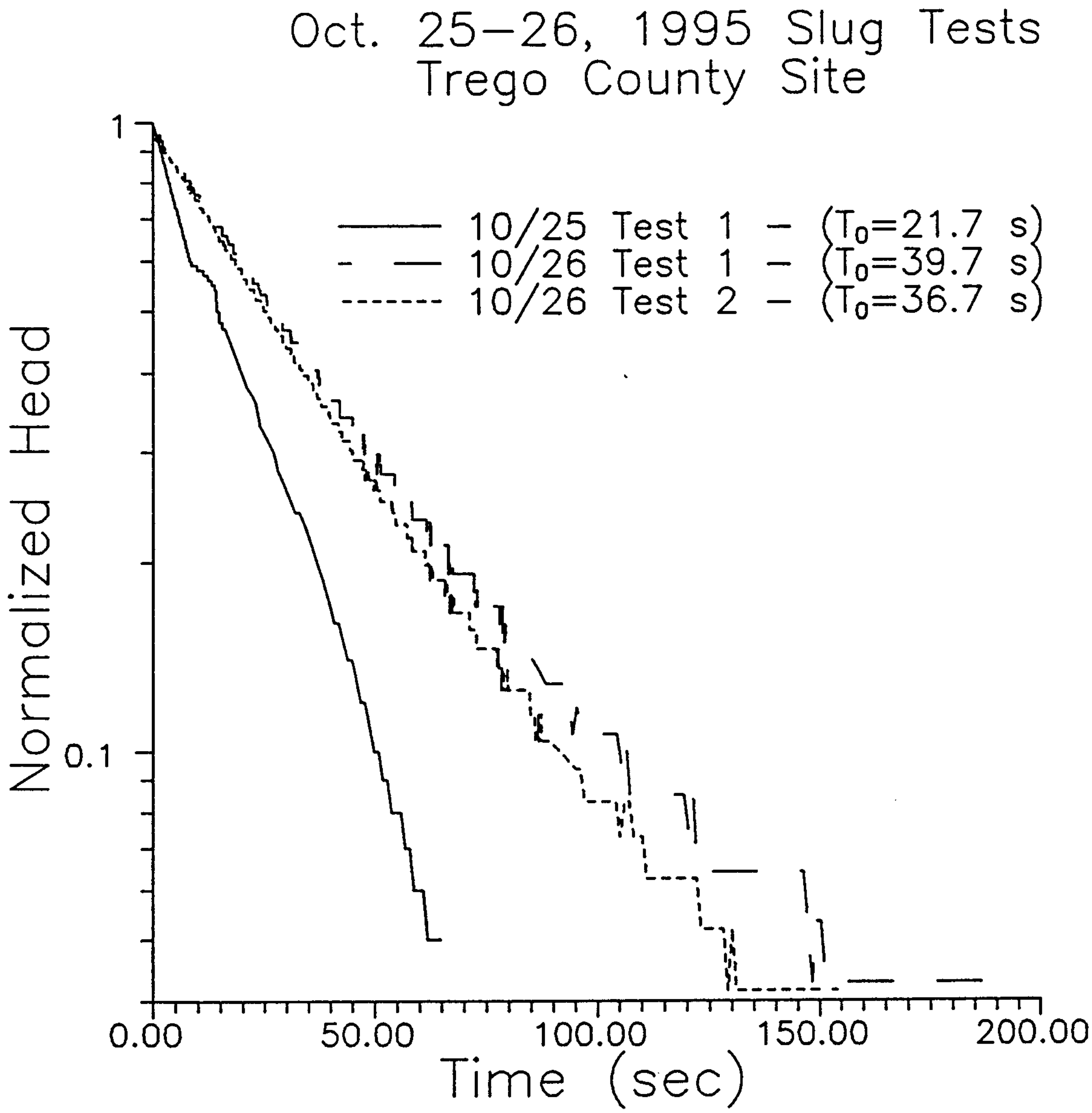

FIGURE 7 - LOG NORMALIZED HEAD VERSUS TIME PLOTS OF 10/26/95 SLUG TESTS (10/25/95 TEST 1 PLOT INCLUDED FOR COMPARISON PURPOSES).

Since even the most rapid test, 10/25 test 1, had not completely reached static conditions prior to test initiation and was also suspected to be affected by a dynamic skin, no attempt was made to analyze the slug-test data in great detail. Instead, the isotropic form of the Hvorslev method (Hvorslev, 1951; Fetter, 1994) was employed to obtain an approximate estimate for K from 10/25 test 1 data. In the isotropic form of the Hvorslev method, K is calculated using equation (2)

$$K = \frac{r_c^2 \ln((b/2r_w)+[1+(b/2r_w)^2]^{0.5})}{2bT_0} \tag{2}$$

where

r_c = radius of well casing;

r_w = effective screen radius;

b = effective screen length;

T_0 = basic time lag, time at which a normalized head of 0.37 is reached.

Using the quantities given in Tables 1 and 3, and assuming the effective screen length is the nominal screen length (15 ft), a K estimate of 22.0 ft/day (17.4 ft/day converted to pure water at 15.6 deg. C) is obtained. Note that this value was calculated assuming an ideal well (i.e. one without a low-permeability skin) screened in an isotropic, homogeneous formation. Hyder et al. (1994), Butler et al. (1994), and Butler et al. (1995) have shown how anisotropy, layering, and a low-permeability skin can produce slug-test estimates that are considerably below the average K of the formation. It is assumed that those same factors are primarily responsible for the difference observed here between pumping-test and slug-test parameters.

November 1995 Tests

A second series of slug tests were performed on November 16-17, 1995. A total of seven tests were performed as part of this series. Figure 8 displays the normalized head versus log time plots for this series of tests, while Table 3 provides test details.

One of the goals of this series of tests was to determine the reason for the much longer time required for recovery after pressurization of the air column than after column depressurization. It was unclear if this difference was due to factors related to the pressurization phenomenon or if it was somehow related to flow direction. Several approaches were planned to answer this question. The first was to carefully monitor heads in the water column during both the pressurization and depressurization phases of the test. If the initial air pressurization is done rapidly, the changes in water level in response to this pressurization constitute a slug test. These data can then be compared to the data collected during the depressurization phase. The primary difference between these two phases is that, in the first case, water is flowing out of the well

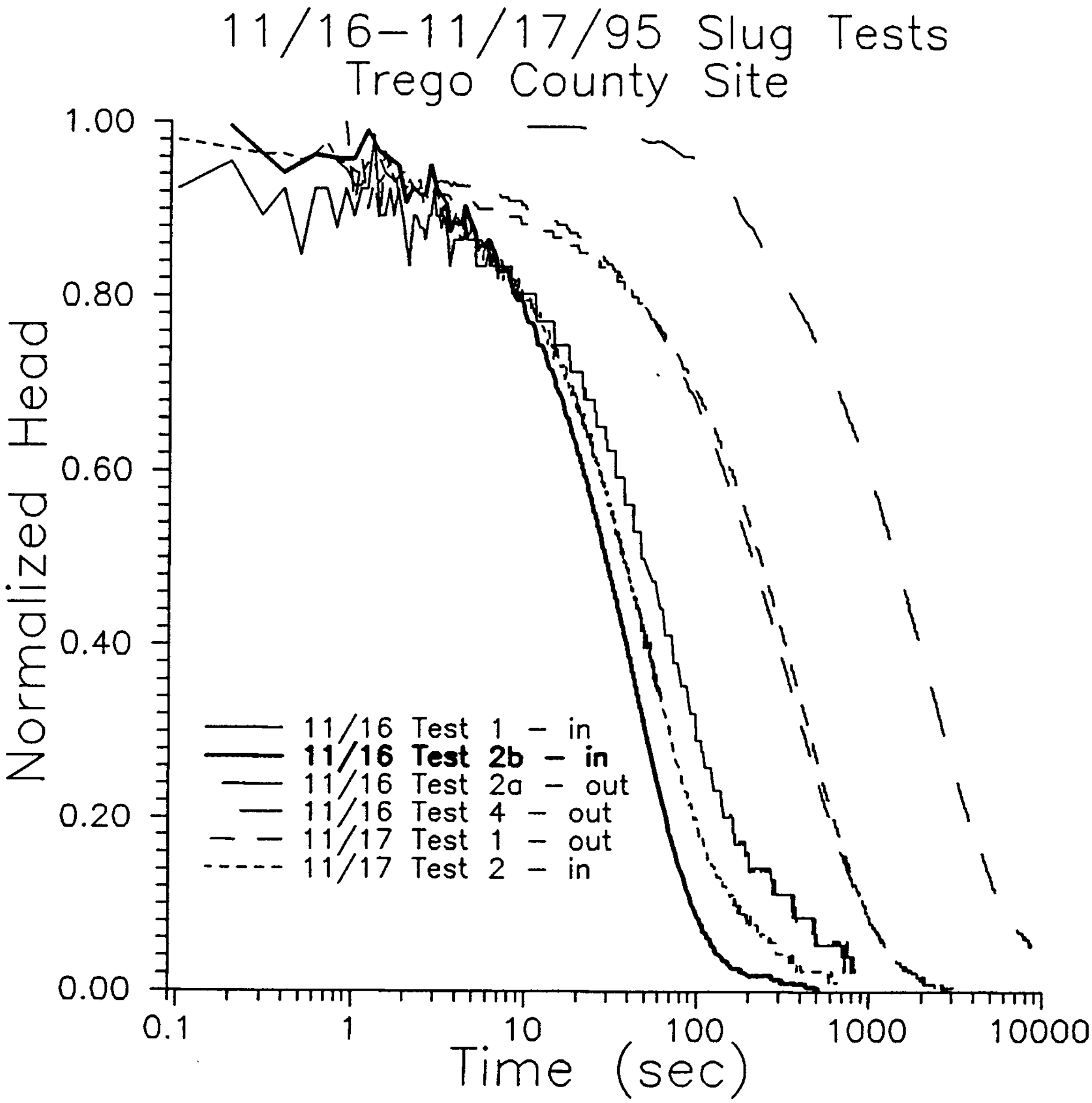

FIGURE 8 - NORMALIZED HEAD VERSUS LOG TIME PLOTS OF 11/16-11/17/95 SLUG TESTS.

in response to the slug-induced disturbance, while, in the second case, water is flowing into the well in response to the disturbance. In order to enable the initial pressurization to be done rapidly, the special down-hole tool described earlier was employed. In addition, in order to remove possible effects related to pressurization and further confirm the dependence on flow direction, a series of tests initiated with the dipper and bailer mechanisms were also performed. Water flows out of the well in tests initiated with the dipper mechanism, while it flows into the well in tests initiated with the bailer mechanism.

As shown on Figure 8, the results of this series of tests clearly confirmed a dependence on flow direction. In all cases, tests that induced a flow into the well were much faster than those that induced a flow out of the well. Note that 11/16 test 4 and 11/17 test 1 were much faster than 11/16 Test 2a, although all three tests involved flow out of the well. The reason for this difference is that 2-inch PVC casing was employed with the dipper mechanism, so the casing radius for the dipper tests was 2 inches. In 11/16 test 2a, the pneumatic approach was employed and the casing radius was 5 inches. Butler (1996) shows how tests performed at the same well using different casing radii can be employed to determine if a low-permeability skin is present. In this method, the ratio of the right-hand side of equation (2) for the 2-inch-casing tests over the right-hand side of equation (2) for the 5-inch-casing tests is used to assess if a well skin exists. If a low-permeability skin is present, the ratio of

Hvorslev terms should be very close to 1. In this case, the comparison of 11/16 test 4 with 11/16 test 2a produced a Hvorslev ratio of 1.04, while the comparison of 11/17 test 1 with 11/16 test 2a produced a ratio of 0.95. These ratios are considered very good evidence of a low-permeability well skin. However, it was not immediately obvious why the low-permeability skin was having a much larger impact on flow out of the well than on flow into the well.

One possible explanation for this dependence on flow direction is that a bacterial/oxyhydroxide mat (consisting of bacteria (probably iron and manganese bacteria), associated byproducts, and oxyhydroxide deposits) is building up at either the screen-gravel pack interface or the gravel pack-formation interface. In either case, larger pores are located on the well side of the interface, so flow into the well is much less impacted by the buildup than outward flow. Note than an amorphous black material was repeatedly found in bailers that were lowered to the bottom of the well on 11/15/95 prior to the start of the final round of slug tests. This material was thought to consist primarily of manganese oxyhydroxide deposits (D. Whittemore, personal communication).

Since the most rapid test of this series, 11/16 test 2b, had a T_0 that was 1.91 times greater than that of 10/25 test 1, none of the tests of this series were analyzed further. Note that the difference between 10/25 test 1 and 11/16 test 2b is primarily attributed to dynamic-skin effects and not the apparent bacterial/oxyhydroxide mat buildup, since both tests involved flow of water into the well.

SUMMARY OF TESTING PROGRAM

A series of hydraulic tests (a 21.5-hour pumping test and slug tests) were carried out at a Kansas Geological Survey monitoring site in Trego County, Kansas in the summer of 1994 and the fall of 1995. The primary purpose of these tests was to obtain an estimate of the average hydraulic conductivity of the sand units comprising the Dakota aquifer. 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 44-50 ft/day (35-40 ft/day for pure water at 15.6 deg. C), although it could be as high as 71 ft/day (56 ft/day for pure water at 15.6 deg. C). Estimates obtained from slug tests varied over two orders of magnitude and were strongly influenced by dynamic-skin effects and the apparent buildup of a bacterial/oxyhydroxide mat near the well screen. One interesting aspect of the slug tests was that test responses were strongly dependent on flow direction. The highest conductivity estimate obtained from the slug tests was 22 ft/day (17 ft/day for pure water at 15.6 deg. C). More extensive well development and more elaborate slug-test procedures would be required to obtain a slug-test estimate closer to the average K obtained from the pumping test. Note that the K estimates at this site are relatively high with respect to other values obtained outside of the subcrop region of the Dakota aquifer (Macfarlane et al., 1990).

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