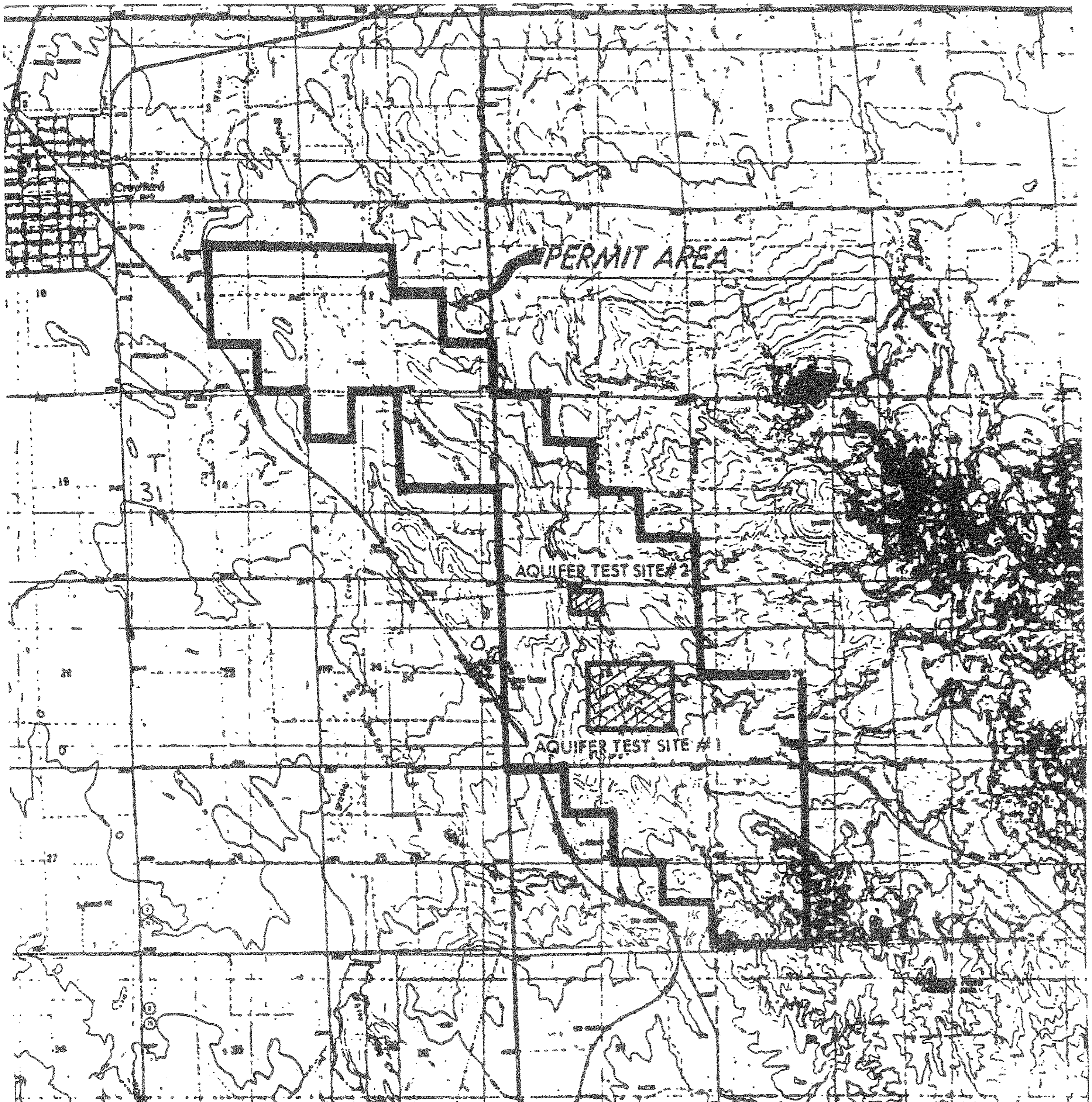
Aquifer Test #2

Second Aquifer Test:

A second multiple-well aquifer test was performed in the mineralized area near the northern boundary of Section 19. This test was part of a hydrogeo-geologic investigation of the commercial permit area north of the R&D site. This investigation consisted of: (1) a review of exisiting geologic and hydrogeologic data; (2) design of an appropriate aquifer test; (3) design and construction of an appropriate well array for the aquifer test; (4) laboratory testing of core samples from confining layers; (5) conducting the aquifer test, (6) analyzing the aquifer test data, and (7) interpret-ing the results. This hydrogeologic investigation was structured to address environmental and operational questions pertinent to ISL uranium mining at the site. Specifically, the requirements outlined by the Nuclear Regulatory Commission (NRC) in Regulatory Guide 3.46, Section 2.7.1 and Draft Staff Technical Position Paper WM-8203, Section 3.1.2. Therefore, this hydrogeo-logic investigation was oriented toward the characterization of the hy-draulic properties of the ore-bearing aquifer, and the hydraulic relation-ship of the aquifer to the overlying and underlying confining strata and the overlying aquifer. The aquifer test site is located near the north boundary of Section 19, T 31 N, R51 W, Dawes County, Nebraska. This site is approximately 2800 feet north of the R & D site (Figure 2.7-7).

Site Hydrostratigraphy:

The uranium-bearing aquifer is formed by a coarse-grained arkosic sandstone which is locally known as the Basal Sandstone Member of the Chadron Formation. The Basal Sandstone is believed to be the depositional product of a large, vigorous, braided-stream system which occurred during the early Oligocene age (approximately 36 to 40 million years before present). Regionally, the thickness of the Basal Sandstone ranges from 0 to 350 feet. Exploration drilling in the vicinity of the test site shows that the average thickness of Basal Sandstone is approximately 40 feet. At the test site, the Basal Sandstone is approximately 550 to 600 feet below ground surface. The Chadron Formation lies with marked unconformity on top of the Pierre Shale.



REV. DATE	FERRET OF NEBRASKA, INC.	
	CROW BUTTE PROJECT Dawes County, Nebraska	
	LOCATION MAP	
	PREPARED BY: F.E.N.	
	DWN. BY: JC · DATE: 8/5/87	FIGURE: 2.7-7

The Pierre Shale of late Cretaceous age forms the underlying confining layer for the Basal Chadron Sandstone. The Pierre is a wide-spread dark-gray to black marine shale which is essentially impermeable. Regionally, the Pierre Shale is up to 5000 feet thick. In Dawes County, deep oil test holes have encountered thicknesses of 1200 to 1500 feet of Pierre Shale.

The clays, claystones, and siltstones of the Middle and Upper Members of the Chadron Formation and the Lower Brule Formation form the overlying confining layer for the Basal Chadron Sandstone. At the test site, the overlying confining layer is approximately 315 to 325 feet thick.

Purpose of Investigation:

The purpose of this hydrogeologic investigation was to accurately characterize the hydrogeologic regime of the commercial permit area north of the R&D site as it pertains to ISL uranium mining. The specific objectives of this investigation were to:

- confirm confinement of the ore-bearing aquifer,
- determine the transmissivity, hydraulic conductivity, and storativity of the ore-bearing aquifer,
- determine the azimuth and magnitude of the major and minor axes of transmissivity in the ore-bearing aquifer,
- use the Neuman-Witherspoon Method to determine the vertical hydraulic conductivity under in situ conditions, of the confining layers which overlie and underlie the ore-bearing aquifer.

In addition to its use in the commercial permit application, the information gathered during this investigation may be used for:

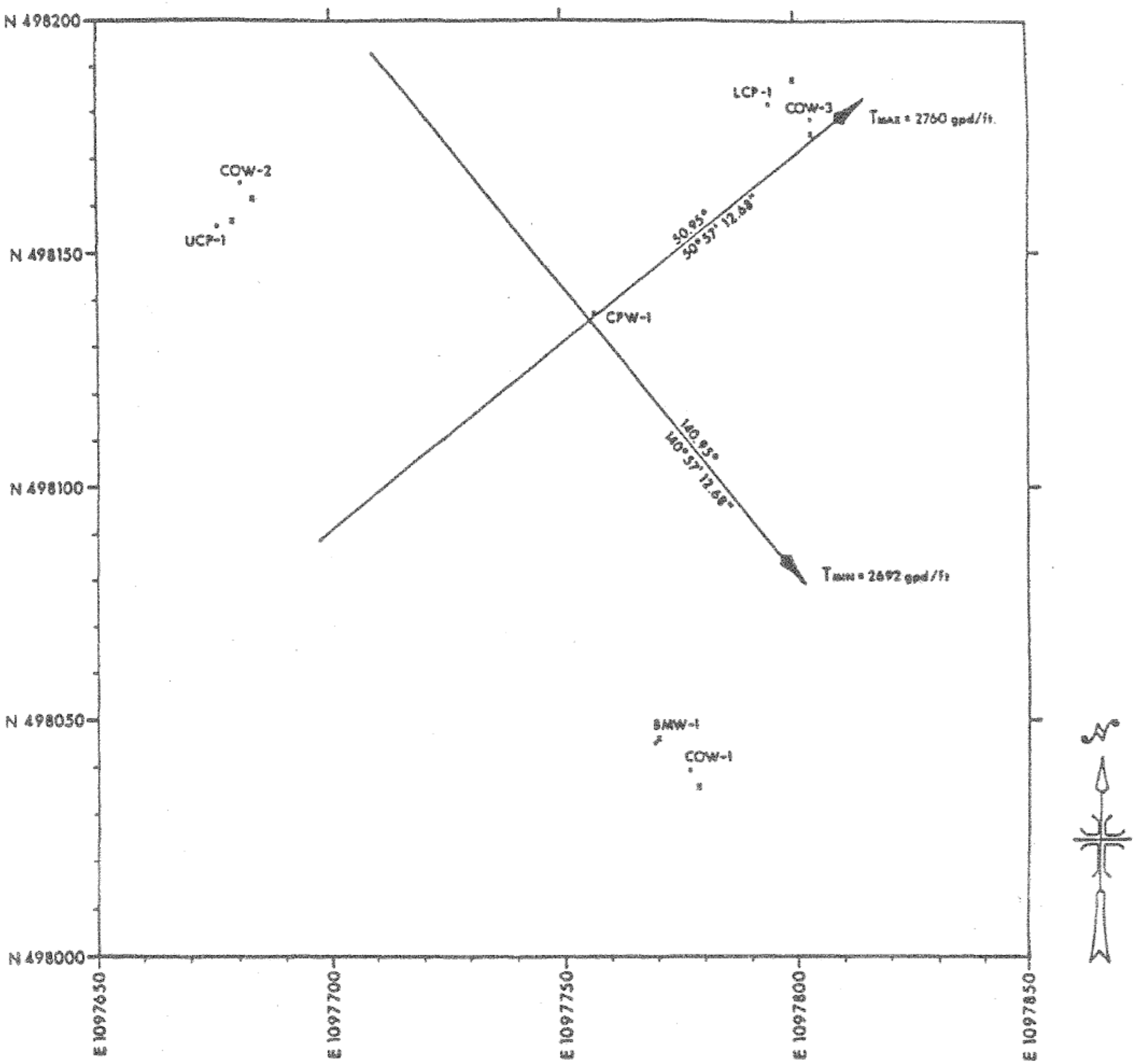
- design of the commercial wellfield,
- selection of commercial production parameters,
- design of the groundwater monitoring system,
- predictive analysis of the mining and restoration efficiency.

AQUIFER TESTING PROGRAM

The aquifer test program was designed to quantify the hydrogeologic parameters recommended by the NRC in Regulatory Guide 3.46, Section 2.7.1, and Draft Staff Technical Position Paper WM-8203. Specifically, this test was designed to allow analysis of the confining layers by the Neuman/Witherspoon Method (1972) which is currently considered by the NRC to be the most applicable to aquifer-aquitard systems commonly associated with uranium deposits.

Configuration of Well Array:

The well array used for the aquifer test consisted of five wells and two high-sensitivity piezometers configured as shown in Figure 2.7-8. All of the wells and piezometers used to perform this test were constructed during April and May, 1987 specifically for use in this test. The location and completion details of these wells and piezometers are shown on Tables 2.7-2 and 2.7-3. One pumping well (CPW-1) and three observation wells (COW-1,COW-2? COW-3) were completed in the ore-bearing aquifer (Basal Chadron Sandstone). These wells were screened through the entire thickness of the aquifer (fully penetrating), (Figure 2.7-9). The three observation wells were located in an equiangular arrangement around the central pumping well (Figgure 2.7-8). This configuration provided the data needed to define the magnitude and direction of the major and minor axes of transmissivity, the effective transmissivity, the hydraulic conductivity, and the storativity of the ore-bearing aquifer.



EXPLANATION:

- SURFACE LOCATION OF WELL
- BOTTOMHOLE LOCATION OF WELL

DIRECTION AND MAGNITUDE OF MAJOR AND MINOR AXIS OF TRANSMISSIVITY OF BASAL CHADRON SANDSTONE.

0 50 FEET

REV. DATE	FERRET OF NEBRASKA, INC.	
	CROW BUTTE PROJECT Dawes County, Nebraska	
	AQUIFER TEST WELL ARRAY	
	PREPARED BY: F.E.N.	
	DWN. BY: JC DATE: 8/5/87	FIGURE: 2.7-8

TABLE 2.7-2

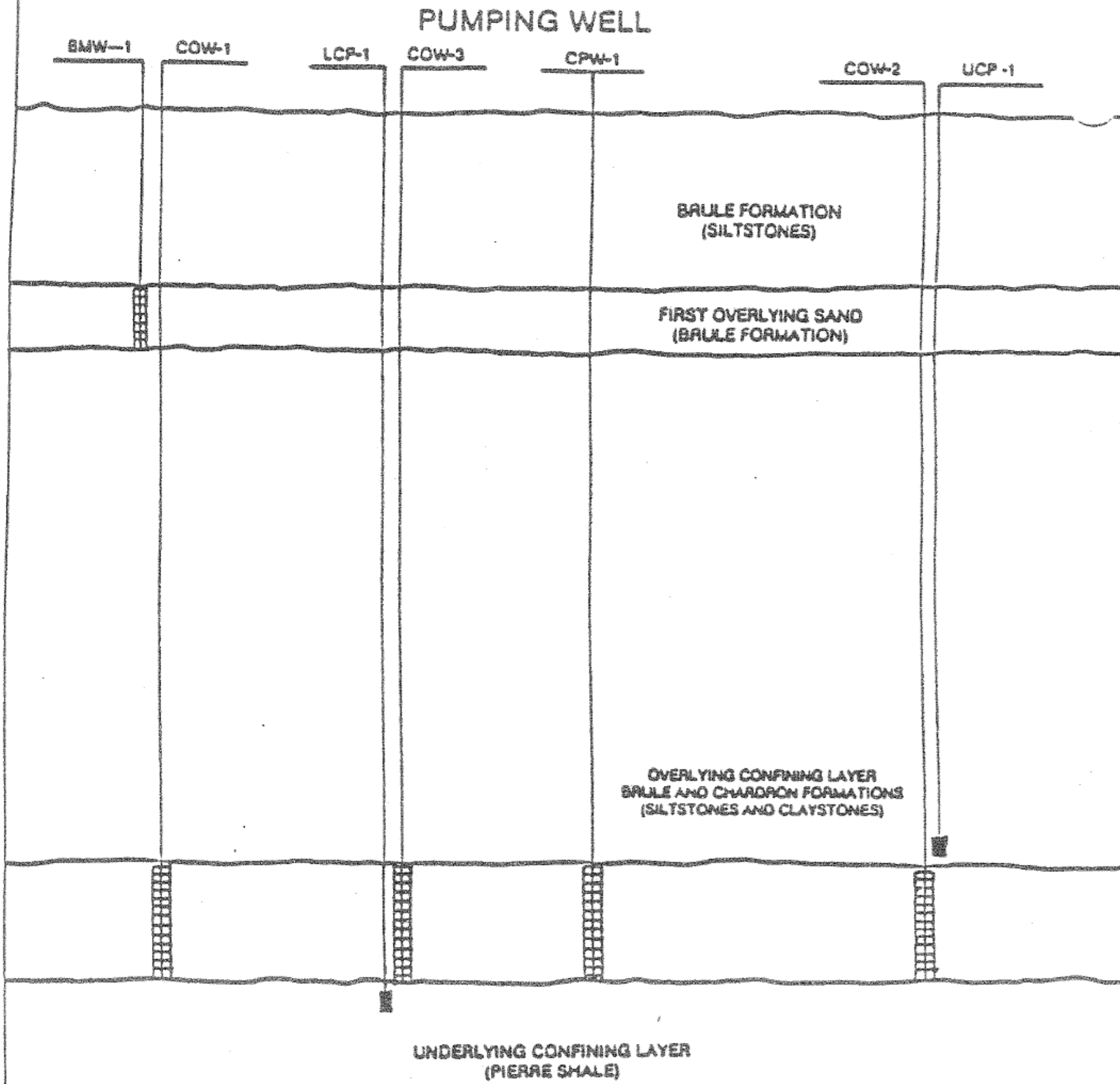
WELL LOCATIONS

Well	Surface Coordinates (ft) E	Surface Coordinates (ft) N	Deviation (ft) E	Deviation (ft) N	Bottom-hole Coordinates (ft) E	Bottom-hole Coordinates (ft) N	Ground Surface Elevation (ft)	Top of Casing Elevation (ft)
CPW-1	1,097,757.20	498,137.28	- .64	-1.02	1,097,756.56	498,136.26	3837.55	3838.75
COW-1	1,097,774.33	498,039.39	+3.02	-2.62	1,097,777.35	498,036.77	3840.21	3842.25
COW-2	1,097,681.13	498,164.90	+1.89	-2.33	1,097,683.02	498,162.57	3833.61	3835.57
COW-3	1,097,803.23	498,177.05	- .19	-1.39	1,097,803.04	498,175.66	3840.40	3842.36
BMW-1	1,097,768.97	498,045.32	+1.63	+ .76	1,097,770.60	498,046.08	3839.85	3841.82
UCP-1	1,097,676.19	498,156.47	+2.33	+ .58	1,097,678.52	498,157.05	3834.16	3836.82
LCP-1	1,097,794.73	498,181.79	+4.41	+6.07	1,097,799.14	498,187.86	3840.02	3840.98

TABLE 2.7-3

WELL COMPLETION DETAILS

Well	Open Interval Depth (ft)	Completion Stratum	Casing Size I.D. (in)	Total Depth (ft)	From CPW-1 (bottomhole) Distance (ft)	From CPW-1 (bottomhole) Azimuth	Elevation of Piezometric Surface in ft above MSL (6/28/87
CPW-1	572-612	Basal Chadron	4.5	617	----	----	3749.3
COW-1	585-625	Basal Chadron	4.5	630	101.64	168.20°	3749.4
COW-2	565-610	Basal Chadron	4.5	615	78.10	289.69°	3749.3
COW-3	575-615	Basal Chadron	4.5	620	60.93	49.71°	3749.4
BMW-1	235-260	Upper Aquifer	4.5	265	91.27	171.15°	3808.0
UCP-1	555-557	Upper Aquiclude	2.0	557	80.76	284.92°	3750.7
LCP-1	618-620	Lower Aquiclude	2.0	620	66.90	39.53	3748.8



NOT TO SCALE

REV. DATE	
	FERRET OF NEBRASKA, INC.
	CROW BUTTE PROJECT Dawes County, Nebraska
	SCHEMATIC OF WELL COMPLETION INTERVALS
	PREPARED BY: F.E.N.
	DWN. BY: JC · DATE: 8/5/87 · FIGURE: 2.7-9

One monitor well (BMW-1) was completed in the first overlying sand of the Brule Formation (Figure 2.7-9). Well BMW-1 is also screened through the entire thickness of the aquifer (fully penetrating). This well was used to monitor the water level in the first overlying sand during the aquifer test.

Two small-diameter, high-sensitivity piezometers (UCP-1, LCP-1) were completed in the confining layers which overlie and underlie the ore-bearing aquifer (Figure 2.7-9). These piezometers provided the data to calculate the vertical hydraulic conductivities of these confining layers under in-situ field conditions.

Well Construction and Completion Techniques

All well and piezometer boreholes were drilled with a conventional rotary drill rig using a bentonite based drilling fluid. The borehole was drilled to the appropriate depth and was geophysically logged. The log suite consisted of a gamma log, a resistivity log, a neutron log and a deviation survey. The geophysical logs were then used to determine the exact completion interval of each well or piezometer.

The pumping, observation and monitor wells were completed by a single stage or integral completion method. Figure 2.7-10 is a schematic of this completion method. This method consisted of drilling a nominal 8-inch borehole to the desired depth. Next, a string of 4.5-inch diameter Yelomine casing with the desired length of screen attached to the lower end was placed in the hole. A cement basket was attached to the blank casing just above the screen to exclude cement from the screen interval during cementing. The cement was then pumped down the inside of the casing to a plug set just below the cement basket. The cement passed out through weep holes in the casing above the cement basket and was directed by the cement basket back to the surface through the annulus between the casing and the drill hole. After the cement had cured sufficiently, the residual cement and plug were drilled out. The completed wells were then developed by air-lifting. The confining layer piezometers were cased with two-inch I.D. Yelomine casing and a porous stone tip. The porous stone tip was two feet

Two small-diameter, high-sensitivity piezometers (UCP-1, LCP-1) were completed in the confining layers which overlie and underlie the ore-bearing aquifer (Figure 2.7-9). These piezometers provided the data to calculate the vertical hydraulic conductivities of these confining layers under in-situ field conditions.

Well Construction and Completion Techniques

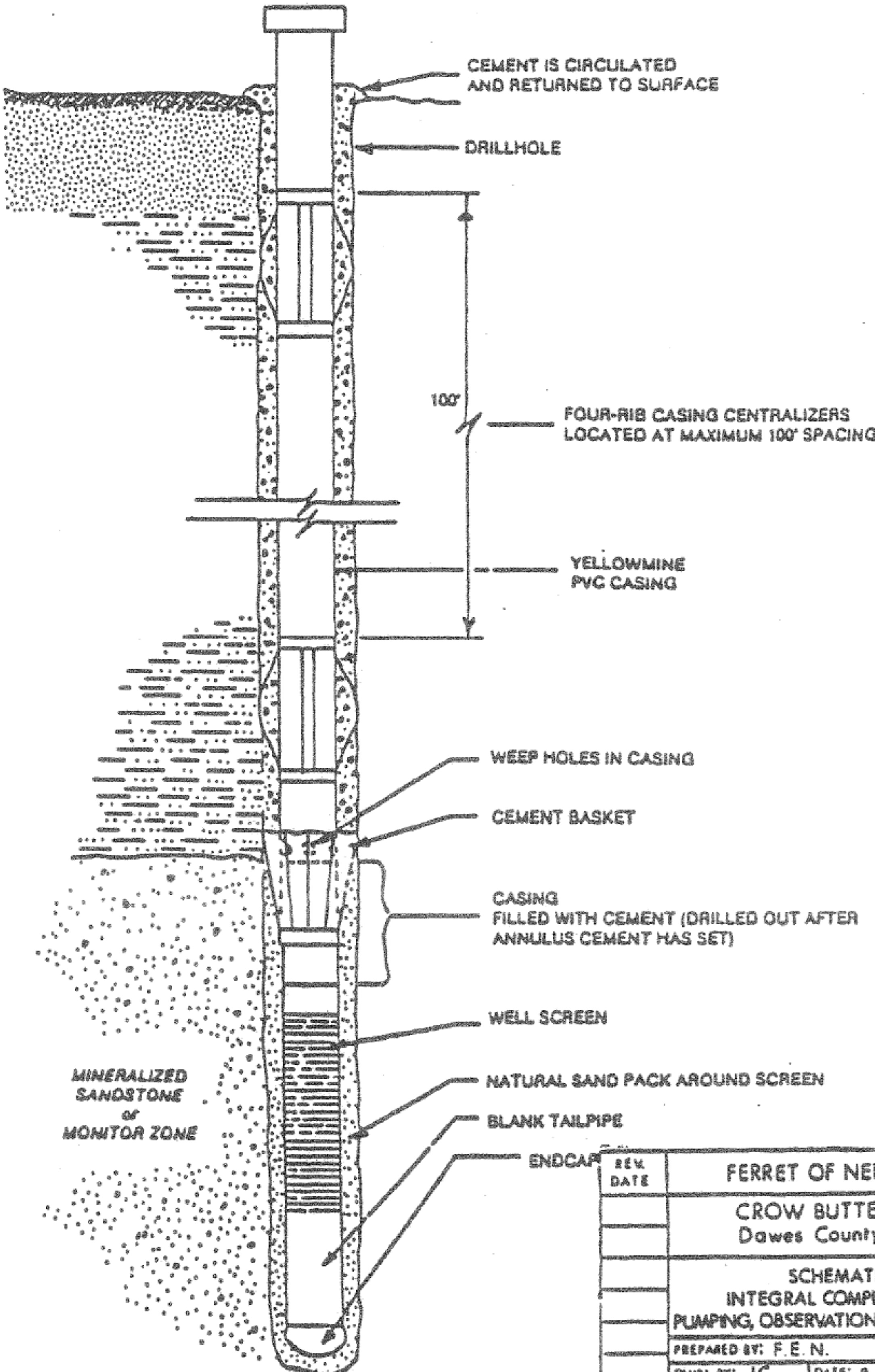
Duplicative Text

All well and piezometer boreholes were drilled with a conventional rotary drill rig using a bentonite based drilling fluid. The borehole was drilled to the appropriate depth and was geophysically logged. The log suite consisted of a gamma log, a resistivity log, a neutron log and a deviation survey. The geophysical logs were then used to determine the exact completion interval of each well or piezometer.

The pumping, observation and monitor wells were completed by a single stage or integral completion method. Figure 2.7-10 is a schematic of this completion method. This method consisted of drilling a nominal 8-inch borehole to the desired depth. Next, a string of 4.5-inch diameter Yelomine casing with the desired length of screen attached to the lower end was placed in the hole. A cement basket was attached to the blank casing just above the screen to exclude cement from the screen interval during cementing. The cement was then pumped down the inside of the casing to a plug set just below the cement basket. The cement passed out through weep holes in the casing above the cement basket and was directed by the cement basket back to the surface through the annulus between the casing and the drill hole. After the cement had cured sufficiently, the residual cement and plug were drilled out. The completed wells were then developed by air-lifting. The confining layer piezometers were cased with two-inch I.D.Yelomine casing and a porous stone tip. The porous stone tip was two feet long, 1.5 inches in diameter, with 50 micron pores. These piezometers were grouted through a tremie line from the top of the completion interval to ground surface with cement slurry. The cement was excluded from the completion interval by an inflatable packer. Figure 2.7-11 is a generalized diagram of the drilling and completion procedures for the piezometers. The completed piezometers were then cleaned and developed by inserting a one-inch pipe to the bottom of the piezometer and circulating clean water. During the construction of the confining layer piezometers, cores were cut from the completion intervals. These cores were sealed in nitrogen purged containers made of PVC pipe to preserve in situ moisture content and to prevent oxidation during transportation to the testing laboratory.

Standard consolidation tests were performed on samples of these cores to determine the coefficient of consolidation, c_v, compression index, C_c, coefficient of compressibility, a_v ,and vertical hydraulic conductivity, k_v, of the

WELL COMPLETION METHOD

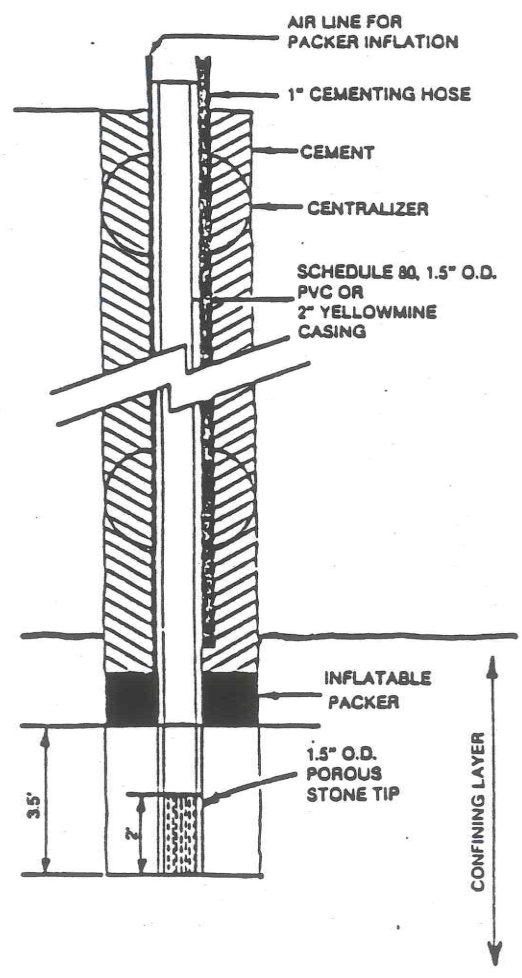


REV. DATE	FERRET OF NEBRASKA, INC.	
	CROW BUTTE PROJECT Dawes County, Nebraska	
	SCHEMATIC OF INTEGRAL COMPLETION METHOD FOR PUMPING, OBSERVATION AND MONITOR WELL:	
	PREPARED BY: F.E.N.	
	DWN. BY: JC	DATE: 8/5/87	FIGURE: 2.7-10

New Figure in
Revised Exhibit

Figure 2.7-11: Schematic of Completion Method for Confining Layer Piezometers

DRILLING AND COMPLETION PROCEDURES



1. Drill pilot hole to top of completion interval.
2. Core (2" minimum diameter) through completion interval.
3. Run geophysical logs.
4. Set casing with an inflatable packer at top of completion interval. Porous stone piezometer will be used in the completion interval.
5. Inflate the packer.
6. Cement the annulus through 1" cementing line and shut the well in.
7. Top off annulus with cement after setting has occurred.

SCHEMATIC NOT TO SCALE

REV. DATE	
	CROW BUTTE PROJECT Dawes County, Nebraska
	SCHEMATIC OF COMPLETION METHOD FOR CONFINING LAYER PIEZOMETERS
	PREPARED BY:
	DWN. BY: JC — DATE: 8/5/87 — FIGURE: 2.7-11

TABLE 2.7-4

RESULTS OF CONSOLIDATION TESTS
OF CONFINING LAYER CORE SAMPLES

Borehole	Depth (ft)	Lithology	Porosity	Coefficient of Consolidation, c_v (cm^2/sec.)	Compression Index, Cc	Coefficient of Compressibility, a_v (cm^2/g)	Vertical Hydraulic Conductivity, k[1] (cm/sec.)
UCP-1	546.5	red clay	.341	$6.65x10^{-5}$	$2.75x10^{-2}$	$4.46x10^{-7}$	$2.22x10^{-11}$
UCP-1	550.6	red clay	.328	$1.13x10^{-4}$	$2.69x10^{-2}$	$4.37x10^{-7}$	$3.78x10^{-11}$
UCP-1	555.6	red clay	.284	$1.78x10^{-4}$	$1.94x10^{-2}$	$3.15x10^{-7}$	$4.46x10^{-11}$
UCP-1	Average		.318	$1.19x10^{-4}$	$2.46x10^{-2}$	$3.99x10^{-7}$	$3.49x10^{-11}$
LCP-1	617.0	shale	.317	$1.04x10^{-4}$	$2.28x10^{-2}$	$3.70x10^{-7}$	$2.89x10^{-11}$
LCP-1	621.8	shale	.333	$9.10x10^{-5}$	$4.04x10^{-2}$	$6.56x10^{-7}$	$4.36x10^{-11}$
LCP-1	Average		.325	$9.70x10^{-5}$	$3.16x10^{-2}$	$5.13x10^{-7}$	$3.63x10^{-11}$

[1] Calculated for 600 psi effective overburden pressure from consolidation test data.

confining layers (Table 2.7-4). Laboratory determination of these parameters allowed calculation of the specific storage of the confining layers and their vertical hydraulic conductivity.

Pre-Test Monitoring

Construction and development of the five wells and two piezometers in the well array was completed on May 28, 1987. For the next 33 days, the well array was allowed to stabilize. During this time, the water levels in all the wells and piezometers and the barometric pressure were measured and recorded daily. These data were used to ensure that the wells and piezometers had reached a true static water level.

Aquifer Test Equipment and Instrumentation

During the aquifer test, the pumped well (CPW-1) was equipped with a 7.5 HP submersible pump which was set at a depth of about 500 feet. A two-inch I.D. discharge pipe conveyed the pumped water to the surface. Electrical power for the pump was supplied by a diesel-powered portable generator which ran continuously throughout the pumping phase of the test. A one-inch diaphragm valve was used to control the discharge rate. Two ~~Haliburton meters which measured both flow rate and volume were installed in the discharge line to measure instantaneous discharge rate and cumulative discharge volume. Only one meter was used at any one time, keeping the second in reserve as a backup.~~

~~The discharge line extended about 400 feet from the wellhead to prevent discharged water from leaking downward and recharging the shallow overlying aquifer. The three Chadron observation wells (COW-1, COW-2, and COW-3), the overlying monitor well (BMW-1),and the two confining layer piezometers (UCP-1 and LCP-1) were equipped with electronic pressure transducers. These six pressure transducers were connected to a computer-controlled datalogger which automatically recorded the water levels in each well at specified time intervals. A seventh electronic pressure transducer was used to measure barometric pressure which was also recorded by the data-logger each time the water levels were recorded.~~

Duplicative Text

~~Aquifer Test~~

~~The pumping phase of the aquifer test began at 12:47 on June 30, 1987 and concluded at approximately 12:47 on July 3, 1987. Thus, the length of the pumping phase of the test was 4322 minutes, or about 72 hours. Just prior to the start of the pumping, static water levels of all the wells were measured and recorded (Table 2.7-5). The recovery phase of the test began at 12:47~~

Haliburton meters which measured both flow rate and volume were installed in the discharge line to measure instantaneous discharge rate and cumulative discharge volume. Only one meter was used at any one time, keeping the second in reserve as a backup.

The discharge line extended about 400 feet from the wellhead to prevent discharged water from leaking downward and recharging the shallow overlying aquifer. The three Chadron observation wells (COW-1, COW-2, and COW-3), the overlying monitor well (BMW-1), and the two confining layer piezometers (UCP-1 and LCP-1) were equipped with electronic pressure transducers. These six pressure transducers were connected to a computer-controlled datalogger which automatically recorded the water levels in each well at specified time intervals. A seventh electronic pressure transducer was used to measure barometric pressure which was also recorded by the data-logger each time the water levels were recorded.

Aquifer Test

The pumping phase of the aquifer test began at 12:47 on June 30, 1987 and concluded at approximately 12:47 on July 3, 1987. Thus, the length of the pumping phase of the test was 4322 minutes, or about 72 hours. Just prior to the start of the pumping, static water levels of all the wells were measured and recorded (Table 2.7-5). The recovery phase of the test began at 12:47 on July 3, 1987 and concluded at 13:17 on July 6, 1987, which is a period of 4350 minutes, or 72.5 hours.

The average discharge rate during the pumping phase of the test was 47.74 gpm and the total volume of water discharged was 206,288 gallons. Throughout the pumping phase, the discharge rate was regularly monitored to insure that it remained constant. Tables 2.7-6 and 2.7-7 present the recorded drawdown and recovery data corrected for changes in barometric pressure. The static water level in the pumped well was approximately 484 feet above the top of the aquifer. The calculated maximum drawdown in the pumped well was 36.86 feet, which is approximately 447 feet above the top of the aquifer. Therefore, the aquifer was under confined conditions throughout the test.

TABLE 2.7-5

STATIC WATER LEVELS

Well	Static Water Level 6/30/87 (ft. above MSL)
CPW-1	---- *
COW-1	3749.5
COW-2	3749.5
COW-3	3749.5
BMW-1	3808.2
UCP-1	3751.3
LCP-1	3749.4

* Could not measure water level because pump was in well.

TABLE 2.7-6

DRAWDOWN DATA

	DATE	REAL TIME HH:MM	REAL TIME SEC	COW-1	COW-2	COW-3	LCP-1	UCP-1	BMW-1	BAROM	ELAPSED TIME HOURS	ELAPSED TIME MIN.	ELAPSED TIME SEC.	TOTAL MIN.
1	181	1247	24.750	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.000	0.00
2	181	1247	43.750	0.02	0.06	0.00	-0.00	0.00	-0.00	0.00	0.0	0.0	9.875	0.16
3	181	1247	52.750	0.04	0.18	-0.02	-0.00	-0.00	-0.00	0.00	0.0	0.0	19.750	0.33
4	181	1248	1.750	0.09	0.36	0.05	-0.00	-0.00	-0.01	0.00	0.0	0.0	29.625	0.49
5	181	1248	10.750	0.17	0.57	0.06	-0.00	-0.00	-0.00	0.00	0.0	0.0	39.500	0.66
6	181	1248	19.750	0.27	0.75	0.10	0.00	-0.00	-0.00	0.00	0.0	0.0	49.375	0.82
7	181	1248	28.750	0.38	0.96	0.14	-0.01	-0.00	-0.00	0.00	0.0	0.0	59.250	0.99
8	181	1248	39.750	0.53	1.17	0.15	-0.01	0.00	-0.00	0.00	0.0	1.0	11.125	1.18
9	181	1248	50.750	0.68	1.37	0.22	-0.00	-0.01	-0.01	0.00	0.0	1.0	23.000	1.38
10	181	1249	1.750	0.84	1.57	0.32	-0.00	-0.00	-0.00	0.00	0.0	1.0	34.875	1.58
11	181	1249	12.750	0.99	1.75	0.44	-0.00	-0.00	-0.01	0.00	0.0	1.0	46.750	1.78
12	181	1249	23.750	1.14	1.89	0.51	-0.01	0.00	-0.00	0.00	0.0	1.0	58.625	1.98
13	181	1249	34.750	1.28	2.05	0.59	-0.00	0.00	-0.00	0.00	0.0	2.0	10.500	2.17
14	181	1249	45.750	1.41	2.19	0.64	-0.00	-0.00	-0.01	0.00	0.0	2.0	22.375	2.37
15	181	1249	56.750	1.54	2.32	0.76	-0.00	-0.00	-0.00	0.00	0.0	2.0	34.250	2.57
16	181	1250	7.750	1.67	2.41	0.78	-0.00	0.00	0.00	0.00	0.0	2.0	46.125	2.77
17	181	1250	18.750	1.79	2.52	0.89	-0.00	0.01	-0.00	0.00	0.0	2.0	58.000	2.97
18	181	1250	32.750	1.93	2.66	0.98	-0.00	0.00	-0.00	0.00	0.0	3.0	12.875	3.21
19	181	1250	46.750	2.07	2.76	1.15	0.00	0.00	0.00	0.00	0.0	3.0	27.750	3.46
20	181	1251	0.750	2.20	2.86	1.20	-0.00	-0.00	-0.00	0.00	0.0	3.0	42.625	3.71
21	181	1251	14.750	2.31	2.99	1.30	-0.00	0.00	-0.00	0.00	0.0	3.0	57.500	3.96
22	181	1251	28.750	2.42	3.06	1.48	0.00	0.00	-0.00	0.00	0.0	4.0	12.375	4.21
23	181	1251	42.750	2.52	3.16	1.54	0.00	-0.00	-0.00	0.00	0.0	4.0	27.125	4.45
24	181	1251	56.750	2.61	3.22	1.66	-0.00	0.00	-0.00	0.00	0.0	4.0	42.000	4.70
25	181	1252	10.750	2.71	3.30	1.76	-0.00	0.00	0.00	0.00	0.0	4.0	56.875	4.95
26	181	1252	29.750	2.82	3.40	1.95	-0.00	-0.00	-0.00	0.00	0.0	5.0	16.750	5.28
27	181	1252	48.750	2.93	3.52	2.01	-0.00	0.00	-0.00	0.00	0.0	5.0	36.625	5.61
28	181	1253	7.750	3.03	3.60	2.24	0.00	0.00	0.00	0.00	0.0	5.0	56.500	5.94
29	181	1253	26.750	3.13	3.69	2.36	0.00	-0.00	0.00	0.00	0.0	6.0	16.375	6.27
30	181	1253	45.750	3.22	3.81	2.42	-0.00	-0.00	0.00	0.00	0.0	6.0	36.250	6.60
31	181	1254	4.750	3.32	3.87	2.58	-0.00	0.00	-0.00	0.00	0.0	6.0	56.125	6.93
32	181	1254	23.750	3.42	3.98	2.77	-0.00	0.00	-0.00	0.00	0.0	7.0	16.000	7.27
33	181	1254	42.750	3.49	4.06	2.81	0.00	0.00	-0.00	0.00	0.0	7.0	35.875	7.60
34	181	1255	1.750	3.57	4.13	2.97	-0.00	-0.00	-0.00	0.00	0.0	7.0	55.750	7.93
35	181	1255	20.750	3.64	4.19	3.09	-0.00	0.00	-0.00	0.00	0.0	8.0	15.625	8.26
36	181	1255	39.750	3.72	4.24	3.18	-0.00	0.00	0.01	0.00	0.0	8.0	35.500	8.59
37	181	1255	58.750	3.80	4.34	3.32	0.00	0.00	0.01	0.00	0.0	8.0	55.375	8.92
38	181	1256	17.750	3.86	4.38	3.48	-0.00	0.00	0.01	0.00	0.0	9.0	15.250	9.25
39	181	1256	36.750	3.92	4.44	3.55	0.00	0.00	0.01	0.00	0.0	9.0	35.125	9.58
40	181	1256	55.750	3.99	4.53	3.71	0.00	0.01	0.00	0.00	0.0	9.0	55.000	9.92
41	181	1257	54.750	4.16	4.68	3.94	-0.01	-0.01	-0.01	0.01	0.0	10.0	54.875	10.91
42	181	1258	53.750	4.33	4.83	4.23	0.00	0.00	0.00	0.00	0.0	11.0	54.750	11.91
43	181	1259	52.750	4.47	4.97	4.57	0.00	0.00	0.01	0.00	0.0	12.0	54.625	12.91
44	181	1300	51.750	4.60	5.12	4.78	0.00	0.00	0.01	0.00	0.0	13.0	54.500	13.91
45	181	1301	50.750	4.72	5.23	4.99	-0.00	0.00	0.01	0.00	0.0	14.0	54.375	14.91
46	181	1302	49.750	4.85	5.34	5.22	-0.00	0.01	0.00	0.00	0.0	15.0	54.250	15.90
47	181	1303	48.750	4.95	5.45	5.37	-0.00	0.01	0.00	0.00	0.0	16.0	54.125	16.90
48	181	1304	47.750	5.05	5.55	5.61	0.00	0.00	0.01	0.00	0.0	17.0	54.000	17.90
49	181	1305	46.750	5.15	5.62	5.69	0.00	0.00	0.01	0.00	0.0	18.0	53.875	18.90
50	181	1306	45.750	5.23	5.73	5.92	0.00	0.00	0.01	0.00	0.0	19.0	53.750	19.90
51	181	1308	44.750	5.41	5.88	6.12	0.00	0.00	0.01	0.00	0.0	21.0	53.625	21.89
52	181	1310	43.750	5.56	6.05	6.43	0.00	0.00	0.01	0.00	0.0	23.0	53.500	23.89

2.7(30) 07/29/87

TABLE 2.7-6

53	181	1312	42.750	5.72	6.18	6.61	0.00	0.01	0.01	0.00	0.0	25.0	53.375	25.89
54	181	1314	41.750	5.85	6.31	6.85	0.01	0.01	0.00	0.00	0.0	27.0	53.250	27.89
55	181	1316	40.750	5.97	6.44	6.97	-0.01	-0.00	-0.00	0.01	0.0	29.0	53.125	29.88
56	181	1318	39.750	6.11	6.58	7.20	0.00	0.01	0.00	0.00	0.0	31.0	53.000	31.88
57	181	1320	38.750	6.21	6.70	7.30	-0.00	0.01	0.01	0.00	0.0	33.0	52.875	33.88
58	181	1322	37.750	6.33	6.79	7.52	0.00	0.00	0.01	0.00	0.0	35.0	52.750	35.88
59	181	1324	36.750	6.43	6.92	7.64	0.00	0.01	0.01	0.00	0.0	37.0	52.625	37.88
60	181	1326	35.750	6.54	7.02	7.73	0.00	0.00	0.01	0.00	0.0	39.0	52.500	39.87
61	181	1328	34.750	6.63	7.10	7.83	-0.00	0.01	0.01	0.00	0.0	41.0	52.375	41.87
62	181	1330	33.750	6.72	7.20	8.00	0.00	0.00	0.01	0.00	0.0	43.0	52.250	43.87
63	181	1332	32.750	6.81	7.29	8.10	0.00	0.01	0.01	0.00	0.0	45.0	52.125	45.87
64	181	1334	31.750	6.88	7.36	8.11	0.00	-0.00	-0.00	0.01	0.0	47.0	52.000	47.87
65	181	1336	30.750	6.96	7.46	8.26	-0.00	-0.01	-0.00	0.01	0.0	49.0	51.875	49.86
66	181	1339	29.750	7.08	7.57	8.40	0.00	0.00	0.00	0.01	0.0	52.0	51.750	52.86
67	181	1342	28.750	7.19	7.69	8.48	0.00	-0.00	0.00	0.01	0.0	55.0	51.625	55.86
68	181	1345	27.750	7.29	7.81	8.64	0.00	-0.00	0.00	0.01	0.0	58.0	51.500	58.86
69	181	1348	26.750	7.39	7.90	8.75	-0.00	0.00	0.01	0.01	1.0	1.0	51.375	61.86
70	181	1351	25.750	7.48	7.99	8.84	0.00	0.00	0.00	0.02	1.0	4.0	51.250	64.85
71	181	1354	24.750	7.58	8.11	8.89	0.01	0.00	0.01	0.01	1.0	7.0	51.125	67.85
72	181	1357	23.750	7.68	8.20	8.99	0.01	0.01	-0.00	0.01	1.0	10.0	51.000	70.85
73	181	1400	22.750	7.77	8.32	9.17	0.01	0.01	0.01	0.01	1.0	13.0	50.875	73.85
74	181	1403	21.750	7.83	8.38	9.26	-0.00	-0.01	-0.01	0.02	1.0	16.0	50.750	76.85
75	181	1406	20.750	7.92	8.48	9.27	0.01	0.01	0.00	0.01	1.0	19.0	50.625	79.84
76	181	1411	19.750	8.06	8.60	9.46	-0.00	-0.00	-0.01	0.02	1.0	24.0	50.500	84.84
77	181	1416	18.750	8.19	8.74	9.62	0.00	0.00	-0.01	0.02	1.0	29.0	50.375	89.84
78	181	1421	17.750	8.32	8.86	9.70	0.00	0.01	-0.01	0.02	1.0	34.0	50.250	94.84
79	181	1426	16.750	8.42	8.98	9.81	0.01	0.01	-0.01	0.02	1.0	39.0	50.125	99.83
80	181	1436	15.750	8.63	9.18	10.10	0.01	0.01	-0.00	0.02	1.0	49.0	50.000	109.83
81	181	1446	14.750	8.80	9.36	10.23	-0.00	0.00	-0.01	0.03	1.0	59.0	49.875	119.83
82	181	1456	13.750	8.98	9.55	10.45	0.00	0.00	-0.01	0.03	2.0	9.0	49.750	129.83
83	181	1506	12.750	9.14	9.70	10.61	0.01	0.01	-0.01	0.03	2.0	19.0	49.625	139.83
84	181	1516	11.750	9.29	9.86	10.78	0.01	0.01	-0.02	0.03	2.0	29.0	49.500	149.82
85	181	1526	10.750	9.43	9.99	10.95	0.01	0.01	-0.01	0.03	2.0	39.0	49.375	159.82
86	181	1536	9.750	9.55	10.11	11.06	0.00	0.00	-0.01	0.04	2.0	49.0	49.250	169.82
87	181	1546	8.750	9.68	10.24	11.15	0.00	0.00	-0.02	0.05	2.0	59.0	49.125	179.82
88	181	1556	7.750	9.79	10.37	11.33	0.01	0.01	-0.02	0.05	3.0	9.0	49.000	189.82
89	181	1606	6.750	9.91	10.48	11.43	0.01	0.01	-0.01	0.05	3.0	19.0	48.875	199.81
90	181	1626	5.750	10.11	10.68	11.59	0.01	0.00	-0.01	0.06	3.0	39.0	48.750	219.81
91	181	1646	4.750	10.29	10.85	11.80	0.01	-0.00	-0.02	0.06	3.0	59.0	48.625	239.81
92	181	1706	3.750	10.47	11.04	11.94	0.01	0.00	-0.02	0.06	4.0	19.0	48.500	259.81
93	181	1726	2.750	10.64	11.21	12.17	0.00	-0.00	-0.03	0.07	4.0	39.0	48.375	279.81
94	181	1746	1.750	10.80	11.38	12.30	0.01	-0.00	-0.00	0.07	4.0	59.0	48.250	299.80
95	181	1806	0.750	10.93	11.50	12.50	0.00	-0.01	-0.04	0.08	5.0	19.0	48.125	319.80
96	181	1825	59.750	11.05	11.62	12.59	0.02	0.00	-0.03	0.08	5.0	39.0	48.000	339.80
97	181	1845	58.750	11.16	11.71	12.67	0.01	0.00	-0.03	0.08	5.0	59.0	47.875	359.80
98	181	1905	57.750	11.26	11.83	12.77	0.01	-0.01	-0.04	0.09	6.0	19.0	47.750	379.80
99	181	1925	56.750	11.38	11.94	12.95	0.02	-0.00	-0.04	0.08	6.0	39.0	47.625	399.79
100	181	1955	55.750	11.52	12.10	13.05	0.01	-0.01	-0.05	0.09	7.0	9.0	47.500	429.79
101	181	2025	54.750	11.65	12.22	13.17	0.01	-0.01	-0.05	0.09	7.0	39.0	47.375	459.79
102	181	2055	53.750	11.76	12.33	13.28	0.01	-0.01	-0.06	0.09	8.0	9.0	47.250	489.79
103	181	2125	52.750	11.91	12.48	13.47	0.01	-0.01	-0.06	0.08	8.0	39.0	47.125	519.78
104	181	2155	51.750	12.02	12.60	13.58	0.02	0.00	-0.05	0.07	9.0	9.0	47.000	549.78
105	181	2225	50.750	12.13	12.69	13.67	0.02	0.00	-0.06	0.07	9.0	39.0	46.875	579.78
106	181	2255	49.750	12.23	12.81	13.73	0.02	-0.00	-0.07	0.08	10.0	9.0	46.750	609.78
107	181	2325	48.750	12.32	12.91	13.86	0.02	-0.01	-0.06	0.08	10.0	39.0	46.625	639.78
108	181	2355	47.750	12.41	12.98	13.94	0.01	-0.01	-0.07	0.09	11.0	9.0	46.500	669.77
109	182	25	46.750	12.51	13.08	14.07	0.02	-0.01	-0.06	0.08	11.0	39.0	46.375	699.77
110	182	125	45.750	12.67	13.23	14.16	0.02	-0.01	-0.07	0.09	12.0	39.0	46.250	759.77
111	182	225	44.750	12.82	13.40	14.38	0.02	-0.01	-0.06	0.09	13.0	39.0	46.125	819.77
112	182	325	43.750	12.94	13.50	14.47	0.02	-0.01	-0.06	0.09	14.0	39.0	46.000	879.77
113	182	425	42.750	13.05	13.61	14.56	0.02	-0.02	-0.07	0.10	15.0	39.0	45.875	939.76
114	182	525	41.750	13.16	13.72	14.69	0.02	-0.01	-0.08	0.10	16.0	39.0	45.750	999.76

TABLE 2.7-6

115	182	625	40.750	13.27	13.82	14.81	0.02	-0.01	-0.07	0.09	17.0	39.0	45.625	1059.76
116	182	725	39.750	13.39	13.94	14.93	0.02	-0.01	-0.07	0.08	18.0	39.0	45.500	1119.76
117	182	825	38.750	13.49	14.06	15.00	0.03	-0.01	-0.07	0.08	19.0	39.0	45.375	1179.76
118	182	925	37.750	13.60	14.16	15.17	0.03	-0.01	-0.06	0.07	20.0	39.0	45.250	1239.75
119	182	1025	36.750	13.66	14.21	15.18	0.02	-0.02	-0.07	0.07	21.0	39.0	45.125	1299.75
120	182	1125	35.750	13.76	14.31	15.30	0.03	-0.01	-0.07	0.07	22.0	39.0	45.000	1359.75
121	182	1225	34.750	13.85	14.41	15.39	0.03	-0.01	-0.07	0.08	23.0	39.0	44.875	1419.75
122	182	1325	33.750	13.93	14.50	15.42	0.03	-0.02	-0.07	0.09	24.0	39.0	44.750	1479.75
123	182	1425	32.750	14.00	14.56	15.51	0.03	-0.02	-0.06	0.10	25.0	39.0	44.625	1539.74
124	182	1525	31.750	14.08	14.64	15.61	0.03	-0.02	-0.06	0.09	26.0	39.0	44.500	1599.74
125	182	1625	30.750	14.16	14.71	15.70	0.03	-0.01	-0.06	0.08	27.0	39.0	44.375	1659.74
126	182	1705	29.750	14.22	14.78	15.74	0.02	-0.02	-0.05	0.08	28.0	19.0	44.250	1699.74
127	182	2025	28.750	14.38	14.94	15.87	0.03	-0.02	-0.07	0.07	31.0	39.0	44.875	1899.75
128	182	2345	27.750	14.59	15.15	16.13	0.03	-0.03	-0.07	0.05	34.0	59.0	45.500	2099.76
129	183	305	26.750	14.72	15.28	16.22	0.04	-0.03	-0.06	0.05	38.0	19.0	46.125	2299.77
130	183	625	25.750	14.92	15.49	16.43	0.04	-0.03	-0.05	0.02	41.0	39.0	46.750	2499.78
131	183	945	24.750	15.11	15.64	16.57	0.04	-0.03	-0.05	0.02	44.0	59.0	47.375	2699.79
132	183	1305	23.750	15.40	15.91	16.85	0.05	-0.03	-0.04	0.02	48.0	19.0	48.000	2899.80
133	183	1625	22.750	15.52	16.06	17.02	0.05	-0.04	-0.06	0.09	51.0	39.0	48.625	3099.81
134	183	1945	21.750	15.61	16.14	17.11	0.05	-0.04	-0.06	0.07	54.0	59.0	49.250	3299.82
135	183	2305	20.750	15.66	16.19	17.13	0.06	-0.04	-0.05	0.03	58.0	19.0	49.875	3499.83
136	184	225	19.750	15.77	16.28	17.19	0.06	-0.05	-0.05	0.03	61.0	39.0	50.500	3699.84
137	184	545	18.750	15.88	16.38	17.31	0.05	-0.06	-0.04	0.03	64.0	59.0	51.125	3899.85
138	184	905	17.750	15.92	16.43	17.39	0.06	-0.05	-0.06	0.08	68.0	19.0	51.750	4099.86
139	184	1225	16.750	16.01	16.51	17.48	0.06	-0.05	-0.06	0.10	71.0	39.0	52.375	4299.87

LEGEND:

DATE: Julian calendar day of the year.

HH:MM Hours and minutes.

SEC. Seconds

Drawdown units for all wells are feet from the initial water level.

Barometer units are feet of water changes from initial pressure at start of test.

TABLE 2.7-7

RECOVERY DATA

	DATE	REAL TIME HR:MM	REAL TIME SEC	LDW-1	LDW-2	CDW-3	LCF-1	ULF-1	BMW-1	BAROM	ELAPSED TIME HOURS	MIN.	SEC	TOTAL MIN.	t/t'
1	184	1246	48.750	16.01	16.50	17.44	0.06	-0.06	-0.07	0.11	0.0	0.0	0.000	0.00	--------
2	184	1246	57.750	16.00	16.44	17.46	0.06	-0.05	-0.07	0.11	0.0	0.0	9.875	0.16	26191.34
3	184	1247	6.750	15.98	16.32	17.42	0.06	-0.06	-0.07	0.11	0.0	0.0	19.750	0.33	13135.97
4	184	1247	15.750	15.93	16.11	17.37	0.06	-0.05	-0.07	0.11	0.0	0.0	29.625	0.49	8748.79
5	184	1247	24.750	15.85	15.88	17.24	0.06	-0.05	-0.07	0.11	0.0	0.0	39.500	0.66	6568.49
6	184	1247	33.750	15.75	15.66	17.22	0.06	-0.05	-0.07	0.11	0.0	0.0	49.375	0.82	5251.80
7	184	1247	42.750	15.62	15.43	17.14	0.06	-0.05	-0.07	0.11	0.0	0.0	59.250	0.99	4379.32
8	184	1247	53.750	15.46	15.15	17.03	0.06	-0.05	-0.07	0.11	0.0	1.0	11.125	1.18	3647.76
9	184	1248	4.750	15.28	14.92	16.86	0.06	-0.05	-0.07	0.11	0.0	1.0	23.000	1.38	3125.66
10	184	1248	15.750	15.11	14.73	16.71	0.06	-0.05	-0.07	0.11	0.0	1.0	34.875	1.58	2734.34
11	184	1248	26.750	14.95	14.54	16.60	0.06	-0.05	-0.08	0.11	0.0	1.0	46.750	1.78	2430.12
12	184	1248	37.750	14.79	14.40	16.44	0.06	-0.04	-0.07	0.11	0.0	1.0	58.625	1.98	2186.84
13	184	1248	48.750	14.64	14.25	16.29	0.06	-0.05	-0.08	0.11	0.0	2.0	10.500	2.17	1987.85
14	184	1248	59.750	14.50	14.13	16.18	0.06	-0.05	-0.07	0.11	0.0	2.0	22.375	2.37	1822.07
15	184	1249	10.750	14.37	14.03	16.01	0.06	-0.05	-0.08	0.11	0.0	2.0	34.250	2.57	1681.83
16	184	1249	21.750	14.25	13.92	15.80	0.06	-0.06	-0.08	0.11	0.0	2.0	46.125	2.77	1561.64
17	184	1249	32.750	14.14	13.83	15.61	0.06	-0.04	-0.07	0.11	0.0	2.0	58.000	2.97	1457.49
18	184	1249	46.750	14.00	13.71	15.41	0.06	-0.05	-0.08	0.11	0.0	3.0	12.875	3.21	1345.14
19	184	1250	0.750	13.88	13.60	15.26	0.06	-0.05	-0.07	0.11	0.0	3.0	27.750	3.46	1249.24
20	184	1250	14.750	13.76	13.50	15.07	0.06	-0.05	-0.07	0.11	0.0	3.0	42.625	3.71	1165.80
21	184	1250	28.750	13.65	13.41	14.84	0.06	-0.05	-0.07	0.11	0.0	3.0	57.500	3.96	1092.82
22	184	1250	42.750	13.55	13.32	14.74	0.06	-0.05	-0.08	0.11	0.0	4.0	12.375	4.21	1026.44
23	184	1250	56.750	13.45	13.24	14.55	0.06	-0.05	-0.08	0.11	0.0	4.0	27.250	4.45	971.23
24	184	1251	10.750	13.36	13.15	14.33	0.06	-0.05	-0.08	0.11	0.0	4.0	42.125	4.70	920.06
25	184	1251	24.750	13.27	13.07	14.25	0.06	-0.05	-0.07	0.11	0.0	4.0	57.000	4.95	874.01
26	184	1251	43.750	13.15	12.98	13.99	0.06	-0.05	-0.08	0.11	0.0	5.0	16.875	5.28	819.29
27	184	1252	2.750	13.05	12.89	13.82	0.06	-0.06	-0.07	0.11	0.0	5.0	36.750	5.61	771.03
28	184	1252	21.750	12.94	12.80	13.63	0.06	-0.05	-0.07	0.11	0.0	5.0	56.625	5.94	728.02
29	184	1252	40.750	12.85	12.71	13.55	0.06	-0.04	-0.07	0.11	0.0	6.0	16.500	6.27	689.67
30	184	1252	59.750	12.76	12.61	13.34	0.06	-0.05	-0.07	0.11	0.0	6.0	36.375	6.61	655.16
31	184	1253	18.750	12.67	12.54	13.19	0.06	-0.05	-0.07	0.11	0.0	6.0	56.250	6.94	623.86
32	184	1253	37.750	12.59	12.46	13.11	0.06	-0.05	-0.07	0.11	0.0	7.0	16.125	7.27	595.50
33	184	1253	56.750	12.51	12.40	12.96	0.06	-0.05	-0.07	0.11	0.0	7.0	36.000	7.60	569.61
34	184	1254	15.750	12.44	12.32	12.84	0.06	-0.05	-0.07	0.11	0.0	7.0	55.875	7.93	545.88
35	184	1254	34.750	12.37	12.26	12.81	0.06	-0.05	-0.07	0.11	0.0	8.0	15.750	8.26	524.05
36	184	1254	53.750	12.31	12.21	12.67	0.06	-0.05	-0.07	0.11	0.0	8.0	35.625	8.59	503.84
37	184	1255	12.750	12.23	12.13	12.56	0.06	-0.05	-0.07	0.11	0.0	8.0	55.500	8.92	485.19
38	184	1255	31.750	12.18	12.07	12.46	0.06	-0.05	-0.07	0.11	0.0	9.0	15.375	9.26	467.88
39	184	1255	50.750	12.11	11.99	12.44	0.06	-0.05	-0.07	0.11	0.0	9.0	35.250	9.59	451.76
40	184	1256	9.750	12.05	11.94	12.37	0.06	-0.05	-0.07	0.11	0.0	9.0	55.125	9.92	436.67
41	184	1257	8.750	11.88	11.77	12.09	0.06	-0.05	-0.07	0.11	0.0	10.0	55.000	10.92	396.84
42	184	1258	7.750	11.73	11.62	11.91	0.06	-0.06	-0.07	0.11	0.0	11.0	54.875	11.91	362.69
43	184	1259	6.750	11.58	11.50	11.73	0.06	-0.05	-0.07	0.11	0.0	12.0	54.750	12.91	335.68
44	184	1300	5.750	11.45	11.36	11.62	0.06	-0.06	-0.07	0.11	0.0	13.0	54.625	13.91	311.67
45	184	1301	4.750	11.32	11.26	11.46	0.06	-0.05	-0.07	0.11	0.0	14.0	54.500	14.91	290.87
46	184	1302	3.750	11.21	11.12	11.29	0.06	-0.05	-0.07	0.11	0.0	15.0	54.375	15.91	272.68
47	184	1303	2.750	11.10	11.02	11.21	0.06	-0.05	-0.07	0.11	0.0	16.0	54.250	16.90	256.64
48	184	1304	1.750	11.00	10.92	11.12	0.06	-0.05	-0.07	0.11	0.0	17.0	54.125	17.90	242.39
49	184	1305	0.750	10.91	10.82	11.01	0.06	-0.05	-0.07	0.11	0.0	18.0	54.000	18.90	229.65
50	184	1305	59.750	10.82	10.73	10.88	0.06	-0.04	-0.07	0.11	0.0	19.0	53.875	19.90	218.16
51	184	1307	58.750	10.64	10.56	10.71	0.06	-0.05	-0.07	0.11	0.0	21.0	53.750	21.90	198.[illegible]
52	184	1309	57.750	10.48	10.41	10.50	0.06	-0.05	-0.07	0.11	0.0	23.0	53.625	23.89	181.66

TABLE 2.7-7

53	184	1311	56.750	10.33	10.28	10.33	0.06	-0.05	-0.07	0.11	0.0	25.0	53.500	25.89	167.90
54	184	1313	55.750	10.19	10.13	10.23	0.06	-0.05	-0.07	0.11	0.0	27.0	53.375	27.89	155.94
55	184	1315	54.750	10.06	10.00	10.05	0.06	-0.05	-0.07	0.11	0.0	29.0	53.250	29.89	145.59
56	184	1317	53.750	9.95	9.86	9.96	0.06	-0.06	-0.07	0.12	0.0	31.0	53.125	31.88	136.53
57	184	1319	52.750	9.82	9.76	9.83	0.06	-0.05	-0.06	0.11	0.0	33.0	53.000	33.88	128.54
58	184	1321	51.750	9.70	9.64	9.72	0.06	-0.05	-0.07	0.12	0.0	35.0	52.875	35.88	121.44
59	184	1323	50.750	9.60	9.53	9.58	0.06	-0.06	-0.07	0.12	0.0	37.0	52.750	37.88	115.08
60	184	1325	49.750	9.50	9.42	9.51	0.06	-0.06	-0.07	0.12	0.0	39.0	52.625	39.88	109.37
61	184	1327	48.750	9.41	9.34	9.40	0.06	-0.05	-0.07	0.12	0.0	41.0	52.500	41.88	104.20
62	184	1329	47.750	9.32	9.24	9.30	0.06	-0.04	-0.06	0.12	0.0	43.0	52.375	43.87	99.50
63	184	1331	46.750	9.23	9.15	9.21	0.05	-0.05	-0.07	0.12	0.0	45.0	52.250	45.87	95.21
64	184	1333	45.750	9.15	9.07	9.08	0.06	-0.05	-0.06	0.12	0.0	47.0	52.125	47.87	91.28
65	184	1335	44.750	9.06	8.98	8.99	0.06	-0.06	-0.07	0.13	0.0	49.0	52.000	49.87	87.66
66	184	1341	42.625	8.84	8.73	8.77	0.05	-0.05	-0.07	0.13	0.0	52.0	57.250	52.95	82.61
67	184	1344	23.625	8.74	8.65	8.67	0.06	-0.05	-0.07	0.13	0.0	55.0	49.625	55.83	78.41
68	184	1347	14.625	8.64	8.54	8.59	0.06	-0.05	-0.07	0.13	0.0	58.0	48.500	58.81	74.48
69	184	1350	7.625	8.56	8.46	8.48	0.06	-0.05	-0.06	0.13	1.0	1.0	47.625	61.79	70.93
70	184	1353	4.625	8.47	8.36	8.35	0.06	-0.05	-0.06	0.13	1.0	4.0	47.250	64.79	67.70
71	184	1356	1.625	8.38	8.27	8.30	0.06	-0.05	-0.06	0.13	1.0	7.0	46.875	67.78	64.76
72	184	1358	58.625	8.29	8.19	8.23	0.06	-0.05	-0.06	0.13	1.0	10.0	46.500	70.77	62.06
73	184	1404	55.625	8.13	8.02	8.00	0.06	-0.05	-0.06	0.13	1.0	16.0	46.125	76.77	57.29
74	184	1408	53.625	8.03	7.91	7.89	0.05	-0.06	-0.06	0.13	1.0	20.0	45.875	80.76	54.51
75	184	1412	51.625	7.93	7.83	7.86	0.06	-0.05	-0.06	0.13	1.0	24.0	45.625	84.76	51.98
76	184	1418	48.625	7.80	7.68	7.67	0.06	-0.05	-0.06	0.13	1.0	30.0	45.250	90.75	48.62
77	184	1422	46.625	7.70	7.57	7.60	0.05	-0.06	-0.07	0.14	1.0	34.0	45.000	94.75	46.61
78	184	1428	43.625	7.58	7.45	7.46	0.05	-0.05	-0.06	0.14	1.0	40.0	44.625	100.74	43.89
79	184	1437	40.625	7.40	7.26	7.31	0.06	-0.05	-0.06	0.15	1.0	49.0	44.250	109.74	40.38
80	184	1446	37.625	7.24	7.11	7.10	0.06	-0.05	-0.05	0.15	1.0	58.0	43.875	118.73	37.40
81	184	1458	33.625	7.04	6.90	6.91	0.06	-0.05	-0.05	0.15	2.0	10.0	43.375	130.72	34.06
82	184	1508	31.625	6.89	6.75	6.74	0.06	-0.05	-0.05	0.15	2.0	20.0	43.125	140.72	31.71
83	184	1518	29.625	6.75	6.61	6.62	0.05	-0.06	-0.06	0.15	2.0	30.0	42.875	150.71	29.67
84	184	1528	28.625	6.63	6.48	6.44	0.06	-0.05	-0.05	0.13	2.0	40.0	42.750	160.71	27.89
85	184	1538	27.625	6.50	6.37	6.34	0.06	-0.05	-0.05	0.13	2.0	50.0	42.625	170.71	26.31
86	184	1548	26.625	6.37	6.25	6.21	0.06	-0.05	-0.05	0.14	3.0	0.0	42.500	180.71	24.91
87	184	1558	25.625	6.25	6.11	6.09	0.05	-0.06	-0.05	0.16	3.0	10.0	42.375	190.71	23.66
88	184	1608	24.625	6.15	6.03	5.95	0.05	-0.06	-0.04	0.17	3.0	20.0	42.250	200.70	22.53
89	184	1628	22.625	5.95	5.82	5.77	0.05	-0.06	-0.04	0.18	3.0	40.0	42.000	220.70	20.58
90	184	1648	20.625	5.79	5.66	5.61	0.06	-0.06	-0.04	0.18	4.0	0.0	41.750	240.70	18.95
91	184	1718	18.625	5.55	5.41	5.35	0.06	-0.05	-0.03	0.05	4.0	30.0	41.500	270.69	16.96
92	184	1738	17.625	5.55	5.42	5.34	0.22	0.10	0.12	-0.09	4.0	50.0	41.375	290.69	15.87
93	184	1758	16.625	5.41	5.30	5.28	0.22	0.11	0.12	-0.09	5.0	10.0	41.250	310.69	14.91
94	184	1818	15.625	5.26	5.15	5.08	0.20	0.09	0.08	-0.05	5.0	30.0	41.125	330.68	14.07
95	184	1838	14.625	5.15	5.03	4.98	0.21	0.09	0.09	-0.08	5.0	50.0	41.000	350.68	13.32
96	184	1858	13.625	5.04	4.94	4.85	0.21	0.10	0.10	-0.08	6.0	10.0	40.875	370.68	12.66
97	184	1938	11.625	4.85	4.74	4.69	0.24	0.11	0.11	-0.09	6.0	50.0	40.625	410.68	11.52
98	184	1958	10.625	4.77	4.68	4.58	0.25	0.14	0.13	-0.08	7.0	10.0	40.500	430.67	11.03
99	184	2018	9.625	4.64	4.54	4.45	0.22	0.11	0.09	-0.02	7.0	30.0	40.375	450.67	10.59
100	184	2048	8.625	4.51	4.39	4.39	0.21	0.10	0.08	-0.03	8.0	0.0	40.250	480.67	9.99
101	184	2118	7.625	4.39	4.29	4.27	0.20	0.08	0.07	-0.05	8.0	30.0	40.125	510.67	9.46
102	184	2148	6.625	4.29	4.16	4.10	0.21	0.09	0.08	-0.06	9.0	0.0	40.000	540.67	8.99
103	184	2218	5.625	4.21	4.10	4.03	0.22	0.11	0.10	-0.06	9.0	30.0	39.875	570.66	8.57
104	184	2248	4.625	4.12	4.02	4.00	0.23	0.11	0.10	-0.06	10.0	0.0	39.750	600.66	8.19
105	184	2318	3.625	4.03	3.91	3.84	0.22	0.10	0.09	-0.07	10.0	30.0	39.625	630.66	7.85
106	184	2348	2.625	3.96	3.85	3.78	0.23	0.12	0.10	-0.07	11.0	0.0	39.500	660.66	7.54
107	185	18	1.625	3.89	3.78	3.74	0.23	0.11	0.10	-0.08	11.0	30.0	39.375	690.66	7.26
108	185	48	0.625	3.80	3.70	3.63	0.22	0.10	0.08	-0.04	12.0	0.0	39.250	720.65	7.00
109	185	117	59.625	3.74	3.63	3.58	0.22	0.11	0.09	-0.04	12.0	30.0	39.125	750.65	6.76
110	185	217	58.625	3.60	3.49	3.50	0.22	0.10	0.09	-0.04	13.0	30.0	39.000	810.65	6.33
111	185	317	57.625	3.51	3.39	3.40	0.22	0.11	0.09	-0.03	14.0	30.0	38.875	870.65	5.96
112	185	417	56.625	3.39	3.29	3.22	0.21	0.10	0.08	-0.01	15.0	30.0	38.750	930.65	5.64
113	185	517	55.625	3.31	3.19	3.14	0.23	0.11	0.10	-0.02	16.0	30.0	38.625	990.64	5.36
114	185	617	54.625	3.20	3.10	3.10	0.21	0.09	0.08	-0.02	17.0	30.0	38.500	1050.64	5.11

TABLE 2.7-7

115	185	717	53.625	3.12	3.02	3.01	0.21	0.09	0.09	-0.03	18.0	30.0	38.375	1110.64	4.89
116	185	817	52.625	3.06	2.93	2.93	0.22	0.11	0.11	-0.03	19.0	30.0	38.250	1170.64	4.69
117	185	917	51.625	2.98	2.86	2.81	0.22	0.11	0.11	-0.02	20.0	30.0	38.125	1230.63	4.51
118	185	1017	50.625	2.91	2.81	2.76	0.21	0.09	0.09	0.00	21.0	30.0	38.000	1290.63	4.35
119	185	1117	49.625	2.85	2.73	2.70	0.21	0.10	0.10	0.00	22.0	30.0	37.875	1350.63	4.20
120	185	1217	48.625	2.79	2.69	2.63	0.21	0.10	0.10	0.01	23.0	30.0	37.750	1410.63	4.06
121	185	1317	47.625	2.74	2.64	2.59	0.22	0.10	0.11	0.02	24.0	30.0	37.625	1470.63	3.94
122	185	1417	46.625	2.69	2.58	2.53	0.22	0.11	0.10	0.04	25.0	30.0	37.500	1530.62	3.82
123	185	1517	45.625	2.65	2.52	2.55	0.23	0.12	0.11	0.05	26.0	30.0	37.375	1590.62	3.72
124	185	1617	44.625	2.60	2.47	2.46	0.21	0.10	0.10	0.07	27.0	30.0	37.250	1650.62	3.62
125	185	1717	43.625	2.59	2.45	2.47	0.21	0.11	0.10	0.08	28.0	30.0	37.125	1710.62	3.53
126	185	1757	42.625	2.57	2.43	2.44	0.21	0.10	0.10	0.08	29.0	10.0	37.000	1750.62	3.47
127	185	2117	41.625	2.43	2.30	2.24	0.18	0.07	0.06	0.03	32.0	30.0	37.625	1950.63	3.22
128	186	37	40.625	2.32	2.21	2.19	0.18	0.07	0.07	0.01	35.0	50.0	38.250	2150.64	3.01
129	186	357	39.625	2.24	2.12	2.13	0.18	0.08	0.08	0.01	39.0	10.0	38.875	2350.65	2.84
130	186	717	38.625	2.15	2.03	2.00	0.17	0.07	0.08	0.01	42.0	30.0	39.500	2550.66	2.69
131	186	1037	37.625	2.06	1.93	1.88	0.16	0.07	0.08	0.01	45.0	50.0	40.125	2750.67	2.57
132	186	1357	36.625	1.97	1.84	1.82	0.18	0.08	0.10	0.01	49.0	10.0	40.750	2950.68	2.46
133	186	1717	35.625	1.94	1.82	1.76	0.20	0.11	0.13	0.01	52.0	30.0	41.375	3150.69	2.37
134	186	2037	34.625	1.88	1.76	1.77	0.19	0.09	0.12	0.02	55.0	50.0	42.000	3350.70	2.29
135	186	2357	33.625	1.82	1.69	1.70	0.18	0.09	0.12	0.03	59.0	10.0	42.625	3550.71	2.22
136	187	317	32.625	1.79	1.68	1.66	0.21	0.12	0.14	0.04	62.0	30.0	43.250	3750.72	2.15
137	187	637	31.625	1.71	1.58	1.58	0.15	0.06	0.10	0.05	65.0	50.0	43.875	3950.73	2.09
138	187	957	30.625	1.62	1.49	1.48	0.08	-0.01	0.07	0.05	69.0	10.0	44.500	4150.74	2.04
139	187	1317	29.625	1.56	1.44	1.36	0.07	-0.02	0.05	0.06	72.0	30.0	45.125	4350.75	1.99

No equipment failures or interruptions occurred during the aquifer test. However, barometric pressure did vary considerably during the six-day test as the result of the passage of a low pressure system and a cold front with associated thunderstorms and subsequent high pressure.

ANALYSIS OF DATA

Analytical Methods

To accomplish the goals of this investigation, the following methods of analysis were used:

- o Theis' Non-Equilibrium Method (Theis, 1935) for analyzing non-equilibrium pumping test data.
- o Theis' Recovery Method (Theis, 1935) for analyzing recovery test data.
- o Jacob's Modified Non-Equilibrium Method (Cooper and Jacob, 1946) for analyzing non-equilibrium pumping test data.
- o Cooper and Jacob's Distance-Drawdown Method (Cooper and Jacob, 1946) for determining radius of influence.
- o Hantush's Method (Hantush, 1966) for determining the magnitude and direction of the major the minor horizontal axes of transmissivity in an anisotropic aquifer.
- o Neuman and Witherspoon's Method (Neuman and Witherspoon, 1972) for determining the hydraulic diffusivity and vertical hydraulic conductivity of confining layers.
- o Darcy's Law (Darcy, 1856) to determine the average pore velocity and the groundwater flux across the aquifer test site.

- o Standard Consolidation Test (ASTM 1985) to determine the coefficient of consolidation, compression index, coefficient of compressibility, and vertical hydraulic conductivity of the confining layer.

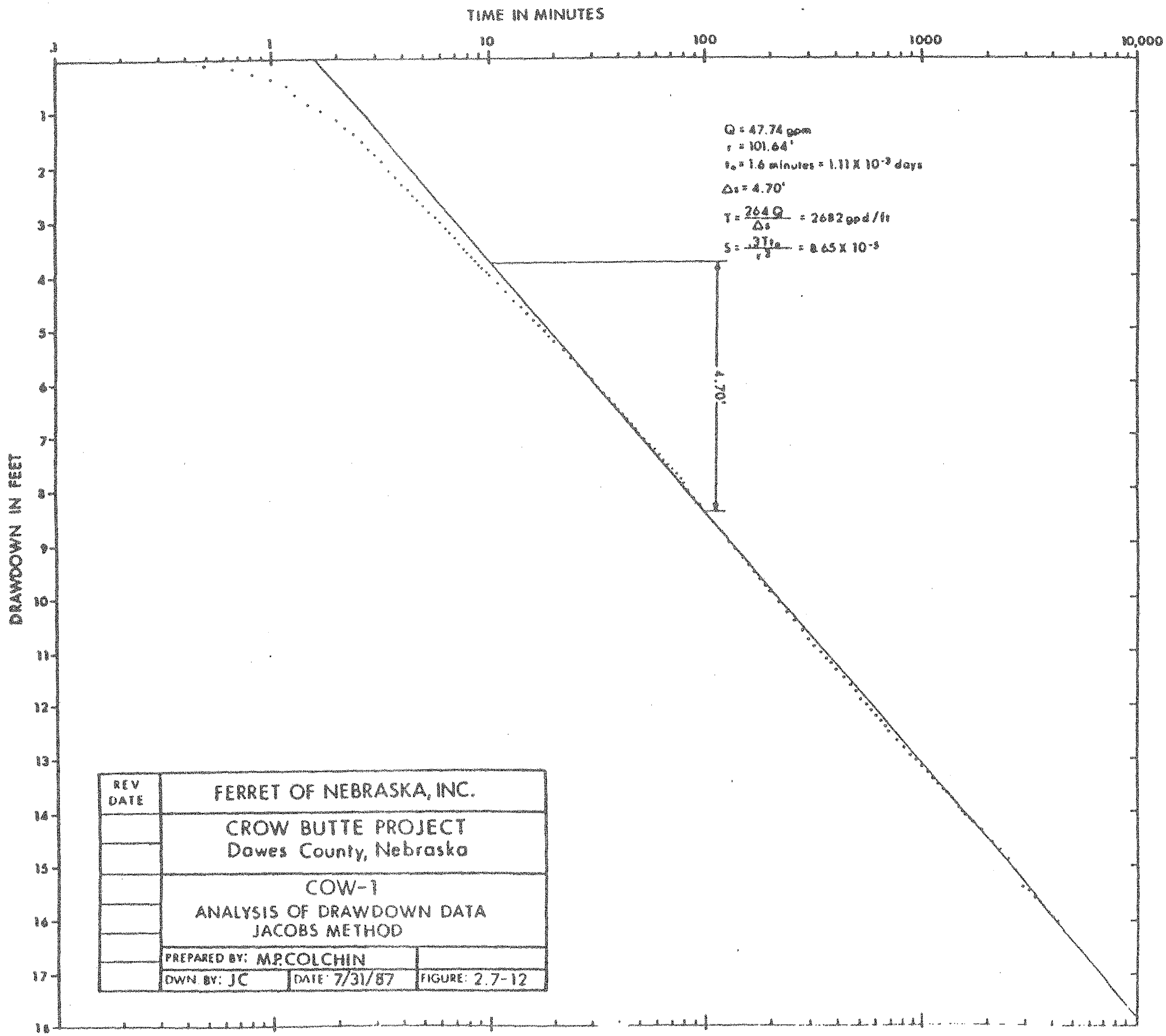
From a practical viewpoint, the field conditions at the test site met all the assumptions and conditions necessary for these analytical methods to be applicable and valid.

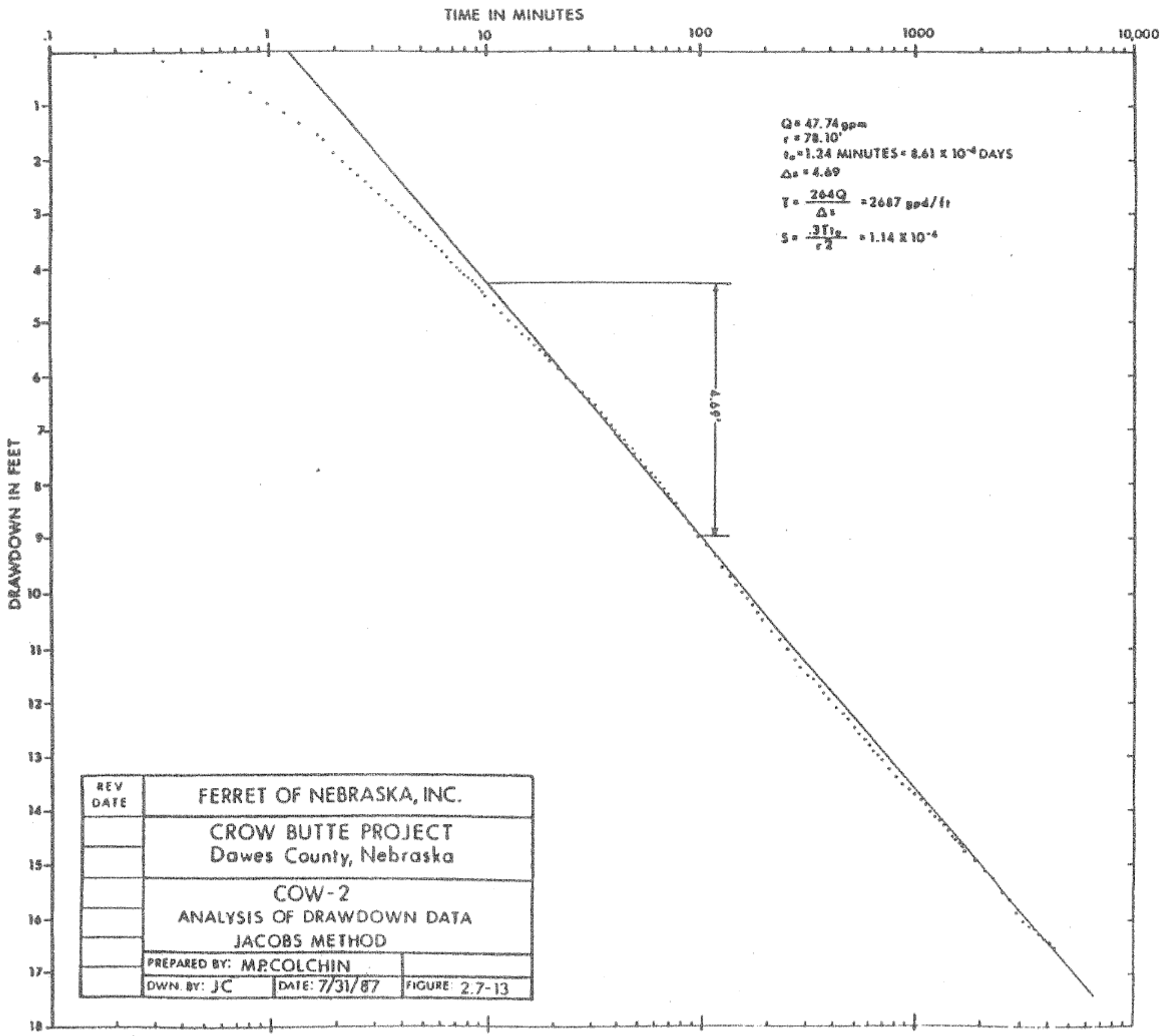
Results of Analysis

Basal Chadron Sandstone

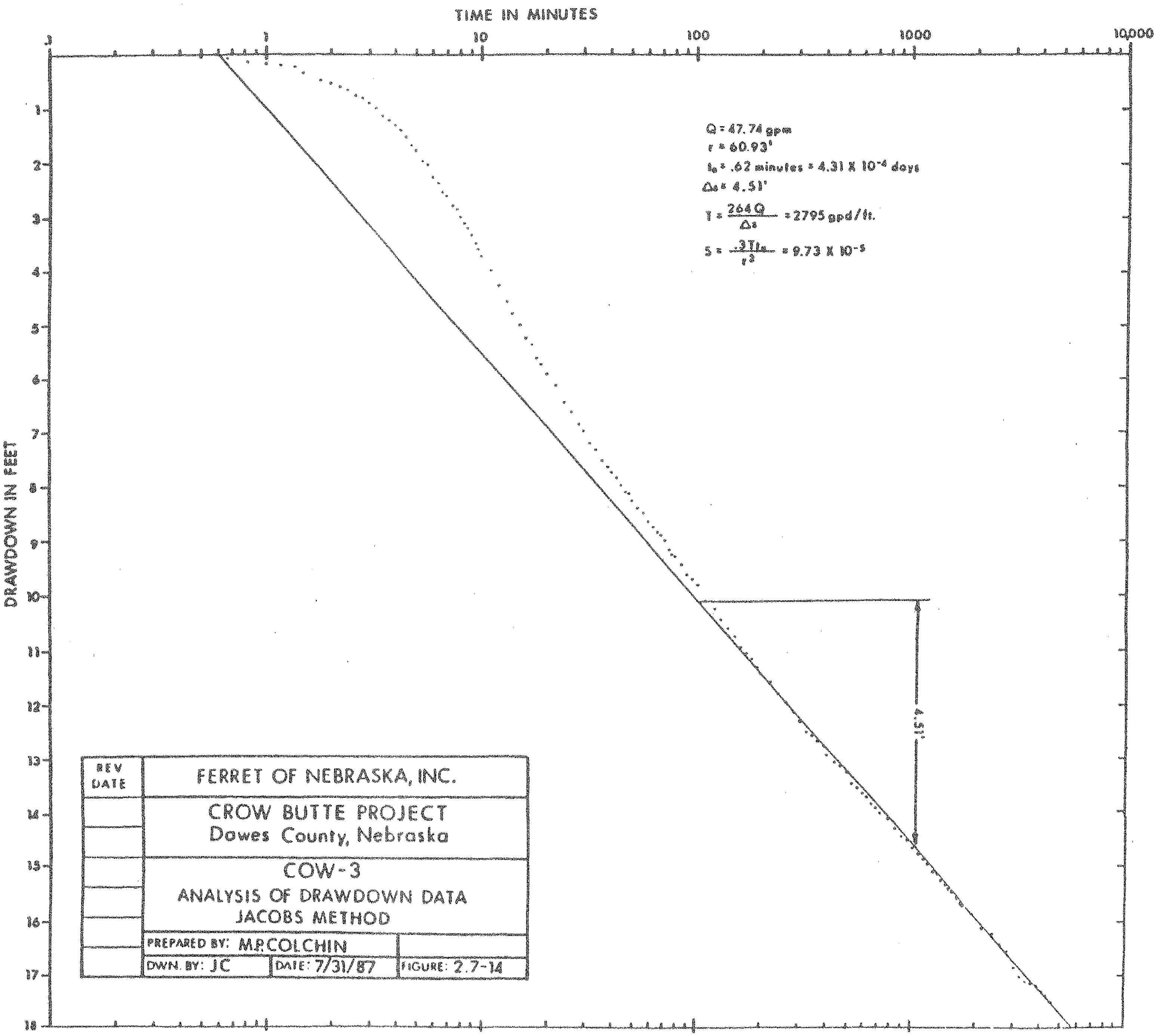
The Jacob Non-Equilibrium Method, the Theis Non-Equilibrium Method and the Theis Recovery Method were used to analyze the aquifer test data from the three Basal Chadron Sandstone wells (Figures 2.7-12 to 2.7-20). A confined non-leaky type of analysis was made because leakage effects were not apparent in the test data and the piezometric surface is well above the top of the aquifer. Inspection of the results of the analyses verifies that these assumptions are valid.

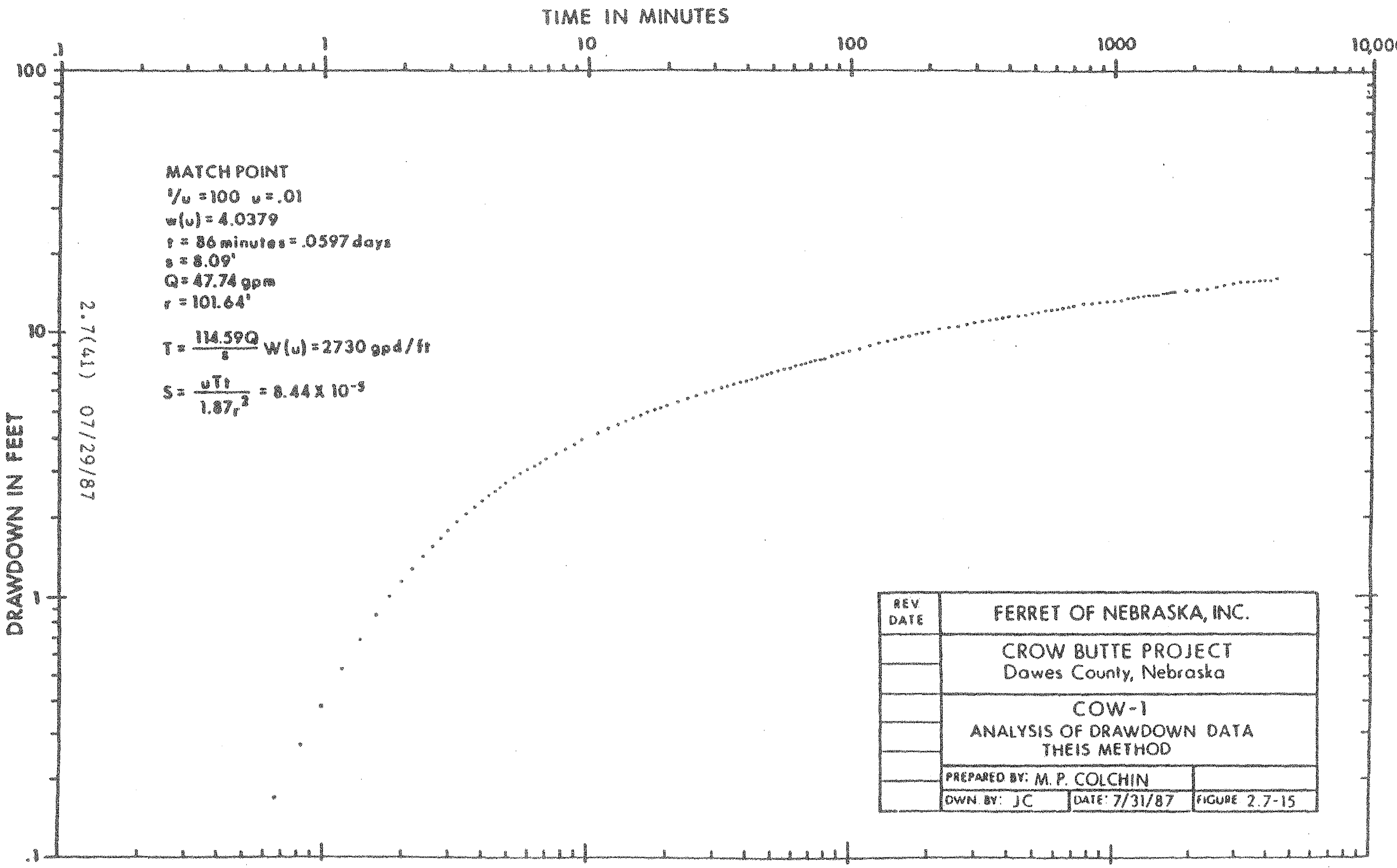
The transmissivities calculated from the drawdown data from the three Basal Chadron Sandstone observation wells ((COW-1, COW-2, COW-3), ranged from 2682 gpd/ft (359 ft^2/day) to 2795 gpd/ft (374 ft^2/day). The storage coefficients for these wells, calculated from the same analyses, ranges from 8.44×10^{-5} to 1.31×10^{-4}. The transmissivities calculated from the recovery data from the three observation wells are slightly lower, ranging from 2604 gpd/ft (348 ft^2/day) to 2659 gpd/ft (355 ft^2/day). The lower transmissivity values calculated from the recovery data are probably the result of the variation in the storage coefficient during pumping and recovery. In theory, the storage coefficient is assumed to be constant during both the pumping and the recovery phases of an aquifer test. This assumption is true if the aquifer is perfectly elastic. In practice, however, a confined aquifer is usually not perfectly elastic. Therefore, it will not rebound vertically during recovery of water levels (recovery of pressure) at the same rate that it consolidates or compresses when pressure is decreased during the preceeding pumping. Therefore, the storage


TIME IN MINUTES
.1
1
10
100
1000
10,000
DRAWDOWN IN FEET
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Q = 47.74 gpm
r = 101.64'
t_o = 1.6 minutes = 1.11 X 10^-3 days
Δs = 4.70'
T = 264 Q / Δs = 2682 gpd/ft
S = .3Tt₀ / r² = 8.65 X 10^-5
4.70'
REV DATE
FERRET OF NEBRASKA, INC.
CROW BUTTE PROJECT
Dawes County, Nebraska
COW-1
ANALYSIS OF DRAWDOWN DATA
JACOBS METHOD
PREPARED BY: M.P.COLCHIN
DWN BY: JC
DATE: 7/31/87
FIGURE: 2.7-12



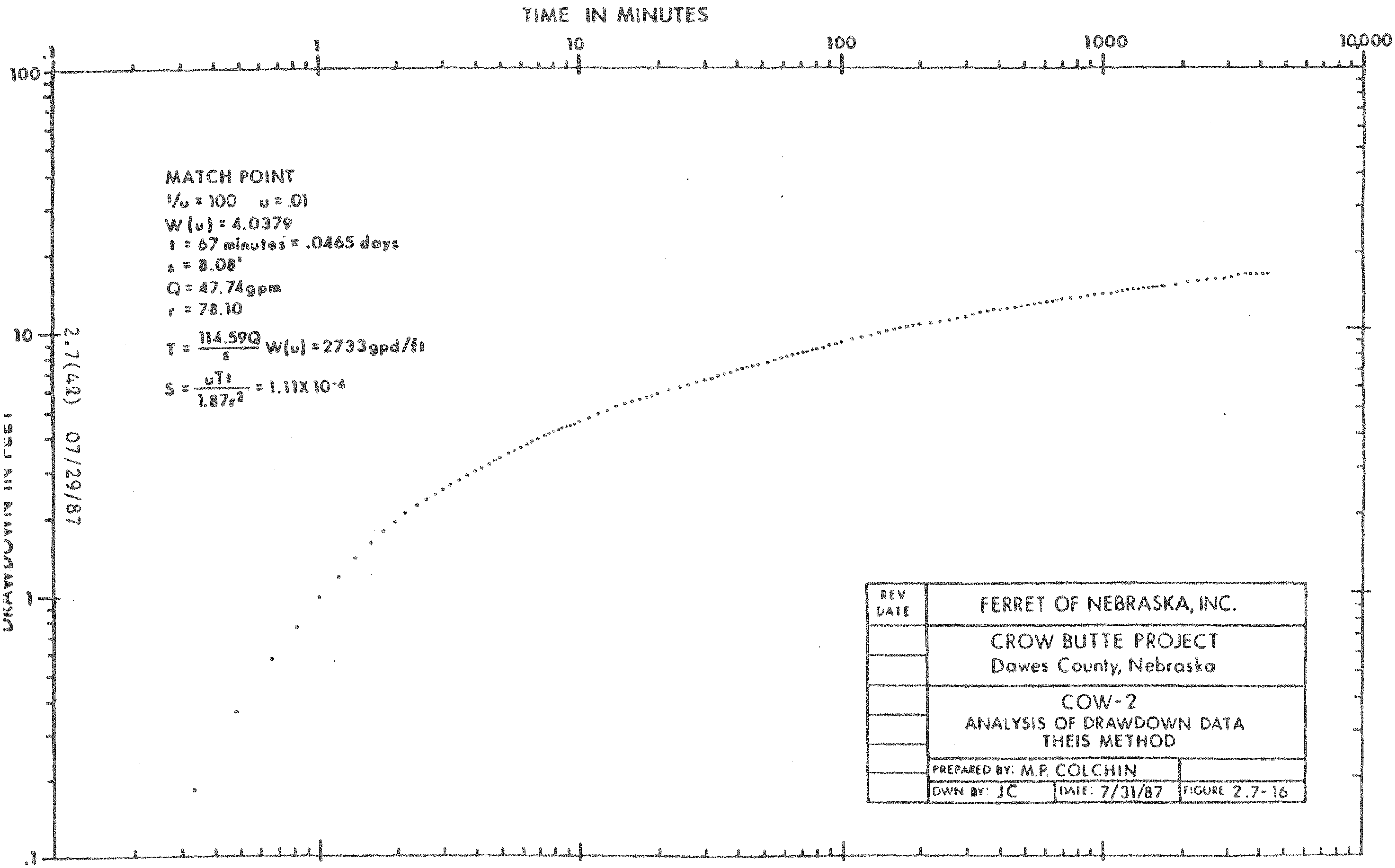
TIME IN MINUTES
.1
1
10
100
1000
10,000
DRAWDOWN IN FEET
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Q = 47.74 gpm
r = 78.10'
t_o = 1.24 MINUTES = 8.61 X 10^{-4} DAYS
Δs = 4.69
$T = \frac{264Q}{\Delta s}$ = 2687 gpd/ft
$S = \frac{.3Tt_o}{r^2}$ = 1.14 X 10^{-4}
4.69'
REV DATE
FERRET OF NEBRASKA, INC.
CROW BUTTE PROJECT
Dawes County, Nebraska
COW-2
ANALYSIS OF DRAWDOWN DATA
JACOBS METHOD
PREPARED BY: M.P. COLCHIN
DWN. BY: JC
DATE: 7/31/87
FIGURE: 2.7-13


TIME IN MINUTES
.1
1
10
100
1000
10,000
DRAWDOWN IN FEET
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Q = 47.74 gpm
r = 60.93'
t₀ = .62 minutes = 4.31 X 10⁻⁴ days
Δs = 4.51'
T = 264Q / Δs = 2795 gpd/ft.
S = .3Tt₀ / r² = 9.73 X 10⁻⁵
4.51'
REV DATE
FERRET OF NEBRASKA, INC.
CROW BUTTE PROJECT
Dawes County, Nebraska
COW-3
ANALYSIS OF DRAWDOWN DATA
JACOBS METHOD
PREPARED BY: M.P. COLCHIN
DWN. BY: JC
DATE: 7/31/87
FIGURE: 2.7-14

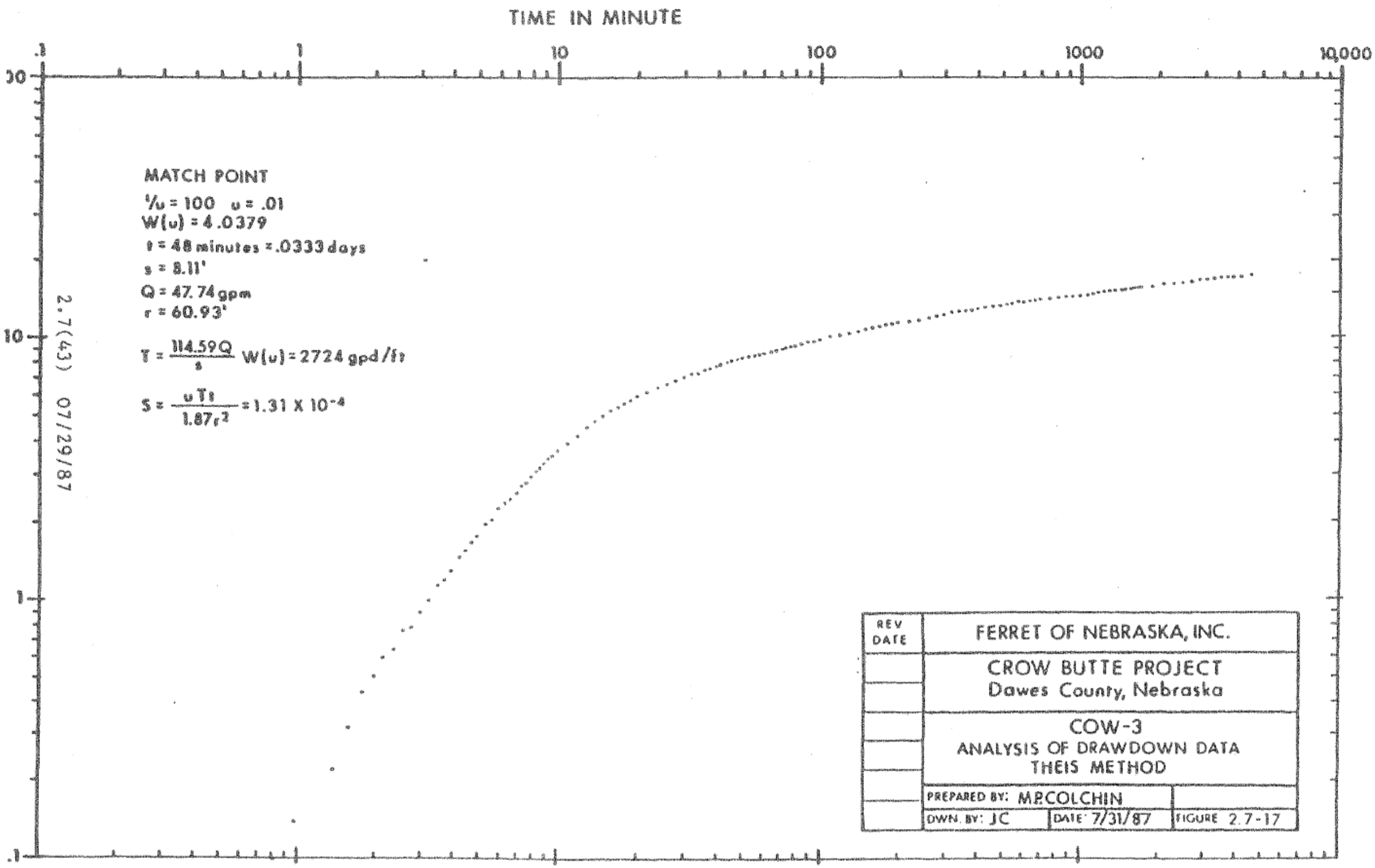


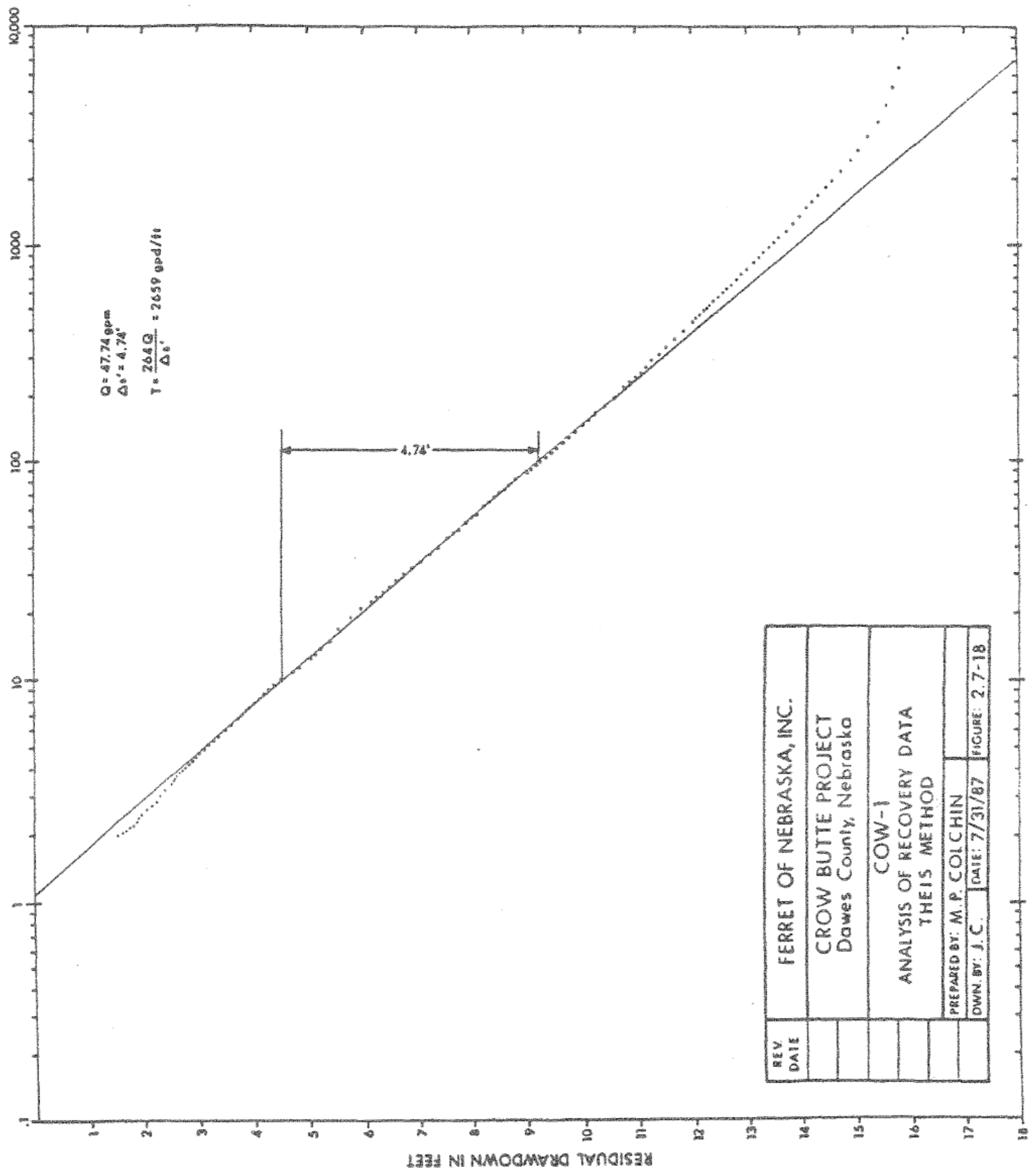
TIME IN MINUTES
.1
1
10
100
1000
10,000
DRAWDOWN IN FEET
100
10
1
.1
MATCH POINT
1/u = 100 u = .01
w(u) = 4.0379
t = 86 minutes = .0597 days
s = 8.09'
Q = 47.74 gpm
r = 101.64'
T = 114.59Q/s W(u) = 2730 gpd/ft
S = uTt/1.87r² = 8.44 X 10⁻⁵
REV DATE
FERRET OF NEBRASKA, INC.
CROW BUTTE PROJECT
Dawes County, Nebraska
COW-1
ANALYSIS OF DRAWDOWN DATA
THEIS METHOD
PREPARED BY: M. P. COLCHIN
DWN. BY: JC
DATE: 7/31/87
FIGURE 2.7-15

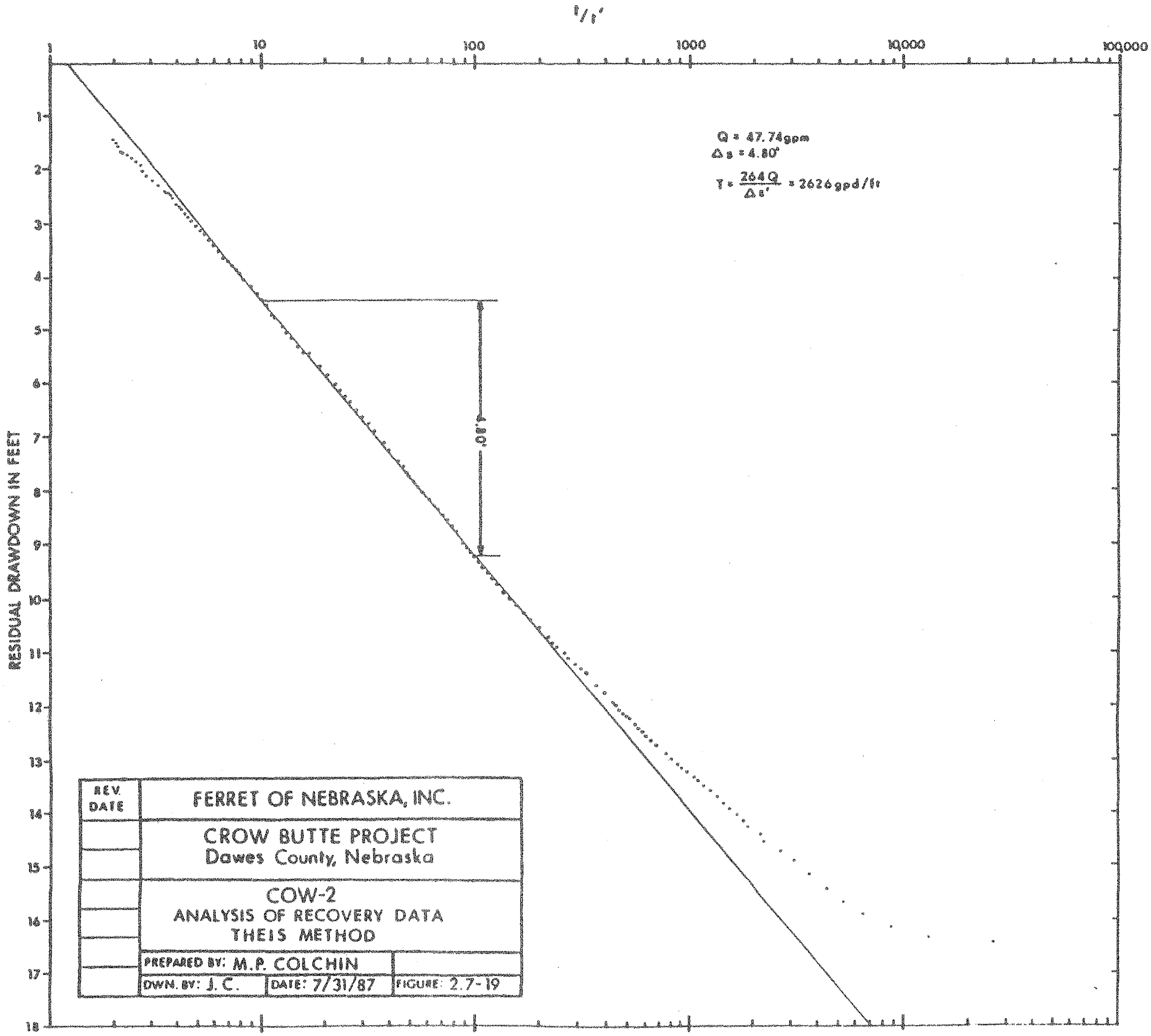
2.7(41) 07/29/87

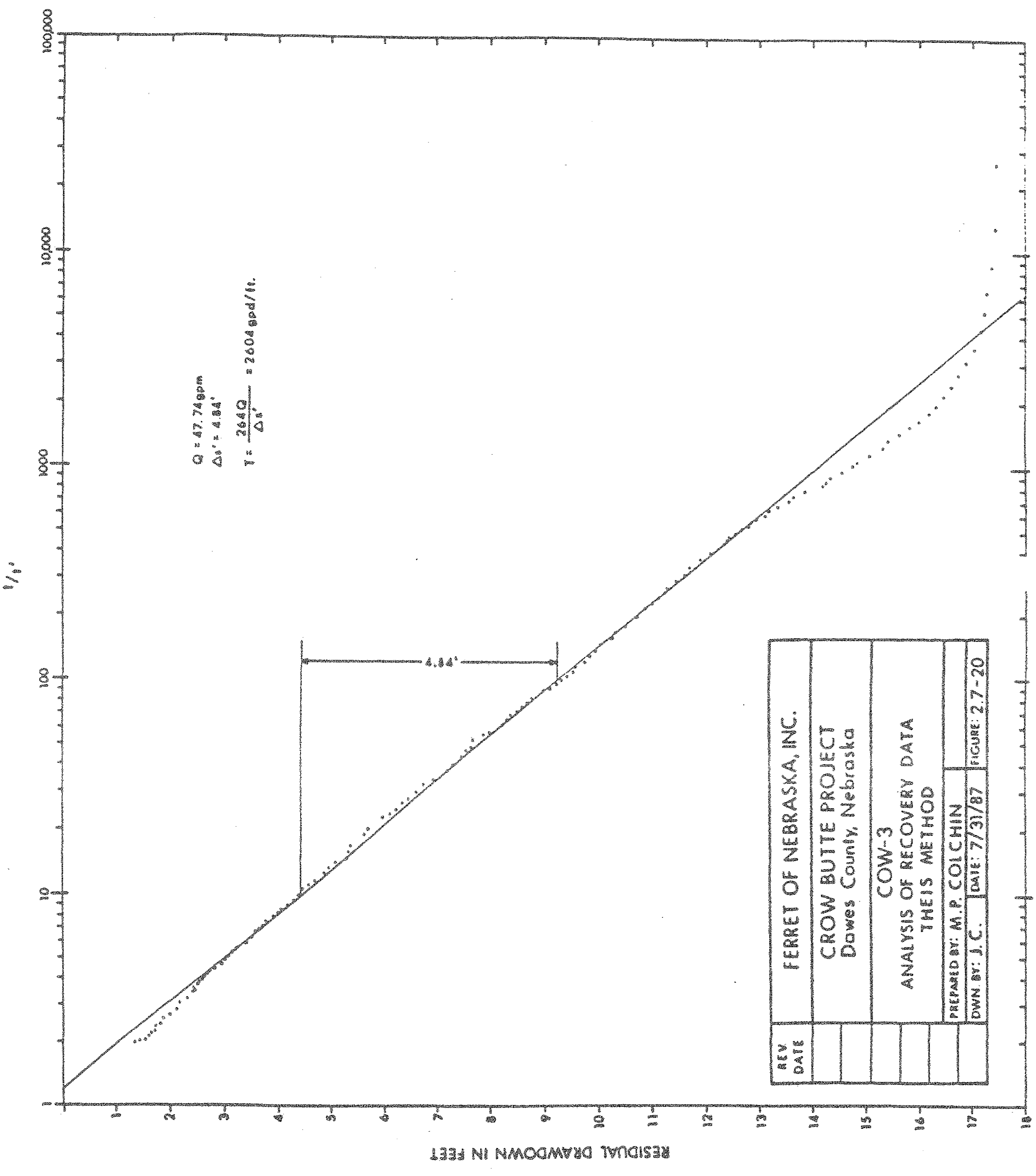

TIME IN MINUTES
1
10
100
1000
10,000
DRAWDOWN IN FEET
100
10
1
.1
MATCH POINT
1/u = 100 u = .01
W(u) = 4.0379
t = 67 minutes = .0465 days
s = 8.08'
Q = 47.74 gpm
r = 78.10
$T = \frac{114.59Q}{s} W(u) = 2733 gpd/ft$
$S = \frac{uTt}{1.87r^2} = 1.11 \times 10^{-4}$
REV DATE
FERRET OF NEBRASKA, INC.
CROW BUTTE PROJECT
Dawes County, Nebraska
COW-2
ANALYSIS OF DRAWDOWN DATA
THEIS METHOD
PREPARED BY: M.P. COLCHIN
DWN BY: JC
DATE: 7/31/87
FIGURE 2.7-16

2.7(42) 07/29/87


TIME IN MINUTE
.1
1
10
100
1000
10,000
.1
1
10
MATCH POINT
1/u = 100 u = .01
W(u) = 4.0379
t = 48 minutes = .0333 days
s = 8.11'
Q = 47.74 gpm
r = 60.93'
T = 114.59Q/s W(u) = 2724 gpd/ft
S = uTt/1.87r² = 1.31 X 10⁻⁴
REV DATE
FERRET OF NEBRASKA, INC.
CROW BUTTE PROJECT
Dawes County, Nebraska
COW-3
ANALYSIS OF DRAWDOWN DATA
THEIS METHOD
PREPARED BY: M.P.COLCHIN
DWN. BY: JC
DATE: 7/31/87
FIGURE 2.7-17


Q = 47.74 gpm
Δs' = 4.74'
T = 264Q / Δs' = 2659 gpd/ft
4.74'
RESIDUAL DRAWDOWN IN FEET
.1
1
10
100
1000
10,000
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
REV. DATE
FERRET OF NEBRASKA, INC.
CROW BUTTE PROJECT
Dawes County, Nebraska
COW-1
ANALYSIS OF RECOVERY DATA
THEIS METHOD
PREPARED BY: M. P. COLCHIN
DWN. BY: J. C.
DATE: 7/31/87
FIGURE: 2.7-18


t/t'
1
10
100
1000
10,000
100,000
RESIDUAL DRAWDOWN IN FEET
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Q = 47.74gpm
Δs = 4.80'
T = 264Q / Δs' = 2626gpd/ft
4.80'
REV. DATE
FERRET OF NEBRASKA, INC.
CROW BUTTE PROJECT
Dawes County, Nebraska
COW-2
ANALYSIS OF RECOVERY DATA
THEIS METHOD
PREPARED BY: M.P. COLCHIN
DWN. BY: J. C.
DATE: 7/31/87
FIGURE: 2.7-19


FERRET OF NEBRASKA, INC.
CROW BUTTE PROJECT
Dawes County, Nebraska
COW-3
ANALYSIS OF RECOVERY DATA
THEIS METHOD
PREPARED BY: M.P. COLCHIN
DWN. BY: J.C.
DATE: 7/31/87
FIGURE: 2.7-20
REV DATE
Q = 47.74 gpm
Δs' = 4.84'
T = 264Q / Δs' = 2604 gpd/ft.
4.84'
t/t'
RESIDUAL DRAWDOWN IN FEET
1
10
100
1000
10,000
100,000
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

coefficient will vary and is likely to be larger during pumping than during the subsequent recovery (Jacob, 1963). Thus, transmissivity values calculated from pumping data are commonly larger than those calculated from recovery data.

The average thickness of the aquifer at the test site is 40 feet. Therefore, the hydraulic conductivities calculated from the drawdown data ranges from about 67 gpd/ft² (8.96 ft/day) to about 70 gpd/ft² (9.34 ft/day). The hydraulic conductivities calculated from the recovery data ranged from about 65 gpd/ft² (8.7 ft/day) to about 66 gpd/ft² (8.89 ft/day) Table 2.7-8 summarizes the results of the analysis of the aquifer test data.

The Hantush Method For Anisotropic aquifers was used to determine the direction and magnitude of the major and minor axes of transmissivity of the Basal Chadron Sandstone. The major axis of transmissivity in the Basal Chadron Sandstone lies along an azimuth of about 51° and has a magnitude of 2760 gpd/ft (369 ft²/day) (Figure 2.7-8). The minor axis of transmissivity has an azimuth of about 141° and a magnitude of 2692 gpd/ft 360 ft²/day.

Overlying and Underlying Confining Layers

The overlying confining layer piezometer (UCP-1) showed no response to the pumping from the Basal Chadron Sandstone during the aquifer test (Figure 2.7-21). However, this piezometer did respond to the rapid changes in barometric pressure that accompanied the passage of a low pressure system and a cold front which confirmed that it was indeed functioning properly. because UCP-1 did not respond to pumping, it was not possible to use the water level data from UCP-1 to calculate the hydraulic properties of the upper confining layer using the Neuman-Witherspoon Method. Therefore, laboratory data from the consolidation tests of core samples from UCP-1 were used to calculate the hydraulic properties of the overlying confining layer.

TABLE 2.7-8

SUMMARY OF AQUIFER-TEST DATA ANALYSIS

Jacob Method (Drawdown)

Well	T (gpd/ft)	T (ft²/day)	S	K (gpd/ft²)	K (ft/day)
COW-1	2682	359	$8.65X10^{-5}$	67	8.98
COW-2	2687	359	$1.14X10^{-4}$	67	8.98
COW-3	2795	374	$9.73X10^{-5}$	70	9.35
Average	2721	364	$9.93x10^{-5}$	68	9.10

Theis Method (Drawdown)

Well	T (gpd/ft)	T (ft²/day)	S	K (gpd/ft²)	K (ft/day)
COW-1	2730	365	$8.44X10^{-5}$	68	9.13
COW-2	2733	365	$1.11X10^{-4}$	68	9.13
COW-3	2724	364	$1.31X10^{-4}$	68	9.10
Average	2729	365	$1.09x10^{-4}$	68	9.12

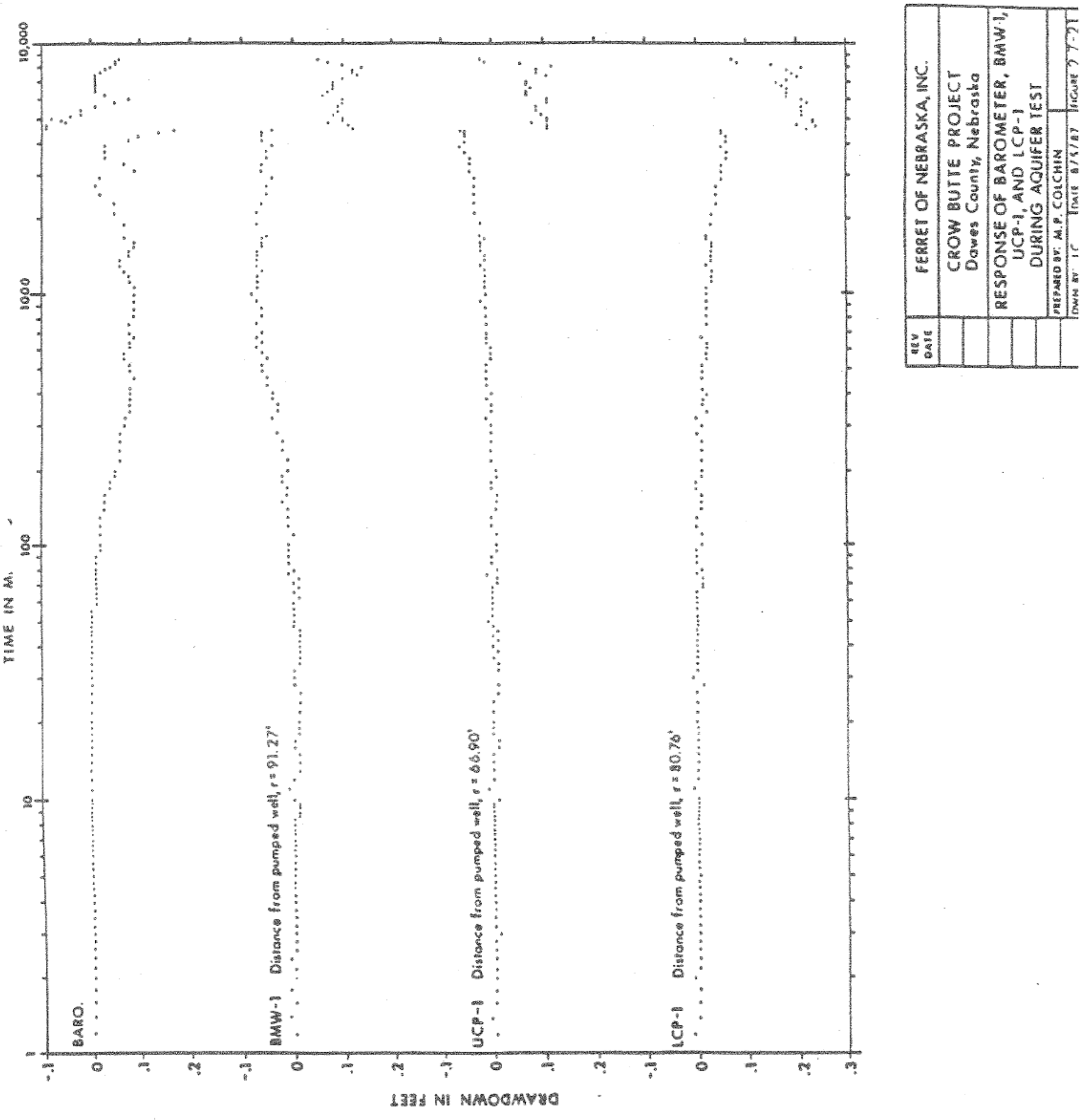
Theis Recovery Method

Well	T (gpd/ft)	T (ft²/day)	K (gpd/ft²)	K (ft/day)
COW-1	2659	355	66	8.88
COW-2	2626	351	66	8.78
COW-3	2604	348	65	8.70
Average	2630	351	66	8.79

Average of Jacob and Theis Methods (Drawdown) *

Well	T (gpd/ft)	T (ft²/day)	S	K (gpd/ft²)	K (ft/day)
COW-1	2706	362	$8.55X10^{-5}$	68	9.05
COW-2	2710	362	$1.13X10^{-4}$	68	9.05
COW-3	2760	364	$1.14X10^{-4}$	69	9.23
Average	2725	364	$1.04x10^{-4}$	68	9.11

* Used in anisotropy calculations.


FERRET OF NEBRASKA, INC.
CROW BUTTE PROJECT
Dawes County, Nebraska
RESPONSE OF BAROMETER, BMW-1, UCP-1, AND LCP-1 DURING AQUIFER TEST
PREPARED BY: M.P. COLCHIN
TIME IN M.
DRAWDOWN IN FEET
BARO.
BMW-1 Distance from pumped well, r = 91.27'
UCP-1 Distance from pumped well, r = 66.90'
LCP-1 Distance from pumped well, r = 80.76'
10
100
1000
10,000

Results of the laboratory consolidation test data from three core samples of UCP-1 are shown earlier in Table 2.7-4. The calculated average coefficient of compressibility, a_v, of the red clay portion of the overlying confining layer, is 3.99 x 10^{-7} cm^2/g and the calculated average vertical hydraulic conductivity is 3.49 x 10^{-11} cm/sec. Using these consolidation test data, the calculated specific storage of the red clay portion of the overlying confining layer is 3.08 x 10^{-7} cm^{-1} and the calculated hydraulic diffusivity is 1.13 X 10^{-4} cm^2/sec. Analysis of drill cuttings and geophysical logs of UCP-1 and exploration holes in the vicinity of the test site show that the lithology of the strata between the Red Clay and the overlying Brule aquifer (Upper Chadron and Lower Brule Formations) is similar to the Red Clay. Therefore, it is reasonable to assume that the hydraulic characteristics of these strata are similar to those of the Red Clay. Given that the red clay is approximately 30 feet thick and the total overlying confining layer is approximately 325 feet thick, the hydraulic resistance, c, (Kruseman and de Ridder, 1979) is about 830,200 years for the red clay and 8,994,000 years for the entire confining layer. The average porosity of the overlying confining layer calculated from the consolidation test data is 31.8%, therefore, the travel time through the red clay portion of the upper confining layer would be about 264,000 years and that of the entire upper confining layer would be about 2,860,000 years under unit gradient. Table 2.7-9 summarizes the confining layer properties determined by laboratory and field methods as part of this investigation.

The underlying confining layer piezometer (LCP-1) responded to the same rapid changes in barometric pressure which were measured in overlying confining layer piezometer (Figure 2.7-21). However, LCP-1 also showed a trend toward a very small amount of drawdown (.06 feet) during the aquifer test.

Because the vertical hydraulic conductivity of the underlying confining layer (Pierre Shale), as determined from the laboratory consolidation tests, is of the same order of magnitude as the vertical hydraulic conductivity of the upper confining layers (10^{-11} cm/sec), no drawdown was anticipated in LCP-1 during the test. For this reason, it is suspected that the small amount of drawdown observed in LCP-1 is the result of annular

<u>TABLE 2.7-9</u>

SUMMARY OF CONFINING LAYER PROPERTIES

Parameters	Red Clay (UCP-1)	Pierre Shale (LCP-1)
Coefficient of compressibility, a_v (cm^2 g/)	$3.99x10^{-7}$	$5.13x10^{-7}$
Specific storage, S_s', (cm^{-1})	$3.08x10^{-7}$	$2.78x10^{-7}$
Diffusivity, ', (cm^2/sec)	$1.13x10^{-4}$	$5.22x10^{-3}$
Vertical hydraulic conductivity, K_v', (cm/sec)		
Lab Data	$3.49x10^{-11}$	$3.63x10^{-11}$
Field Data	-----	$1.45x10^{-9}$
Hydraulic resistance, c, (years)		
Lab Data	830,200 (1)	31,929,000
Field Data	-----	799,300
Porosity (percent)	31.8	32.5
Travel time (years)		
Lab Data	264,000 (2)	259,700
Field Data	-----	10,377,000

(1) Red Clay Member only - total overlying confining layer = 8,994,000.

(2) Red Clay Member only - total overlying confining layer = 2,860,000.

leakage between the borehole and the packer which was set to hydraulically isolate the piezometer tip from the overlying Basal Chadron Sandstone. If the packer did not completely seal the borehole above the piezometer tip, the piezometer would be affected by the pressure drop in the pumped aquifer which would be transmitted by the annulus leaks. Thus, the response of the piezometer would be the result of borehole-packer annulus leaks. If this were the case, the Neuman-Witherspoon analysis of the piezometer water levels would only serve to quantify the vertical leakage or hydraulic conductivity of the packer and borehole seal, not the vertical hydraulic conductivity of the underlying confining layer. Recognizing that this problem may exist, a Neuman-Witherspoon analysis was made of the water level data from LCP-1.

Results of the laboratory consolidation test data from two core samples from LCP-1 are shown earlier in Table 2.7-4. The calculated average coefficient of compressibility, a_v, of the Pierre Shale is 5.13×10^{-7} cm²/g and the calculated average vertical permeability is 3.63×10^{-11} cm/sec. Using these consolidation test data, the calculated specific storage of the top 5 feet of the underlying confining layer (Pierre Shale) is 2.78×10^{-7} cm^{-1} and the calculated hydraulic diffusivity is 5.22×10^{-3} cm²/sec. Applying the Neuman-Witherspoon Method to the data from the aquifer test and the consolidation test, produces a field vertical hydraulic conductivity of 1.45×10^{-9} cm/sec. Oil test holes have shown that the Pierre Shale is approximately 1200 feet thick in the vicinity of the aquifer test site. Therefore, the calculated hydraulic resistance, c, using field measured vertical hydraulic conductivity, is about 799,300 years. The calculated hydraulic resistance using the vertical hydraulic conductivity calculated from the laboratory consolidation tests is about 31,929,000 years. The average porosity of the Pierre Shale calculated from the consolidation test data is 32.5%. Therefore, the travel time through the Pierre Shale would be about 259,770 years using field determined vertical hydraulic conductivity and about 10,377,000 years using laboratory determined vertical hydraulic conductivity under unit gradient.

Overlying Aquifer

The overlying aquifer monitor well, BMW-1, showed no response to the pumping from the Basal Chadron Sandstone during the aquifer test (Figure 2.7-21). However, this well did respond to barometric changes that occurred during the aquifer test which confirmed that it was functioning properly. Because BMW-1 did not respond to pumping, it is evident that the overlying aquifer is not in hydraulic communication with the Basal Chadron Sandstone. Therefore, no further analysis was made of the test data from BMW-1.

INTERPRETATION OF DATA

Aquifer Response to Pumping

The results of this investigation show that the Basal Chadron Sandstone, which is the ore-bearing aquifer at the Crow Butte site, is a non-leaky, confined, slightly-anisotropic aquifer. The effective transmissivity of the Basal Chadron Sandstone is 2726 gpd/ft. The average thickness of the aquifer at the test site is about 40 feet. Therefore, the average hydraulic conductivity is about 68 gpd/ft^2 (9.10 ft/day). The average storativity is 1.04×10^{-4}. The azimuth and magnitude of the major axis of transmissivity are about 51° and 2760 gpd/ft (369 ft^2/day). The azimuth and magnitude of the minor axis of transmissivity are about 141° and 2692 gpd/ft (360 ft^2/day).

The piezometric surface of the Basal Chadron Sandstone is approximately 495 feet above the top of the aquifer. The piezometric surface of the overlying aquifer is about 204 feet above the top of the Brule Sand. The difference between the piezometric surfaces of the two aquifers is about 59 feet. This fact plus the fact that BMW-1 did not respond to pumping from the Basal Chadron Sandstone, are evidence that the Basal Chadron Sandstone is confined and that it is not hydraulically connected to the overlying aquifer.

Integrity of Confinement

Confined aquifers may receive small amounts of water through vertical recharge from the confining layers. Even confining layers formed of very low permeability may yield small amounts of water if the hydraulic gradient in the aquifer-aquitard system is favorable. The aquitards which overlie and underlie the Basal Chadron Sandstone probably yielded some small amount of water as recharge (leakage) to the aquifer during the pumping of the aquifer test. However, the amount of this recharge or leakage was extremely small as evidenced by the piezometer responses and the drawdown analysis of the Basal Chadron Sandstone. The overlying confining layer piezometer did not show any response attributable to the pumping. The underlying confining layer piezometer did show a maximum drawdown of 0.06 feet about 4300 minutes after pumping began. However, it is suspected that this small amount of drawdown is attributable to leakage at the annulus of the packer and borehole rather than to leakage from the confining layer.

The lack of substantial drawdown in the confining layer piezometers is attributable to the extremely low vertical hydraulic conductivity of the confining layers. The vertical hydraulic conductivity of the overlying confining layer is about 3.49×10^{-11} cm/sec., and that of the underlying confining layer is about 1.45×10^{-9} to 3.63×10^{-11} cm/sec. Confining layers with vertical hydraulic conductivities this low are, by definition, called aquicludes, rather than aquitards.

The integrity of confinement of the ore-zone aquifer (Basal Chadron Sandstone) may be characterized most graphically by the hydraulic resistance, c. The calculated hydraulic resistance of the entire thickness of the overlying aquiclude is about 8,994,000 years and that of the underlying aquiclude is between 799,300 years and 31,900,000 years. The times needed for a given water molecule to travel through the entire thicknesses of the aquicludes under unit gradient (one foot of head loss per foot of movement in the direction of flow) are about 2,860,000 years for the upper aquiclude and about 260,000 years to 10,377,000 years for the lower. Because the gradients would be much smaller during mining, actual travel times would be much longer than those stated above.

Movement of Groundwater

The piezometric surface of the Basal Chadron Sandstone dips approximately to the north at a gradient of 7.84×10^{-4} which is equal to 1 foot per 1275 feet. Using a directional hydraulic conductivity of 9.11 ft/day, a gradient 7.84×10^{-4} and a porosity of 29 percent, the average pore velocity across this part of the commercial study area is about 9.00 ft/year. The groundwater flux across the test site was computed to be about .29 ft^3/day per unit width of the aquifer. (Darcy, 1856).

Extent of Investigated Area

Using the Cooper-Jacob Distance-Drawdown Method (Cooper and Jacob, 1946), the radius of influence of the aquifer test in the Basal Chadron Sandstone was calculated to be about 5000 feet. Therefore, the area investigated and characterized by this test is approximately 1803 acres.