TABLE A-1.40
CONSTANT HEAD TEST DATA FOR HOLE 35N-7G (U COAL)

Date	Time	Time Since Injection Started (min)	Discharge (Q, in GPM)	I/Q (min/gal)	Water Level (ft-mp)
5/15/80	0948				31.80
5/18/80	0848				33.14
		T = 11.8°C Cond = 333 umhos/cm @ 25°C			
		Pumped hole			
5/19/80	1115				52.15
	1140	Started bailing			
	1142	T = 10.0°C Cond = 334 umhos/cm @ 25°C			
	1150	Stopped bailing - 5 gal			
		Sample taken			
	1152				59.50
	1221				58.95
5/21/80	1145	Started test			
	1155	10	0.0103	97.3	
	1240	55	0.0059	169.0	
	1355	130	0.0031	321.0	
	1600	275	0.0025	407.0	

TABLE A-1.41 DRAWDOWN DATA FOR OBSERVATION WELLS 887, 886 and 888 FROM PUMPING WELL 885

	Well 887 Distance: 115' 68SS			Well 886 Distance: 64' 70SS			Well 888 Distance: 50' 70SS	
Date	Elapsed Time (min)	Drawdown (ft)	Date	Elapsed Time (min)	Drawdown (ft)	Date	Elapsed Time (min)	Drawdown (ft)
8-17-77	0	0	8-17-77	0	0	8-17-77	0	0.00
	Pumping 3.4 gpm			Pumping 3.4 gpm			Pumping 3.4 gpm	
	37	0.02		30	0.05		17	0.00
	50	0.02		40	0.17		25	0.00
	75	0.02		60	0.26		35	0.00
	105	0.02		195	0.35		50	0.05
	200	0.02		315	0.36		80	0.30
				405	0.43		185	0.79
							245	1.02
							320	1.11
							410	1.41
8-18-77	570	0.57	8-18-77	570	0.48	8-18-77	570	1.66
	925	0.86		747	0.51		873	1.86
	995	0.82		915	0.55		1108	1.88
	1065	0.82		1175	0.68		1275	1.90
	1365	0.74		1269	0.75		1360	1.94
				1385	0.76		1440	Pump Off
	1440	Pump Off		1440	Pump Off			

TABLE A-1.42
RECOVERY TEST FOR WELL 886 (70SS)
(6/24/78)

Time of Measurement	Time since Pumping Started t, minutes	Time since Pumping Stopped t', minutes	$\frac{t}{t'}$	Water Level (Ft-MP)	Residual Drawdown s', feet
12:01	61	1	61	182.23	4.33
12:02	62	2	31	179.13	1.23
12:03	63	3	21	178.55	0.65
12:04	64	4	16	178.39	0.49
12:05	65	5	13	178.30	0.40
12:06	66	6	11	178.26	0.36
12:07	67	7	9.6	178.22	0.32
12:32	92	32	2.9	177.42	0.10
2:30	210	150	1.4	177.33	0.01

Discharge rate, Q = 2 gallons per minute

TABLE A-1.43
RECOVERY TEST FOR WELL 887 (68SS)
(6/24/78)

Time of Measurement	Time since Pumping Started t, minutes	Time since Pumping Stopped t', minutes	$\frac{t}{t'}$	Water Level (Ft-MP)	Residual Drawdown s', feet
15:20	60	0	-	196.63	12.53
15:21	61	1	61	196.42	12.32
15:22	62	2	31	196.25	12.15
15:23	63	3	21	195.92	11.82
15:24	64	4	16	195.71	11.61
15:25	65	5	13	195.46	11.36
15:26	66	6	11	195.25	11.15
15:28	68	8	8.5	194.83	10.73
15:30	70	10	7.0	194.50	10.40
15:34	74	14	5.3	193.83	9.73
15:36	76	16	4.8	193.25	9.15
15:44	84	24	3.5	192.08	7.98
15:49	89	29	3.1	191.50	7.40
15:57	97	37	2.6	190.50	6.40
16:07	107	47	2.3	189.67	5.57
16:20	120	60	2.0	188.67	4.57
16:40	140	80	1.8	187.71	3.61
16:50	150	90	1.7	187.29	3.19
17:30	190	130	1.5	186.21	2.11
18:03	223	163	1.4	185.68	1.58
18:33	253	193	1.3	185.40	1.30
19:03	283	223	1.27	185.08	0.98
20:03	343	283	1.21	184.79	0.69
21:10	410	350	1.17	184.63	0.53
21:45	445	385	1.16	184.54	0.44
09:30	1150	1090	1.06	184.40	0.30

Discharge rate, Q = 0.1 gallons per minute

TABLE A-1.44
DRAWDOWN DATA FOR OBSERVATION WELL 1805 (70SS) ON AFTERNOON OF 6/25/78

Time of Measurement	Time Since Pumping Started (t, min)	Water Level (Ft-MP)	Drawdown (s, ft)
15:00	0	158.75	0
15:10	10	159.25	0.50
15:20	20	159.33	0.58
15:25	25	159.35	0.60
15:42	42	159.40	0.65
15:52	52	159.42	0.67
16:20	80	159.44	0.69
16:35	95	159.45	0.70
17:15	135	159.46	0.71
17:20	140	159.46	0.71

Discharge rate, Q = 3.5 gallons per minute
r = 36 ft.

TABLE A-1.45
DRAWDOWN DATA FOR OBSERVATION WELL 1806 (70SS)
(6/25/78)

Time of Measurement	Time Since Pumping Started (t, min)	Water Level (Ft-MP)	Drawdown (s, ft)
15:00	0	150.00	0
15:07	7	150.21	0.21
15:15	15	150.33	0.33
15:28	28	150.42	0.42
15:38	38	150.46	0.46
15:55	55	150.50	0.50
16:15	75	150.52	0.52
16:45	105	150.54	0.54
17:10	130	150.54	0.54

Discharge rate, Q = 3.5 gallons per minute
r = 73 ft

TABLE A-1.46
DRAWDOWN DATA FOR OBSERVATION WELL 1807 (685S)
(6/25/78)

Time of Measurement	Time Since Pumping Started (t, min)	Water Level (Ft-MP)	Drawdown (s, ft)
10:30	0	155.44	0
11:17	47	155.50	0.06
11:25	55	155.58	0.14
11:30	60	155.63	0.19
11:35	65	155.67	0.23
11:42	72	155.71	0.27
11:53	83	155.75	0.31
12:06	96	155.79	0.35
12:30	120	155.81	0.37
13:00	150	155.81	0.37
13:20	170	155.81	0.37

Discharge rate, Q = 2.5 gallons per minute
r = 111 ft.

TABLE A-1.47
DRAWDOWN FOR OBSERVATION WELL 1816 (70SS) ON 12/01/78

Time since pumping started (t, min)	Drawdown (s, ft)
3	0.12
5	0.23
9	0.29
10	0.31
15	0.34
20	0.38
25	0.42
30	0.45
35	0.46
45	0.55
60	0.61
90	0.73
120	0.84
180	1.03
240	1.14
300	1.29
360	1.41
420	1.49
480	1.67
750	1.67
1140	1.87

Discharge rate, Q = 19 gallons per minute

r = 54.6 ft

TABLE A-1.48
PUMPING AND RECOVERY DATA FOR WELL 1823 (68SS)

Date	Time	Time Since Pumping Started (t,min)	Time Since Pumping Stopped (t',min)	t/t'	Water Level ft below mp)	Discharge (gpm)
5/21/80	1555				110.74	
5/22/80	1704	0	Pump on			
	1714	10	T = 13.0°C , C = 1228, umhos/cm @ 25°C			1.73
	1722	18	T = 11.6°C , C = 1204			1.72
	1733	29	T = 11.5°C , C = 1206			1.71
	1753	49	T = 11.5°C , C = 1206 Sample collected			1.73
	1809	65	T = 11.6°C , C = 1203			1.69
	1814	70	0	Pump off		
	1828	84	14	6.0	116.98	
	1836	92	22	4.18	115.30	
	1848	104	34	3.06	114.20	
	1859	115	45	2.56	113.77	
	1914	130	60	2.17	113.53	
	1929	145	75	1.93	113.40	

TABLE A-1.49
WATER-LEVEL DATA FOR WELL 1816 DURING PUMP TEST OF WELL 1823

Date	Time	Water Level (ft below mp)
5/21/80	1620	157.42
	1725	157.42
5/22/80	1704	Pump on in well 1823
	1709	157.23
	1715	157.16
	1721	157.18
	1725	157.21
	1739	157.24
	1749	157.20
	1813	157.08
	1814	Pump off in well

TABLE A-1.50 PUMPING AND DRAWDOWN DATA FOR WELL 1814 (70 SAND)

DATE	TIME	TIME SINCE PUMPING STARTED (t, in min.)		WATER LEVEL (ft below MP)	DRAWDOWN	DISCHARGE (gpm)	TOTALIZER (gal)
08/13/80	0958	-		159.40	-	-	-
	1130		PUMP ON				
	1150	20		-	-	17.1	-
	1151	21		-	-	-	171860.6
	1158	28	T = 11.0°C, COND = 840 µmhos/cm @ 25°C				
	1159	29		-	-	17.1	-
	1212	42		187.23	27.83	-	-
	1222	52		187.84	28.44	-	-
	1223	53		-	-	17.1	-
	1225	55	T = 11.5°C, COND = 870		-	-	-
	1226	56		-	-	-	172454.1
	1235	65		187.66	28.26	-	-
	1251	71		187.81	28.41	-	-
	1252	72	T = 11.0°C. COND = 790		-	16.7	-
	1316	96		188.44	29.04	-	-
	1348	128		-	-	16.7	173822.3
	1349	129	T = 11.1°C, COND = 800	188.76	29.36	-	-
	1438	178		189.07	-	-	-
	1441	181		-	-	-	-
	1550	250		189.91	-	-	-
	1726	346		188.73	29.33	17.0	-
	1731	351	T = 12.0°C, COND = 800		-	-	-
	2004	504		189.42	30.02	16.9	-

TABLE A-1.50 PUMPING AND DRAWDOWN DATA FOR WELL 1814 (70 SAND) (cont'd)

DATE	TIME	TIME SINCE PUMPING STARTED (t, in min.)		WATER LEVEL (ft below MP)	DRAWDOWN	DISCHARGE (gpm)	TOTALIZER (gal)
08/14/80	0156	856	T = 11.0°C, COND = 690	190.88	31.48	-	-
	0706	1166	T = 10.9°C, COND = 700	191.45	32.05	17.6	-
	1228	1488	T = 11.0°C, COND = 730	190.84	31.44	16.9	-
	1612	1712	T = 12.5°C, COND = 760	190.12	30.72	16.3	-
	2305	2125		190.95	31.55	-	-
	2313		PUMP OFF				
	2328		PUMP ON				
08/15/80	0632	2572	T = 10.9°C, COND = 680	189.81	30.41	16.6	-
	1528	3108	T = 12.0°C, COND = 560	189.55	30.15	15.9	-
08/16/80	0900	PUMP WENT OFF IN MIDDLE OF NIGHT					

TABLE A-1.51 DRAWDOWN DATA FOR OBSERVATION WELL 1815 (70 SAND)

DATE	TIME	TIME SINCE PUMPING STARTED (t, in min.)	WATER LEVEL (ft below MP)	DRAWDOWN (ft)
08/13/80	1102	-	161.68	-
	1130	PUMP ON IN WELL 1814		
	1133	3	161.71	.03
	1135.5	5.5	161.78	.10
	1137.5	7.5	161.82	.14
	1139	9	161.84	.16
	1144	14	161.89	.21
	1149	19	161.91	.23
	1156	26	161.94	.26
	1205	35	161.96	.28
	1216	46	162.00	.32
	1230	60	161.98	.30
	1245	75	162.03	.35
	1248	78	162.04	.36
	1259	89	162.04	.36
	1321	111	162.08	.40
	1348	138	162.07	.39
	1448	198	162.16	.48
	1544	254	162.19	.51
	1736	366	162.26	.58
	2012	522	162.37	.69
08/14/80	0148	858	162.54	.86
	0716	1186	162.65	.97
	1240	1510	162.72	1.04
	1559	1719	162.71	1.03
	2253	2133	162.75	1.07
08/15/80	0623	2583	162.87	1.19
	1537	3137	162.95	1.27

TABLE A-1.52 DRAWDOWN DATA FOR OBSERVATION WELL 1816 (70 SAND)

DATE	TIME	TIME SINCE PUMPING STARTED (t, in min.)	WATER LEVEL (ft below MP)	DRAWDOWN (ft)
08/13/80	1047	-	157.28m	-
	1050	-	157.42e	-
	1130	PUMP ON	-	-
	1131	1	157.25	-.03
	1132	2	157.34	.06
	1133	3	157.34	.06
	1134	4	157.42	.14
	1135	5	157.42	.14
	1136	6	157.61	.23
	1137	7	157.59	.21
	1138	8	157.67	.39
	1139	9	157.74	.45
	1140	10	158.99	.71
	1143	13	158.30	1.02
	1146	16	158.45	1.17
	1152	22	158.41	1.13
	1157	27	158.61	1.33
	1207	37	157.80	.52
	1217	47	157.82	.54
	1227	57	157.89	.61
	1242	72	157.97	.69
	1257	87	158.11	.83
	1313	103	158.10	.82
	1350	140	158.26	.98
	1443	193	158.46	1.18
	1537	247	158.55	1.27
	1750	380	159.01	1.73
	2002	512	159.02	1.74

TABLE A-1.52 DRAWDOWN DATA FOR OBSERVATION WELL 1816 (70 SAND) (cont'd)

DATE	TIME	TIME SINCE PUMPING STARTED (t, in min.)	WATER LEVEL (ft below MP)	DRAWDOWN (ft)
08/14/80	0202	872	159.37	2.09
	0710	1180	158.99	1.71
	1231	1501	159.53	2.25
	1602	1711	159.39	2.11
	2250	2119	159.49	2.21
08/15/80	0629	2578	160.15	2.87
	1527	3116	159.71	2.43
08/16	1600	-	158.58	-

NOTES:

e = 1000' Electric Tape used

m = Metal Tape used

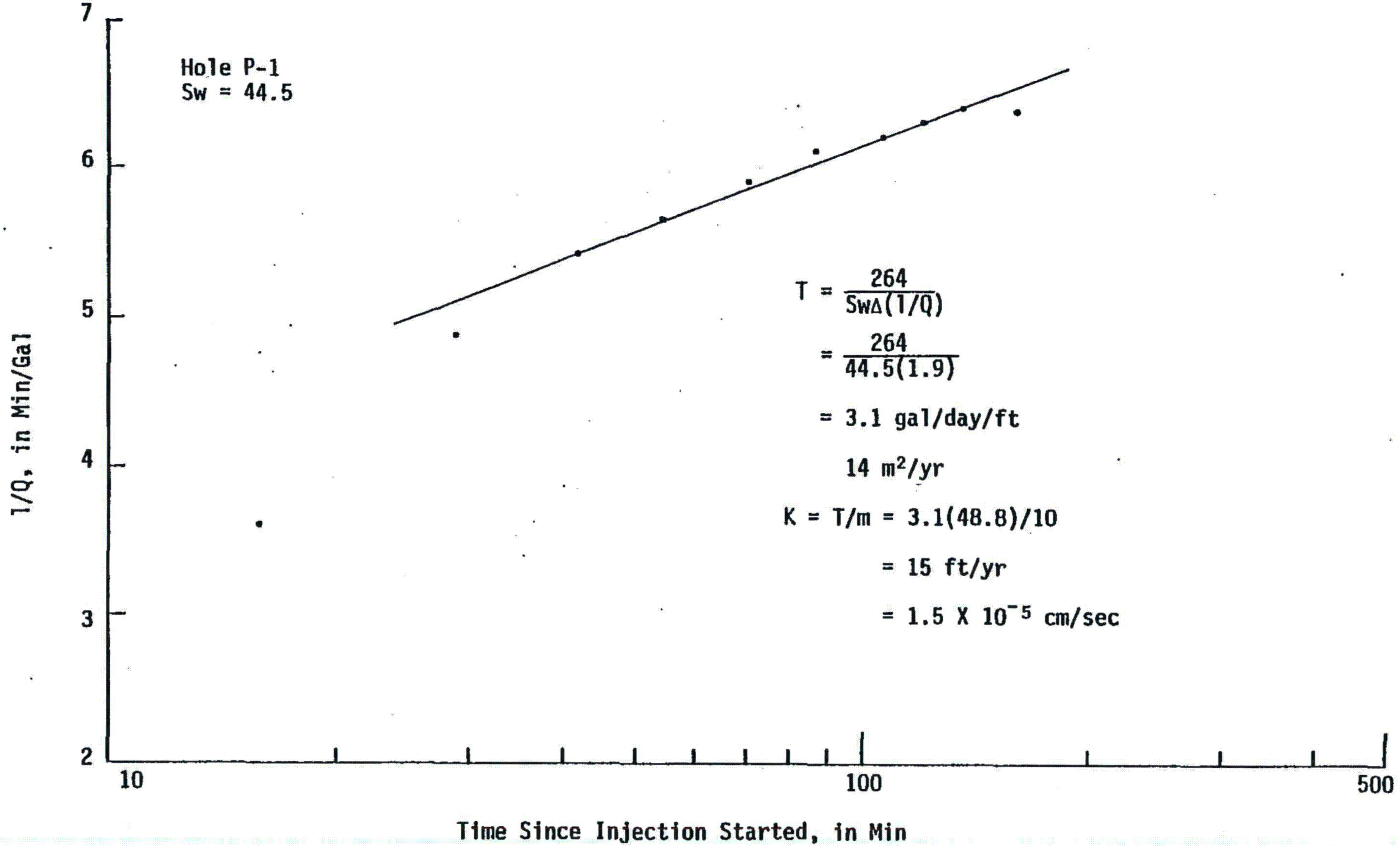
TABLE A-1.53 DRAWDOWN DATA FOR OBSERVATION WELL 1817 (70 SAND)

DATE	TIME	TIME SINCE PUMPING STARTED (t, in min.)	WATER LEVEL (ft below MP)	DRAWDOWN (ft)
08/13/80	1112	-	165.09	-
	1130	PUMP ON IN WELL 1814		-
	1141	11	165.15	.06
	1146.5	16.5	165.16	.07
	1153	23	165.18	.09
	1202	32	165.19	.10
	1220	50	165.19	.10
	1237	67	165.19	.10
	1256	86	165.19	.10
	1319	109	165.20	.11
	1353	143	165.19	.10
	1444	194	165.19	.10
	1601	271	165.20	.11
	1741	371	165.18	.09
	1958	508	165.21	.12
08/14/80	0206	876	165.20	.11
	0703	1179	165.26	.17
	1237	1513	165.27	.18
	1608	1724	165.18	.09
	2258	2134	165.20	.11
08/15/80	0627	2583	165.24	.15
	1532	3128	165.28	.19

TABLE A-1.54 DRAWDOWN DATA FOR OBSERVATION WELL 1823 (68 SAND)

DATE	TIME	TIME SINCE PUMPING STARTED (t, in min.)	WATER LEVEL (ft below MP)	DRAWDOWN (ft)
08/13/80	1054	-	112.61m	-
	1054		112.71e#3	-
	1105	-	112.50e#2	-
	1130	PUMP ON	-	-
	1131	1	111.62	-.99
	1134	4	110.86	-1.75
	1136.5	6.5	108.95	-3.66
	1142	12	108.95	-3.66
	1148	18	111.90	-.71
	1154	24	112.70	.09
	1159	29	112.71	.10
	1209	39	112.72	.11
	1220	50	112.59	-.02
	1230	60	112.66	.05
	1237	67	112.37	-.24
	1253	83	112.57	-.04
	1302	92	112.49	-.12
	1315	105	112.52	-.09
	1353	143	112.52	-.09
	1444	194	112.52	-.09
	1540	250	112.50	-.11
	1738	368	112.48	-.13
	2009	519	112.49	-.12
08/14/80	0152	862	112.50	-.11
	0713	1183	112.51	-.10
	1226	1496	112.50	-.11
	1605	1715	112.42	-.19
	2301	2131	112.48	-.13
8/15/80	0637	2589	112.36	-.25
	1529	3121	112.15	-.46

NOTES: e = Electric Tape used m = Metal Tape used



$$T = \frac{264}{Sw\Delta(1/Q)}$$

$$= \frac{264}{44.5(1.9)}$$

= 3.1 gal/day/ft

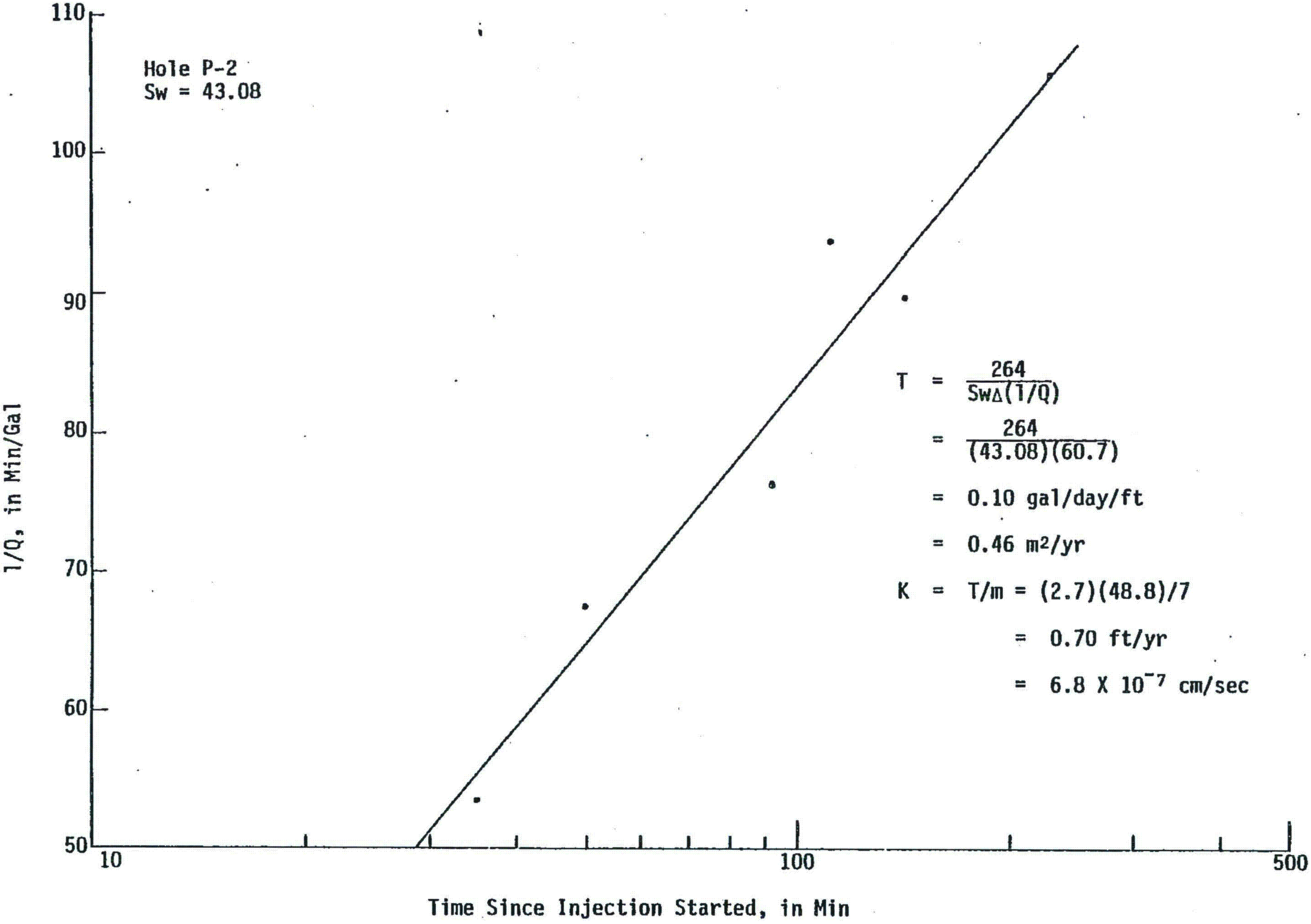
14 m^2/yr

K = T/m = 3.1(48.8)/10

= 15 ft/yr

= 1.5×10^{-5} cm/sec

FIGURE A-1.1 CONSTANT HEAD TEST FOR HOLE P-1 (LOWER MUDSTONE AND E COAL)



Hole P-2
Sw = 43.08

$$T = \frac{264}{S_w \Delta(1/Q)}$$

$$= \frac{264}{(43.08)(60.7)}$$

$= 0.10$ gal/day/ft

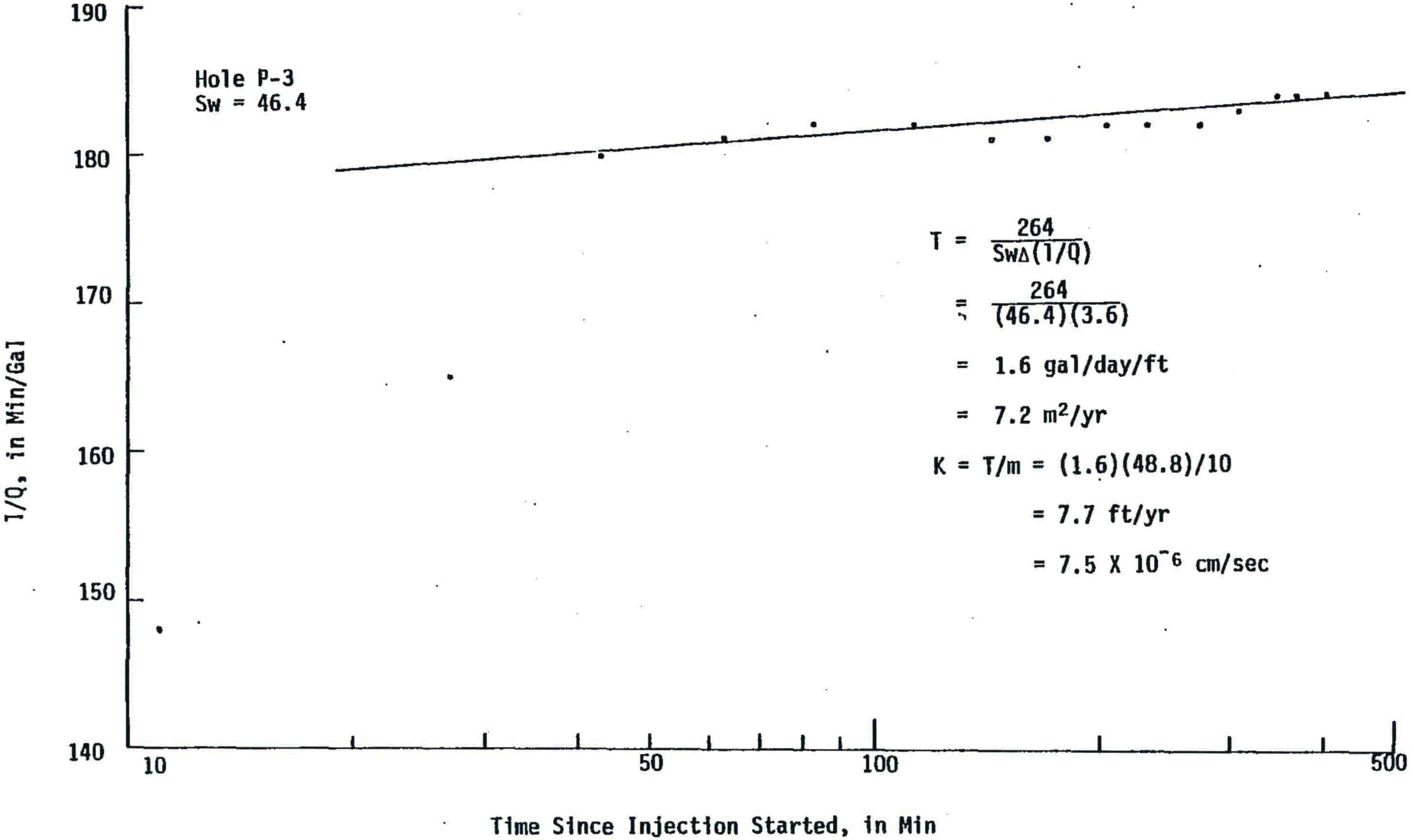
$= 0.46$ m^2/yr

$K = T/m = (2.7)(48.8)/7$

$= 0.70$ ft/yr

$= 6.8 \times 10^{-7}$ cm/sec

FIGURE A-1.2 CONSTANT HEAD TEST FOR HOLE P-2 (LOWER MUDSTONE AND E COAL)



$$T = \frac{264}{Sw\Delta(1/Q)}$$

$$= \frac{264}{(46.4)(3.6)}$$

$$= 1.6 \text{ gal/day/ft}$$

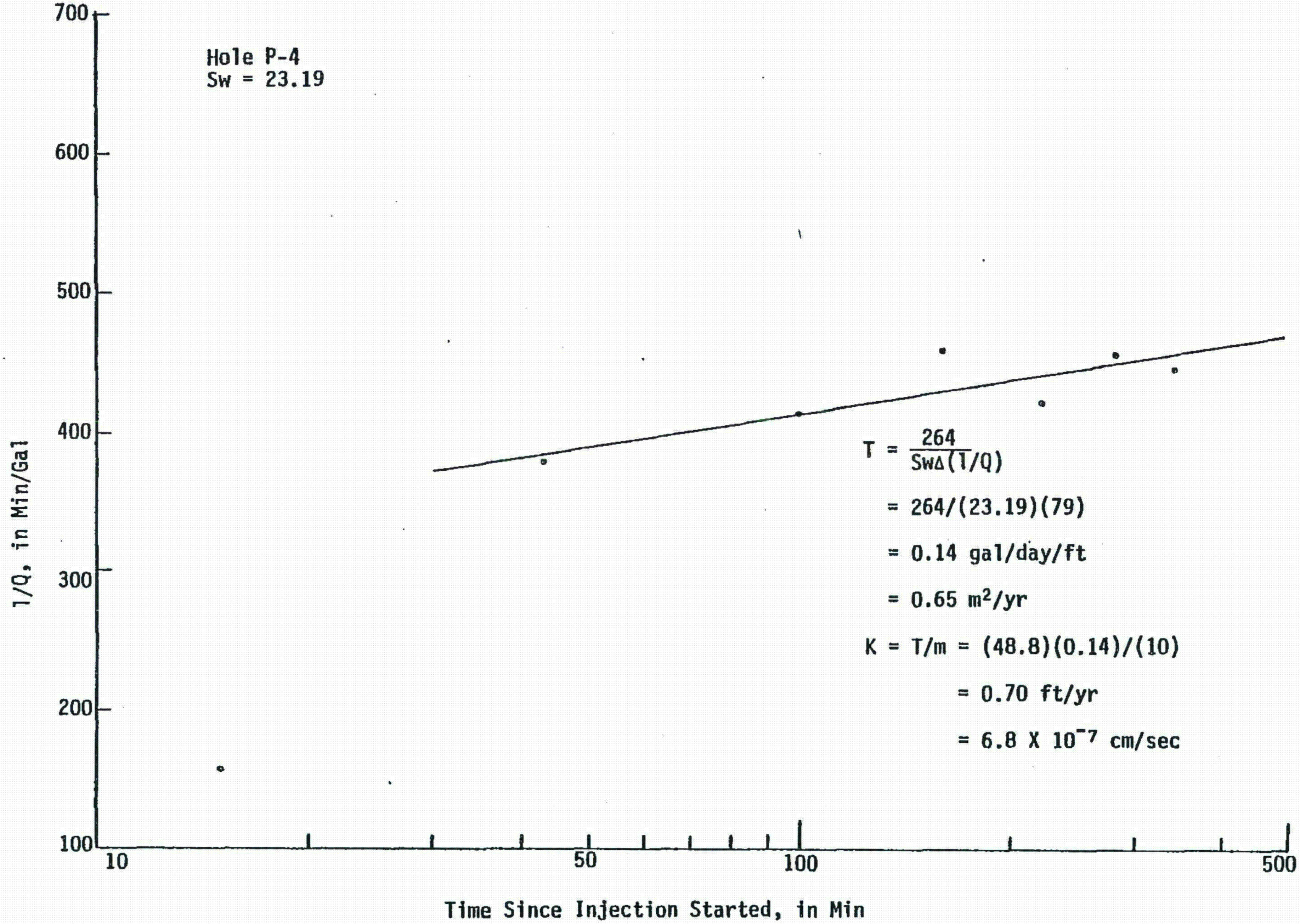
$$= 7.2 \text{ m}^2\text{/yr}$$

$$K = T/m = (1.6)(48.8)/10$$

$$= 7.7 \text{ ft/yr}$$

$$= 7.5 \times 10^{-6} \text{ cm/sec}$$

FIGURE A-1.3 CONSTANT HEAD TEST FOR HOLE P-3 (LOWER MUDSTONE)



$$T = \frac{264}{Sw\Delta(1/Q)}$$

$= 264/(23.19)(79)$

$= 0.14$ gal/day/ft

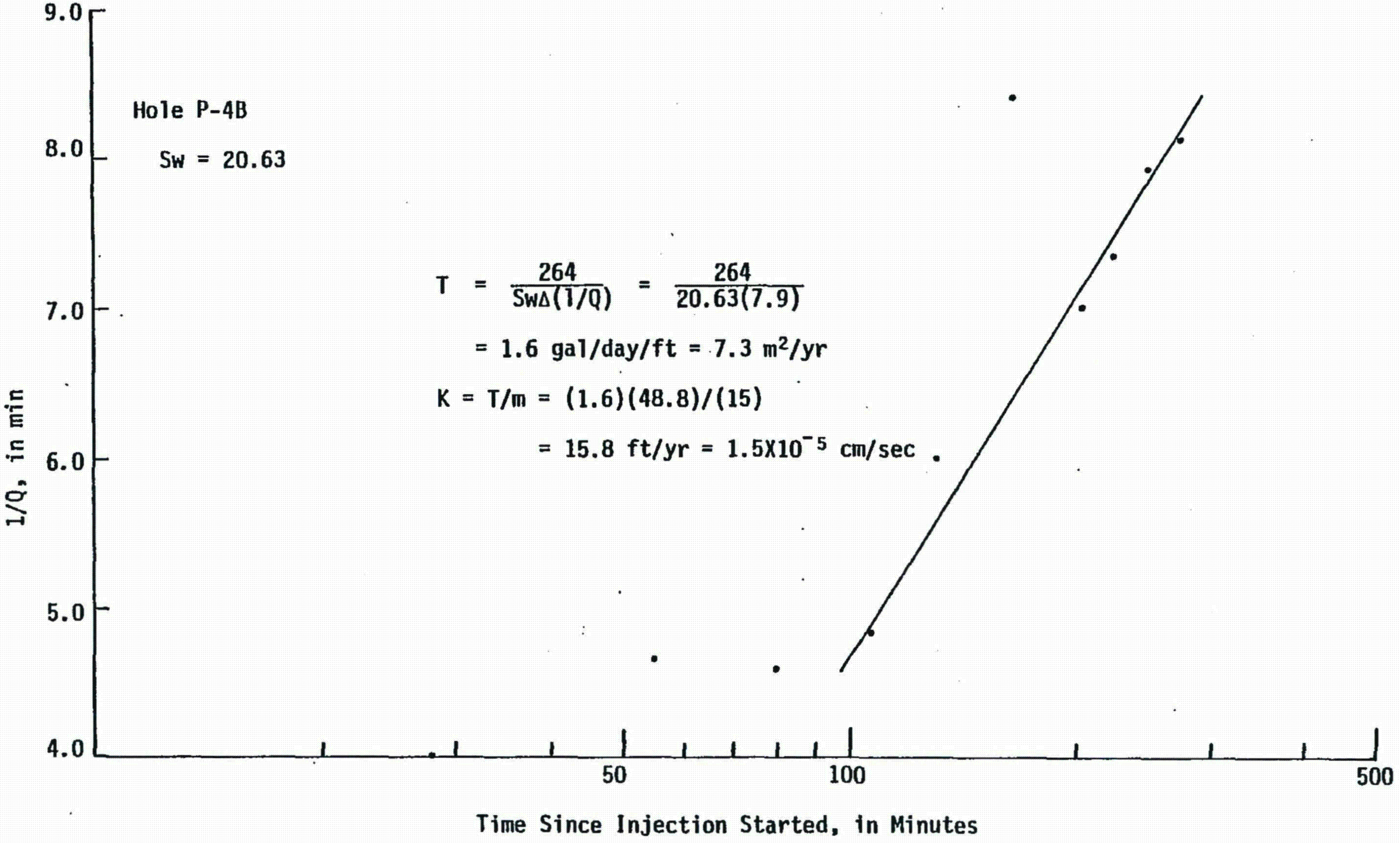
$= 0.65\ m^2/yr$

$K = T/m = (48.8)(0.14)/(10)$

$= 0.70$ ft/yr

$= 6.8 \times 10^{-7}$ cm/sec

FIGURE A-1.4 CONSTANT HEAD TEST FOR HOLE P-4 (LOWER MUDSTONE AND E COAL)



$$T = \frac{264}{S_w\Delta(1/Q)} = \frac{264}{20.63(7.9)}$$

$$= 1.6 \text{ gal/day/ft} = 7.3 \text{ m}^2\text{/yr}$$

$$K = T/m = (1.6)(48.8)/(15)$$

$$= 15.8 \text{ ft/yr} = 1.5 \times 10^{-5} \text{ cm/sec}$$

FIGURE A-1. 5 CONSTANT HEAD TEST FOR HOLE P-4B

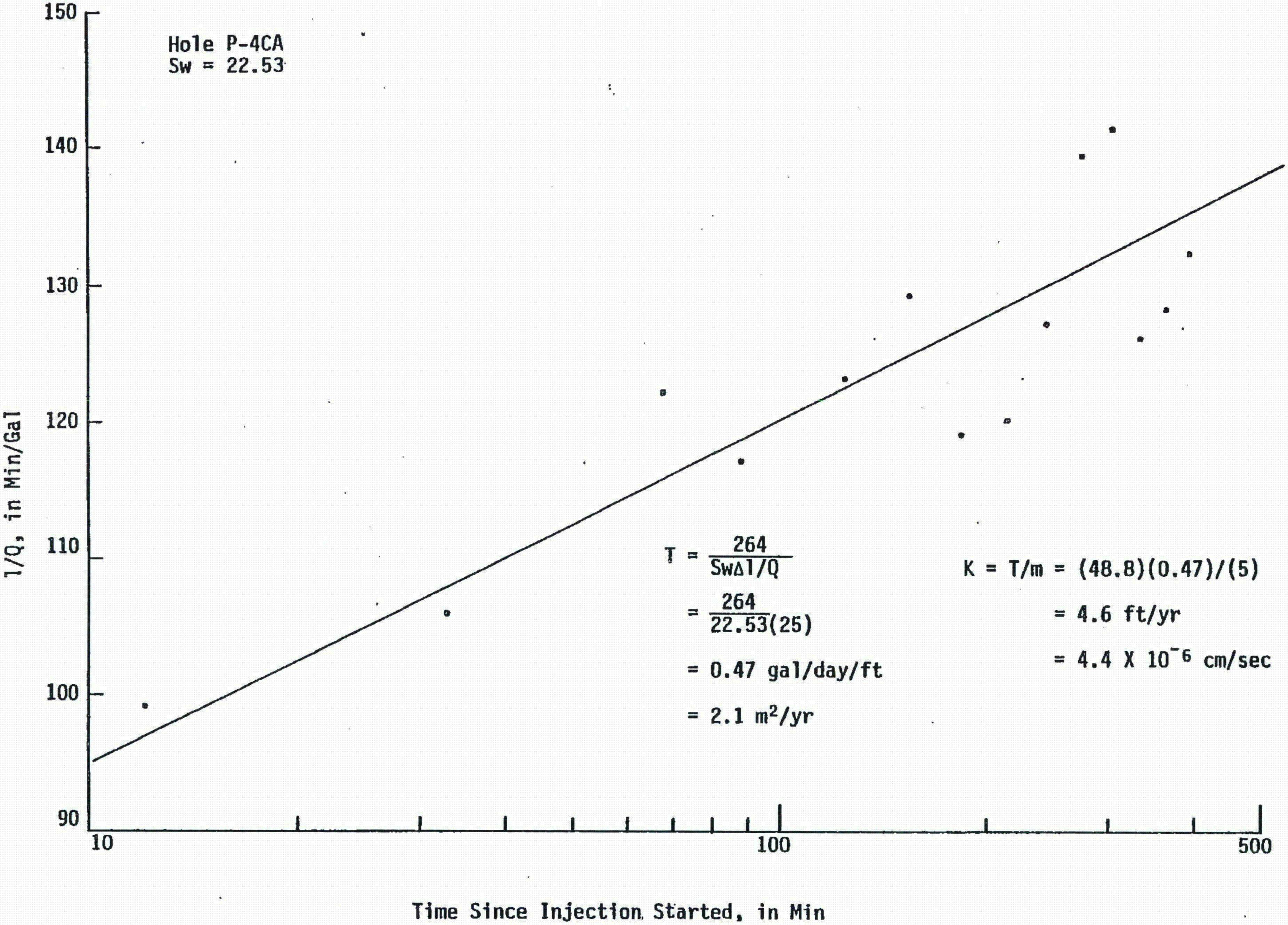
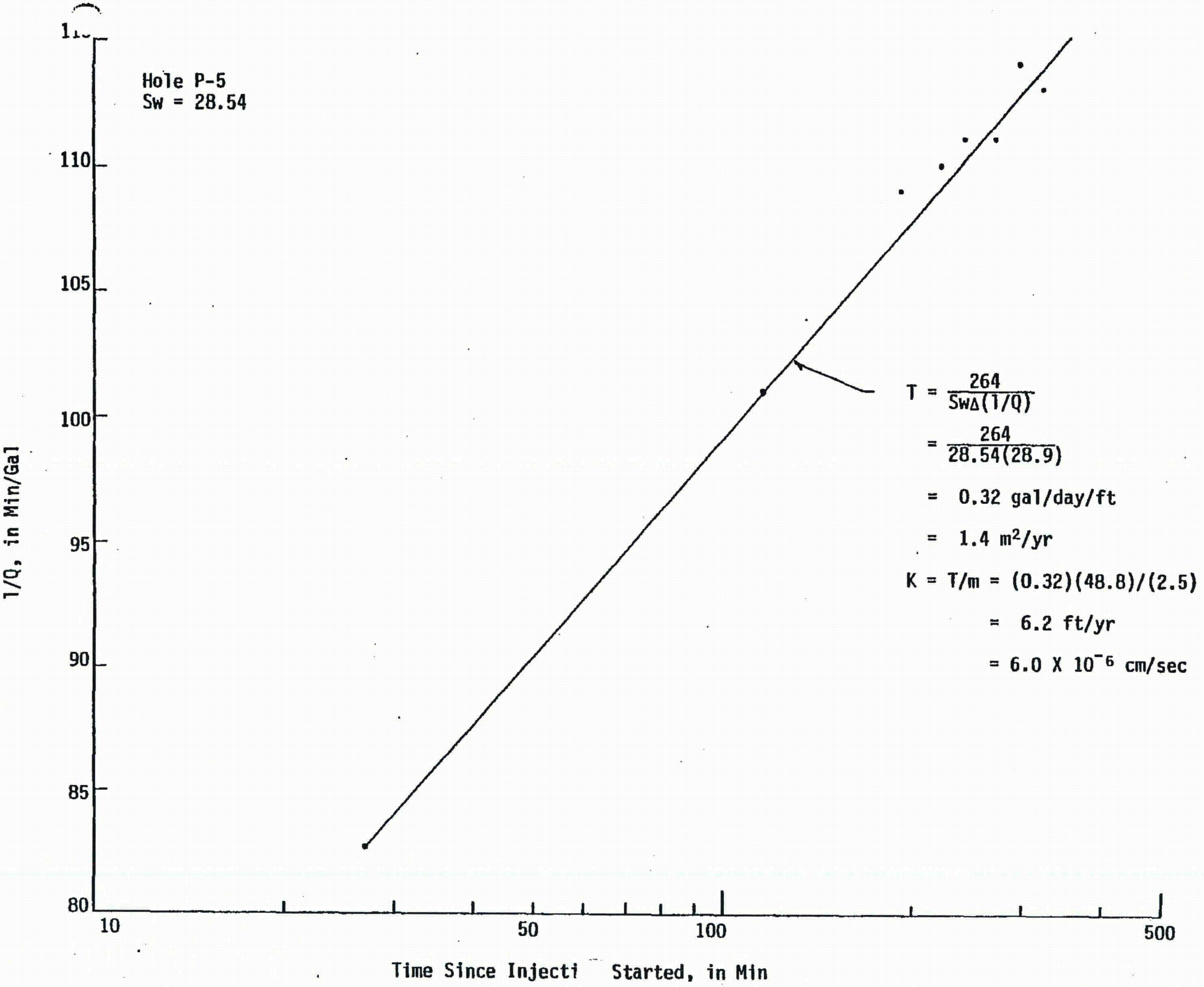


FIGURE A-1.7 CONSTANT HEAD TEST FOR HOLE P-4CA (UPPER MUDSTONE)



$$T = \frac{264}{S_w\Delta(1/Q)}$$

$$= \frac{264}{28.54(28.9)}$$

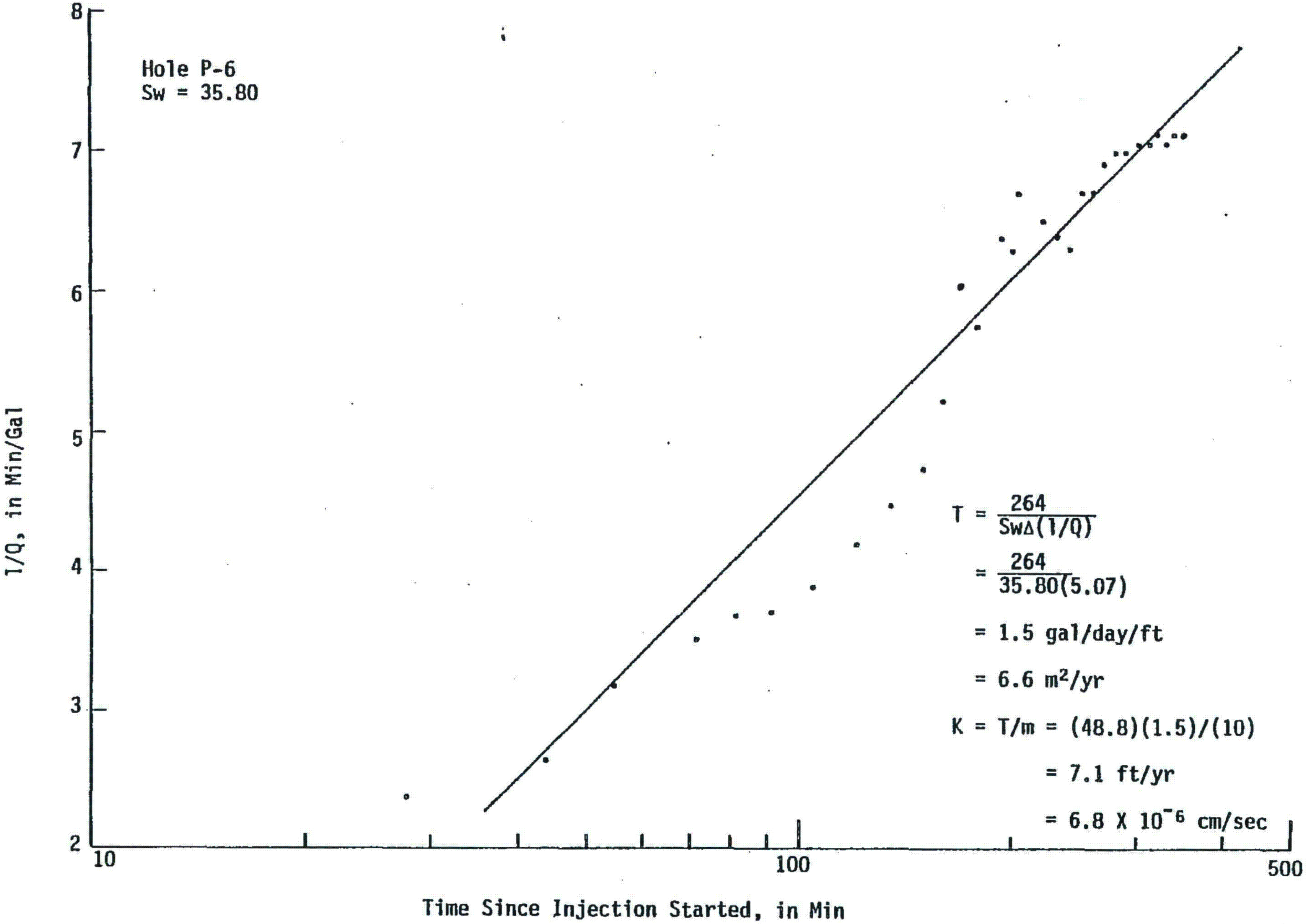
= 0.32 gal/day/ft

= 1.4 m^2/yr

K = T/m = (0.32)(48.8)/(2.5)

= 6.2 ft/yr

= 6.0 X 10^{-6} cm/sec



$$T = \frac{264}{Sw\Delta(1/Q)}$$

$$= \frac{264}{35.80(5.07)}$$

$$= 1.5 \text{ gal/day/ft}$$

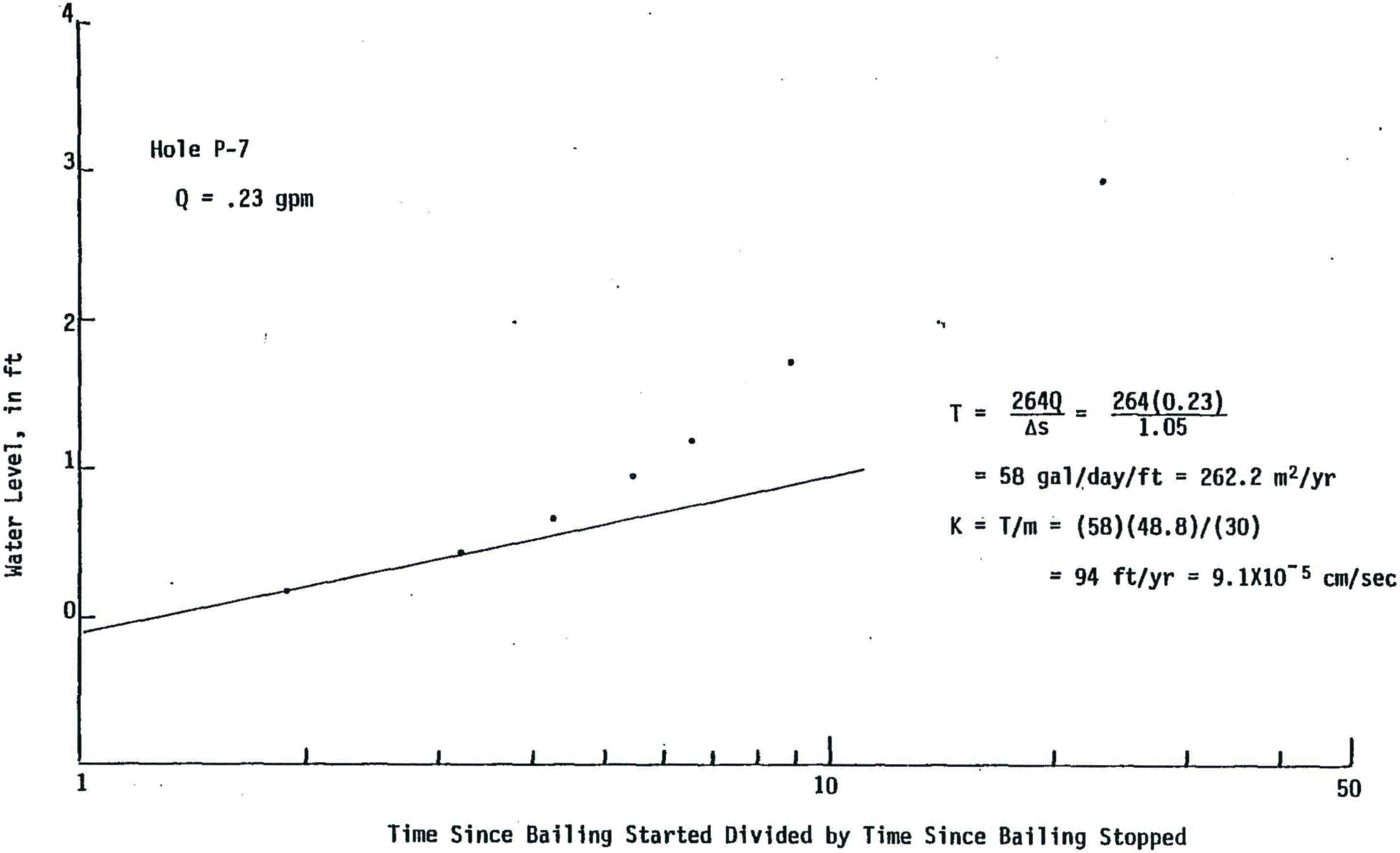
$$= 6.6 \text{ m}^2\text{/yr}$$

$$K = T/m = (48.8)(1.5)/(10)$$

$$= 7.1 \text{ ft/yr}$$

$$= 6.8 \times 10^{-6} \text{ cm/sec}$$

FIGURE A-1.9 CONSTANT HEAD TEST FOR HOLE P-6 (UPPER SANDSTONE)



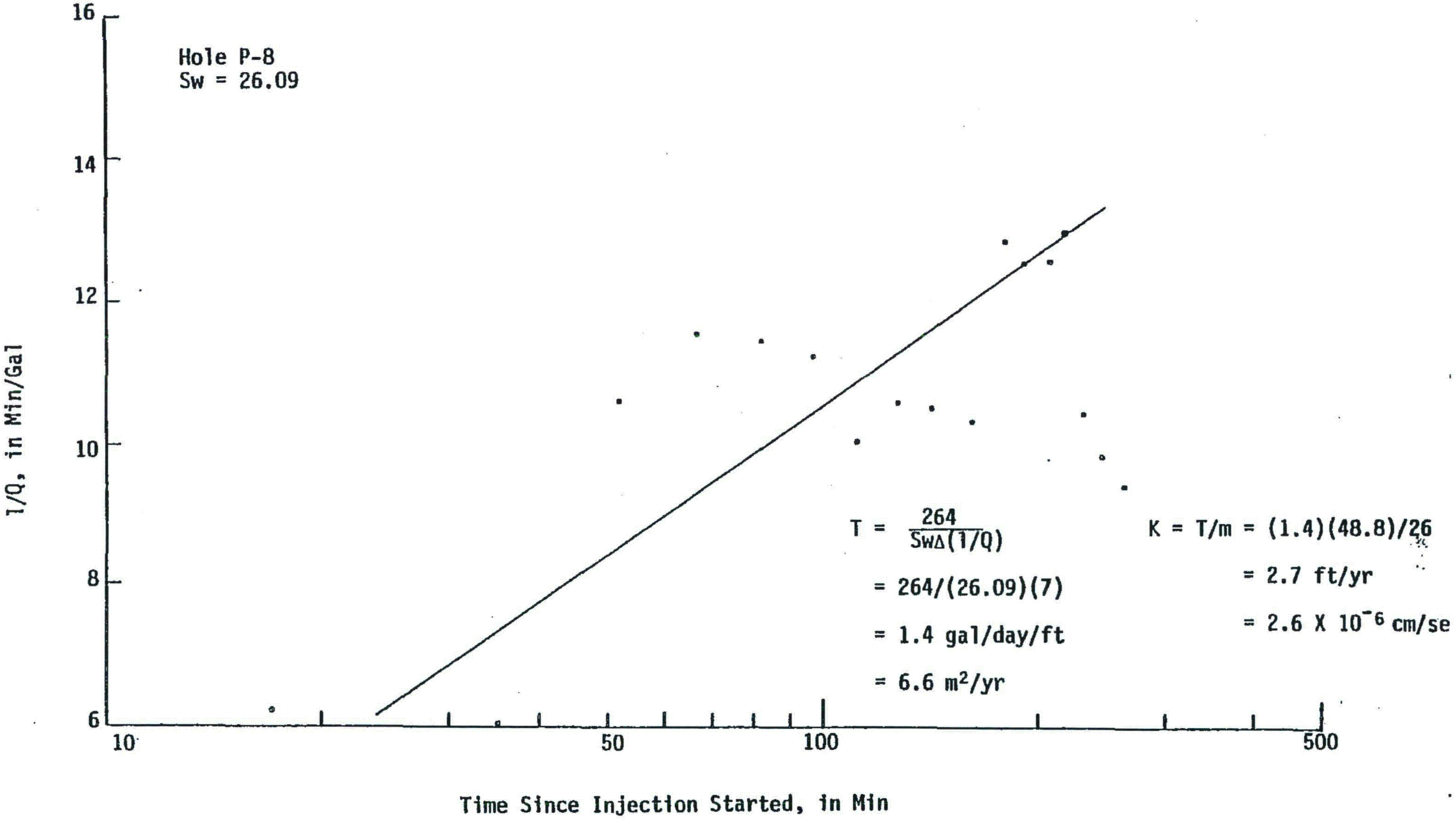
$$T = \frac{264Q}{\Delta s} = \frac{264(0.23)}{1.05}$$

$= 58$ gal/day/ft $= 262.2\ m^2/yr$

$K = T/m = (58)(48.8)/(30)$

$= 94$ ft/yr $= 9.1\times10^{-5}$ cm/sec

FIGURE A-1.10 . RECOVERY TEST FOR HOLE P-7 (70 SAND)



$T = \frac{264}{Sw\Delta(1/Q)}$

$= 264/(26.09)(7)$

$= 1.4$ gal/day/ft

$= 6.6\ m^2/yr$

$K = T/m = (1.4)(48.8)/26$

$= 2.7$ ft/yr

$= 2.6 \times 10^{-6}$ cm/se

FIGURE A-1.11 CONSTANT HEAD TEST FOR HOLE P-8 (LOWER MUDSTONE AND E COAL)

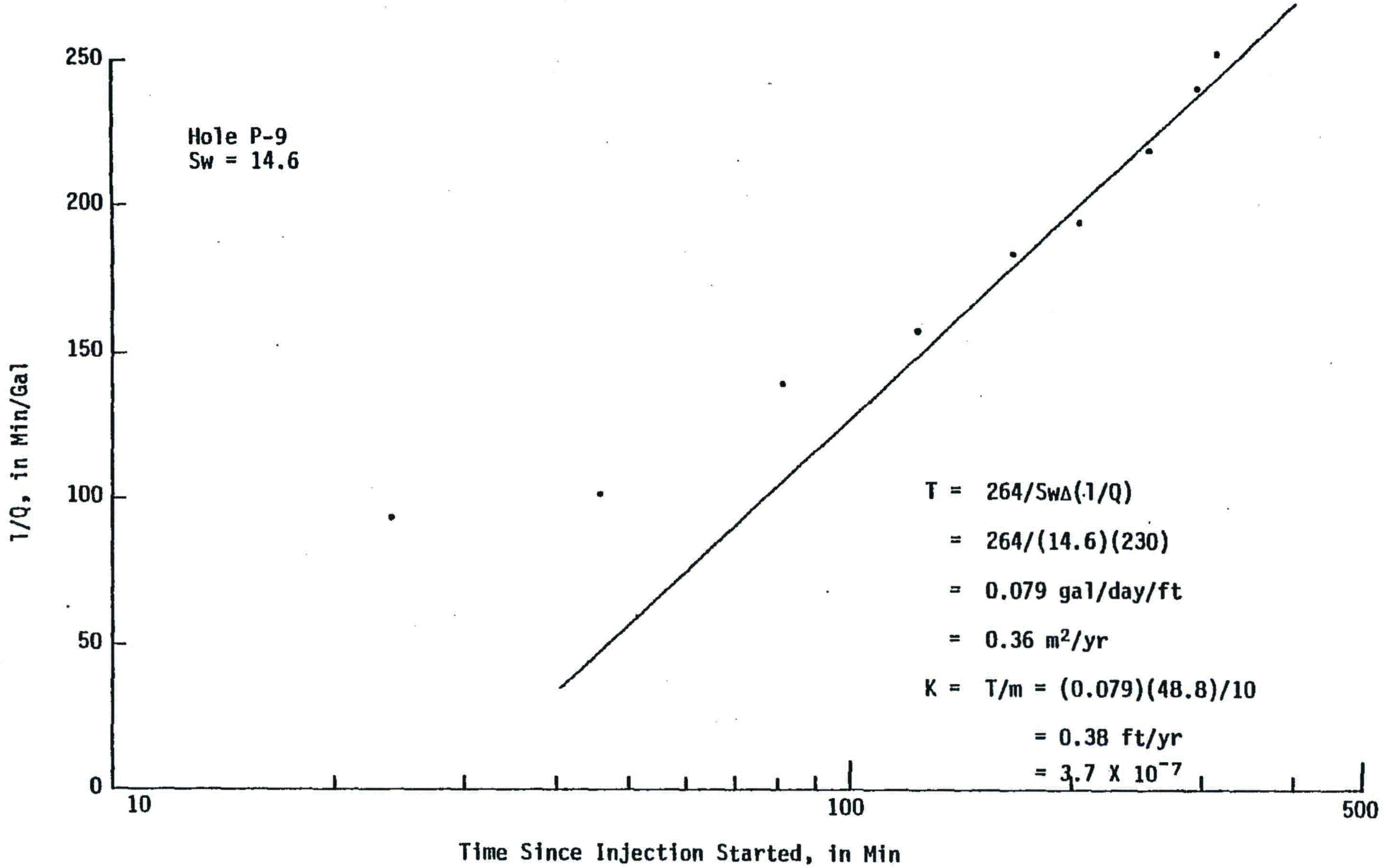
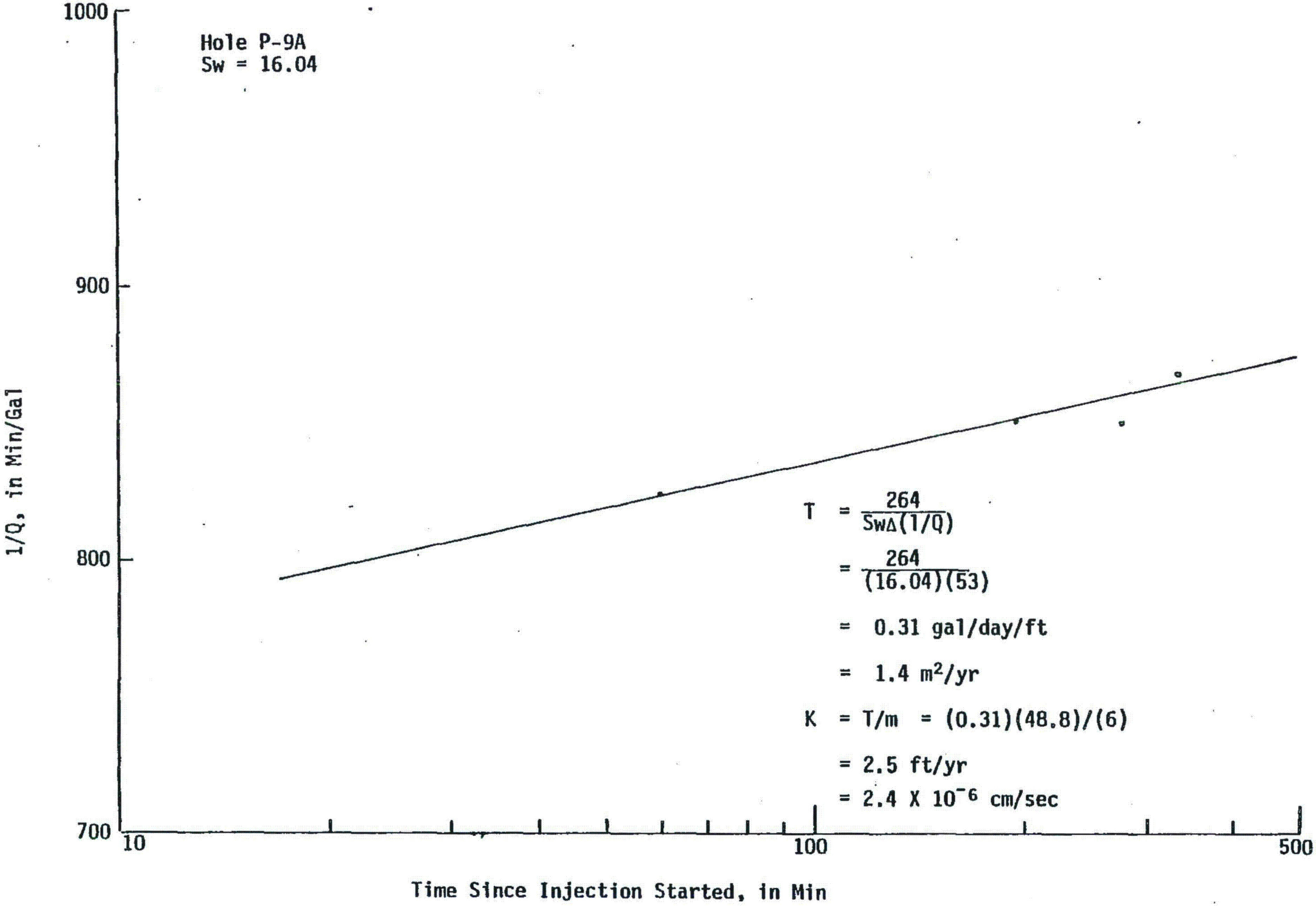


FIGURE A-1.12 CONSTANT HEAD TEST FOR HOLE P-9 (LOWER MUDSTONE AND E COAL)



Hole P-9A
Sw = 16.04

$$T = \frac{264}{Sw\Delta(1/Q)}$$

$$= \frac{264}{(16.04)(53)}$$

= 0.31 gal/day/ft

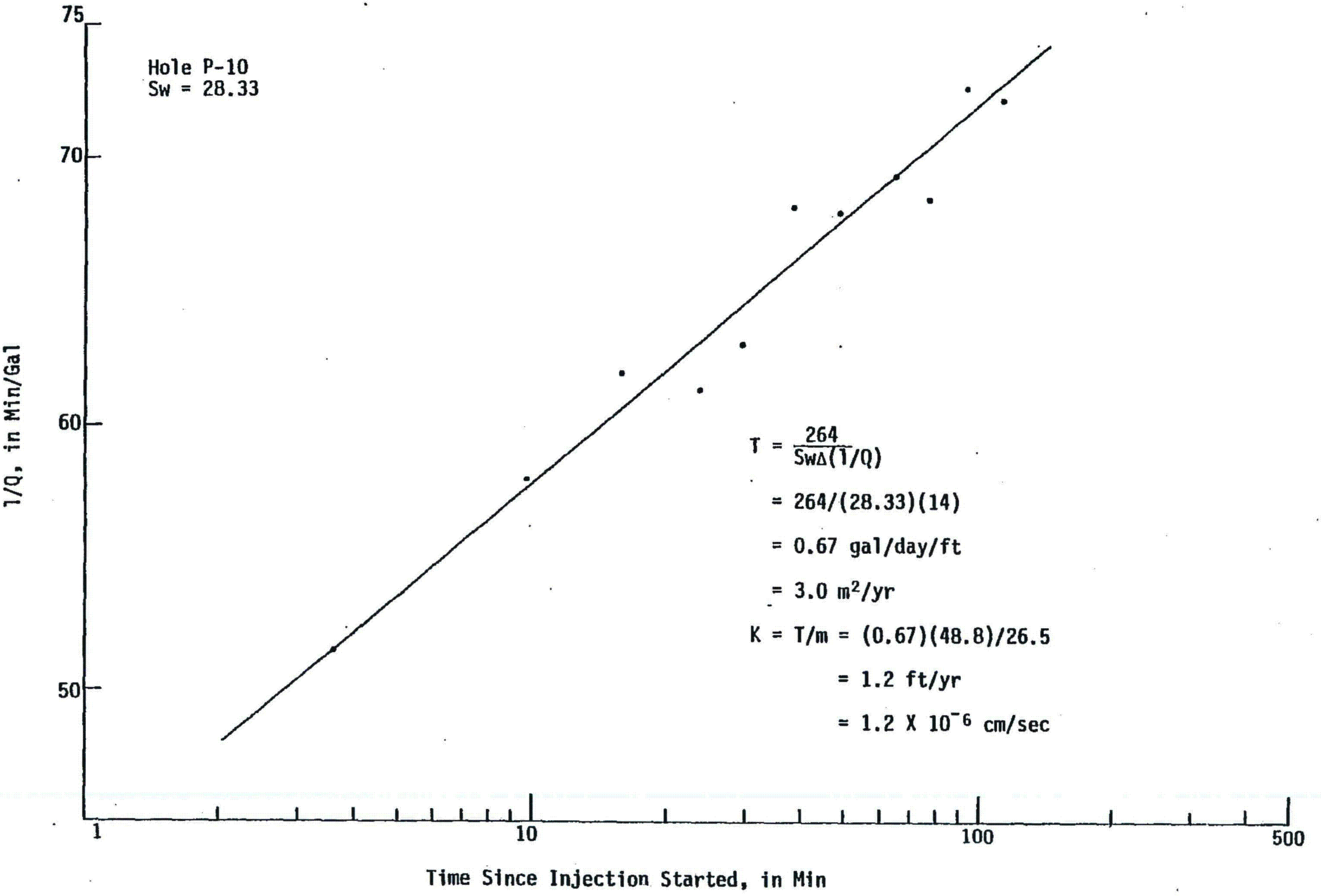
= 1.4 m^2/yr

$K = T/m = (0.31)(48.8)/(6)$

= 2.5 ft/yr

= 2.4 X 10^{-6} cm/sec

FIGURE A-1.13 CONSTANT HEAD TEST FOR HOLE P-9A (UPPER MUDSTONE)



$$T = \frac{264}{Sw\Delta(1/Q)}$$

$= 264/(28.33)(14)$

$= 0.67$ gal/day/ft

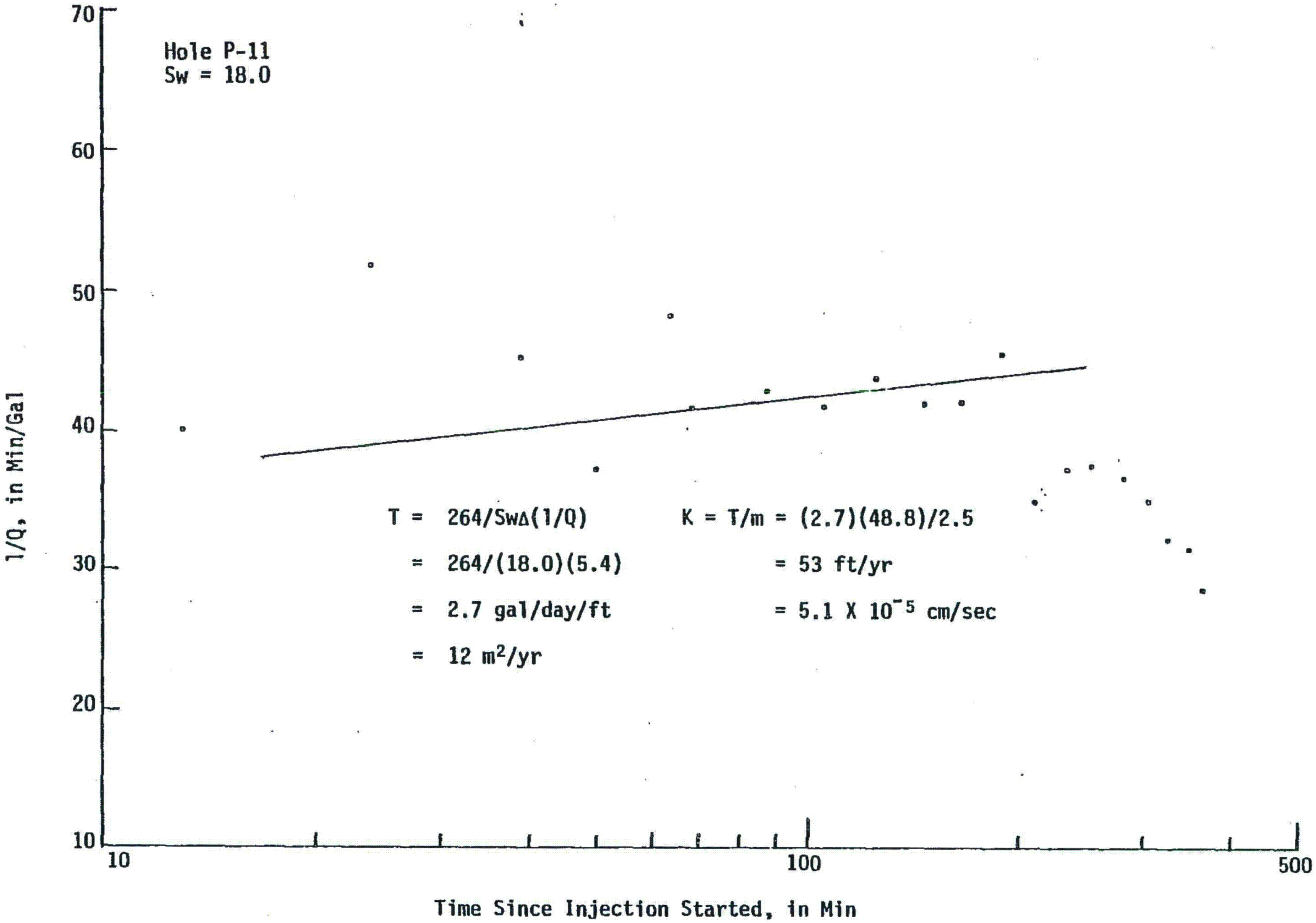
$= 3.0\ m^2/yr$

$K = T/m = (0.67)(48.8)/26.5$

$= 1.2$ ft/yr

$= 1.2 \times 10^{-6}$ cm/sec

FIGURE A-1.14 CONSTANT HEAD TEST FOR HOLE P-10 (LOWER MUDSTONE AND E COAL)



$$\begin{aligned} T &= 264/S_w\Delta(1/Q) \\ &= 264/(18.0)(5.4) \\ &= 2.7 \text{ gal/day/ft} \\ &= 12 \text{ m}^2\text{/yr} \end{aligned}$$

$$\begin{aligned} K = T/m &= (2.7)(48.8)/2.5 \\ &= 53 \text{ ft/yr} \\ &= 5.1 \times 10^{-5} \text{ cm/sec} \end{aligned}$$

FIGURE A-1.15 CONSTANT HEAD TEST FOR HOLE P-11 (E COAL)

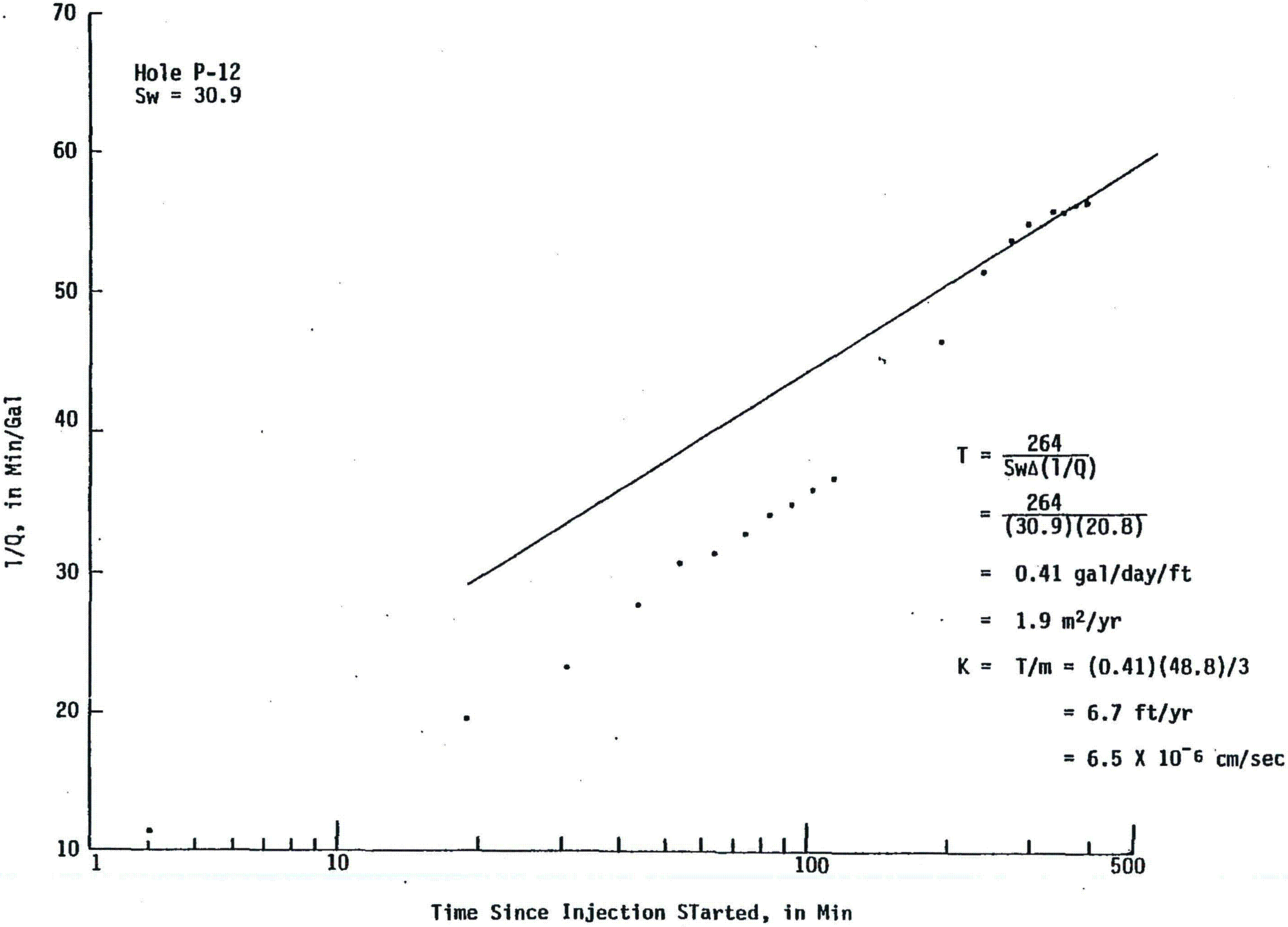
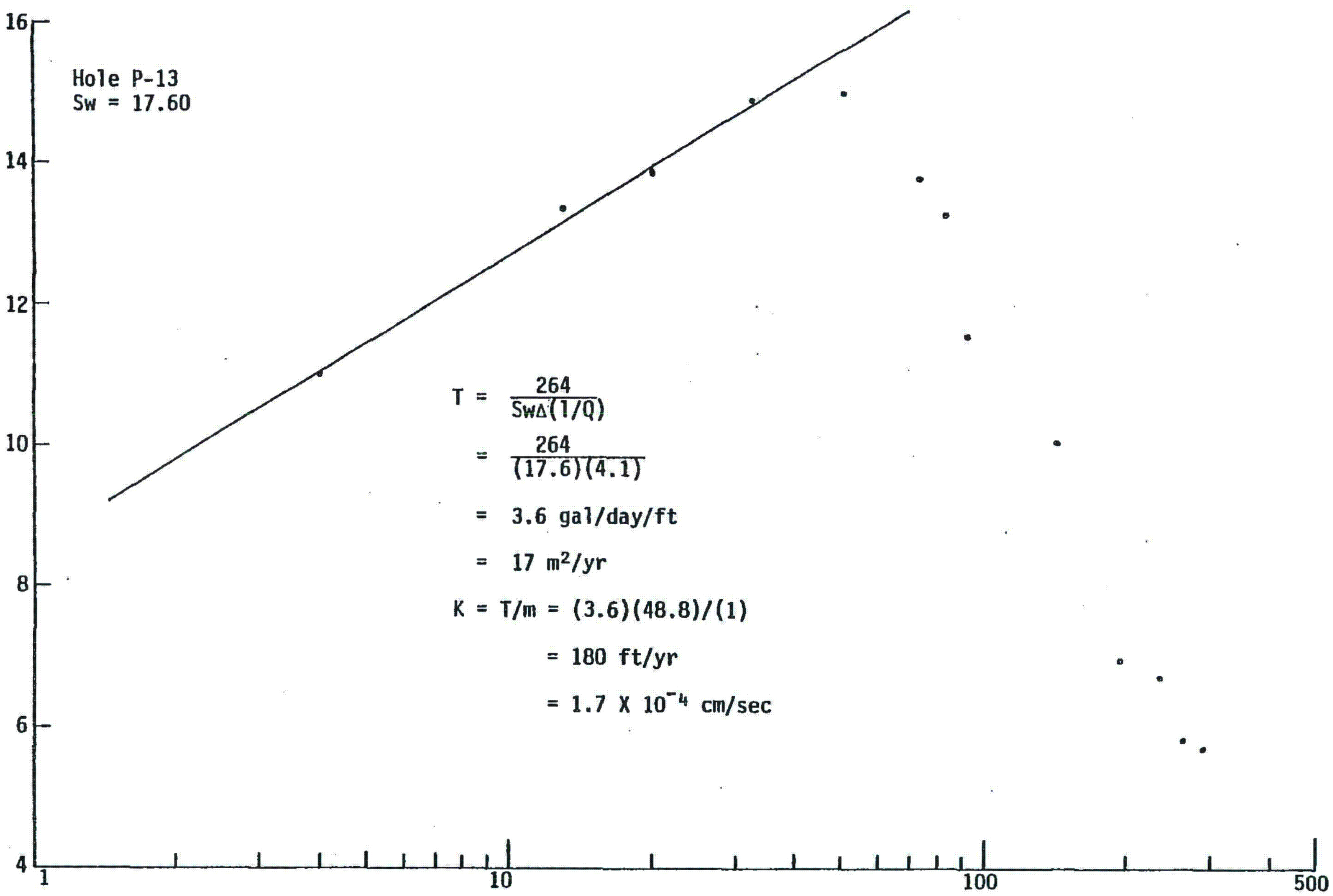


FIGURE A-1.16 CONSTANT HEAD TEST FOR HOLE P-12 (E COAL)



$$T = \frac{264}{Sw\Delta(1/Q)}$$

$$= \frac{264}{(17.6)(4.1)}$$

$$= 3.6 \text{ gal/day/ft}$$

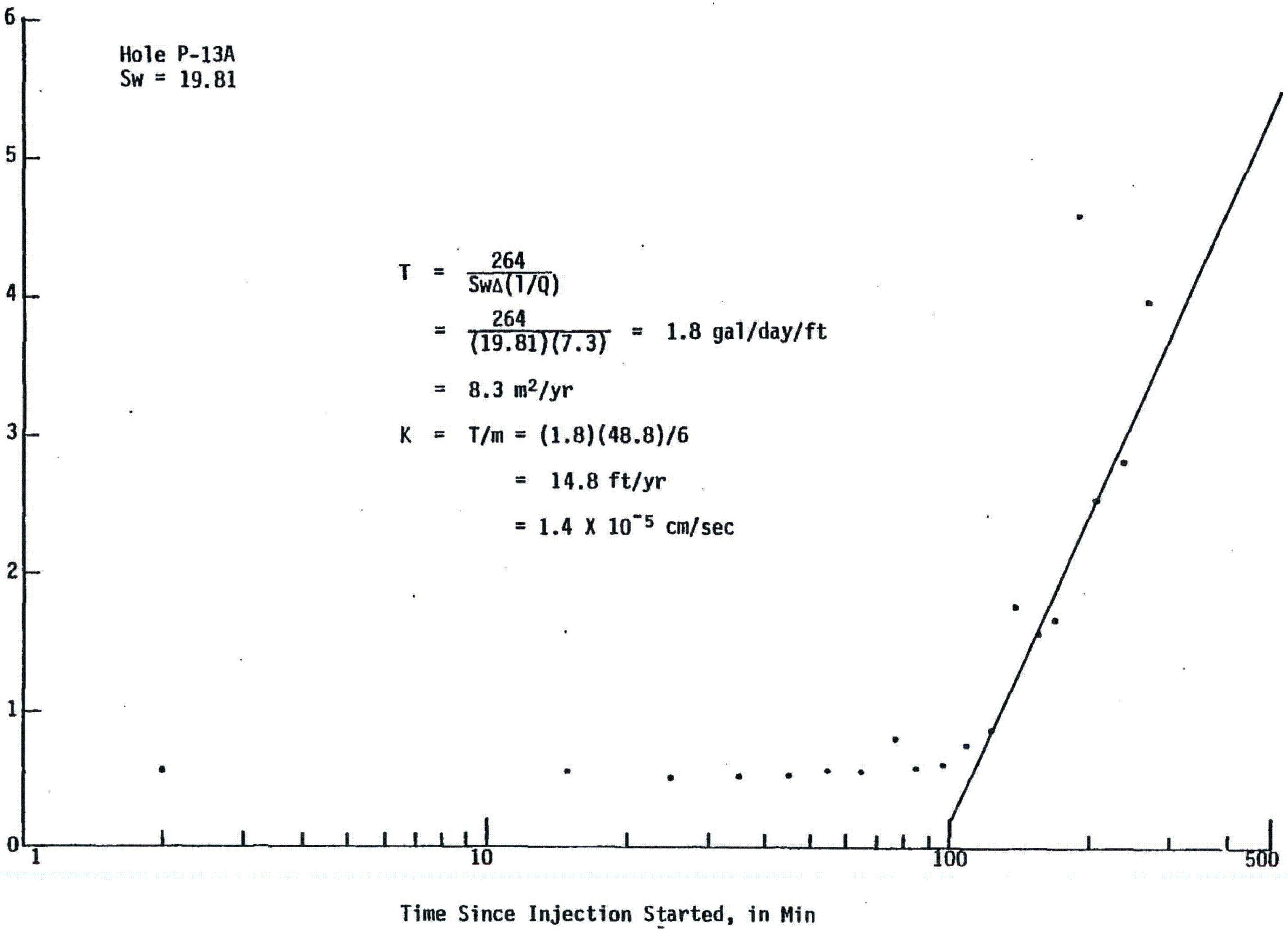
$$= 17 \text{ m}^2\text{/yr}$$

$$K = T/m = (3.6)(48.8)/(1)$$

$$= 180 \text{ ft/yr}$$

$$= 1.7 \times 10^{-4} \text{ cm/sec}$$

FIGURE A-1.17 CONSTANT HEAD TEST FOR HOLE P-13 (UPPER MUDSTONE)



$$T = \frac{264}{Sw\Delta(1/Q)}$$

$$= \frac{264}{(19.81)(7.3)} = 1.8 \text{ gal/day/ft}$$

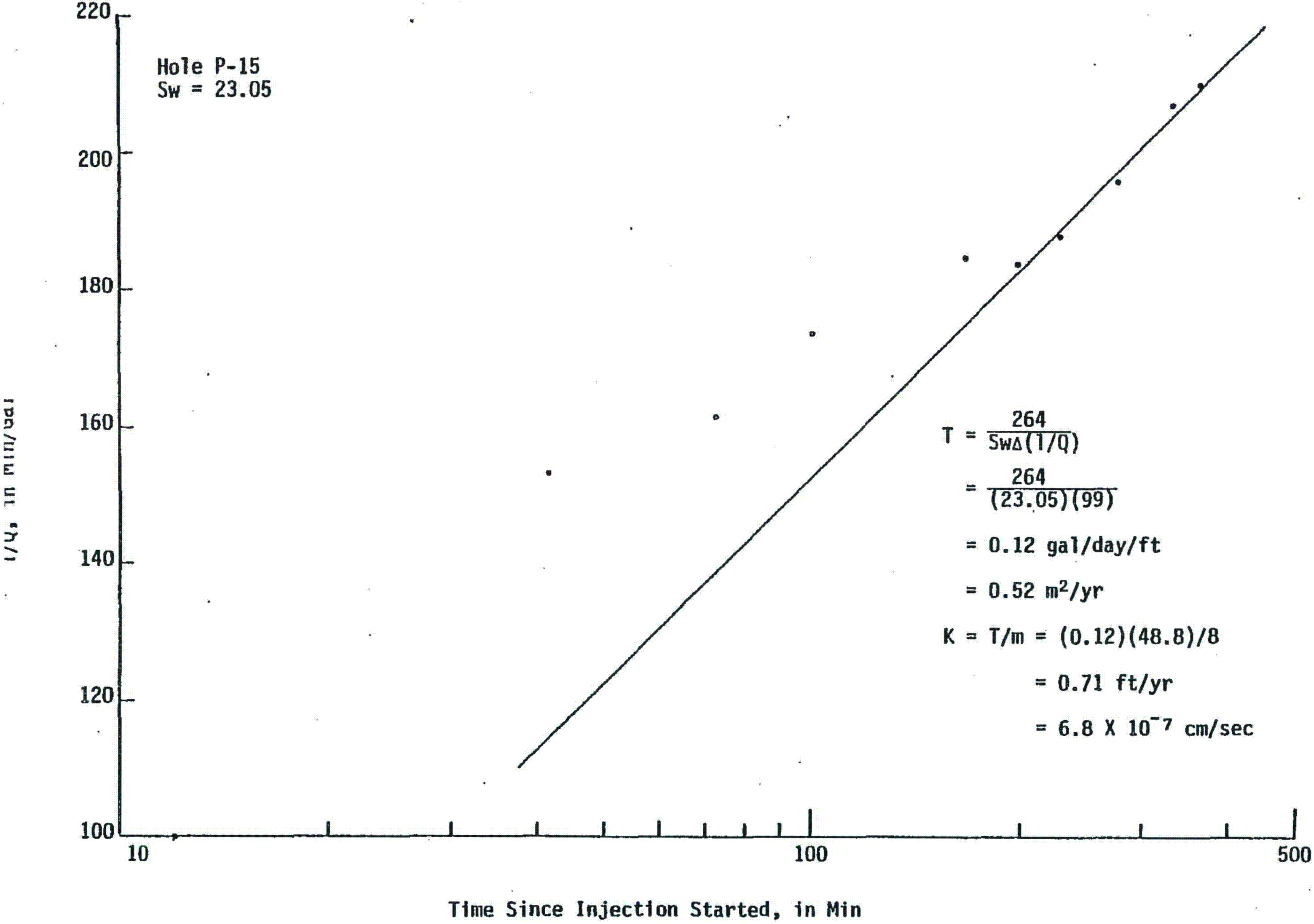
$$= 8.3 \text{ m}^2\text{/yr}$$

$$K = T/m = (1.8)(48.8)/6$$

$$= 14.8 \text{ ft/yr}$$

$$= 1.4 \times 10^{-5} \text{ cm/sec}$$

FIGURE A-1.18 CONSTANT HEAD TEST FOR HOLE P-13A (E COAL)



$$T = \frac{264}{Sw\Delta(1/Q)}$$

$$= \frac{264}{(23.05)(99)}$$

$$= 0.12 \text{ gal/day/ft}$$

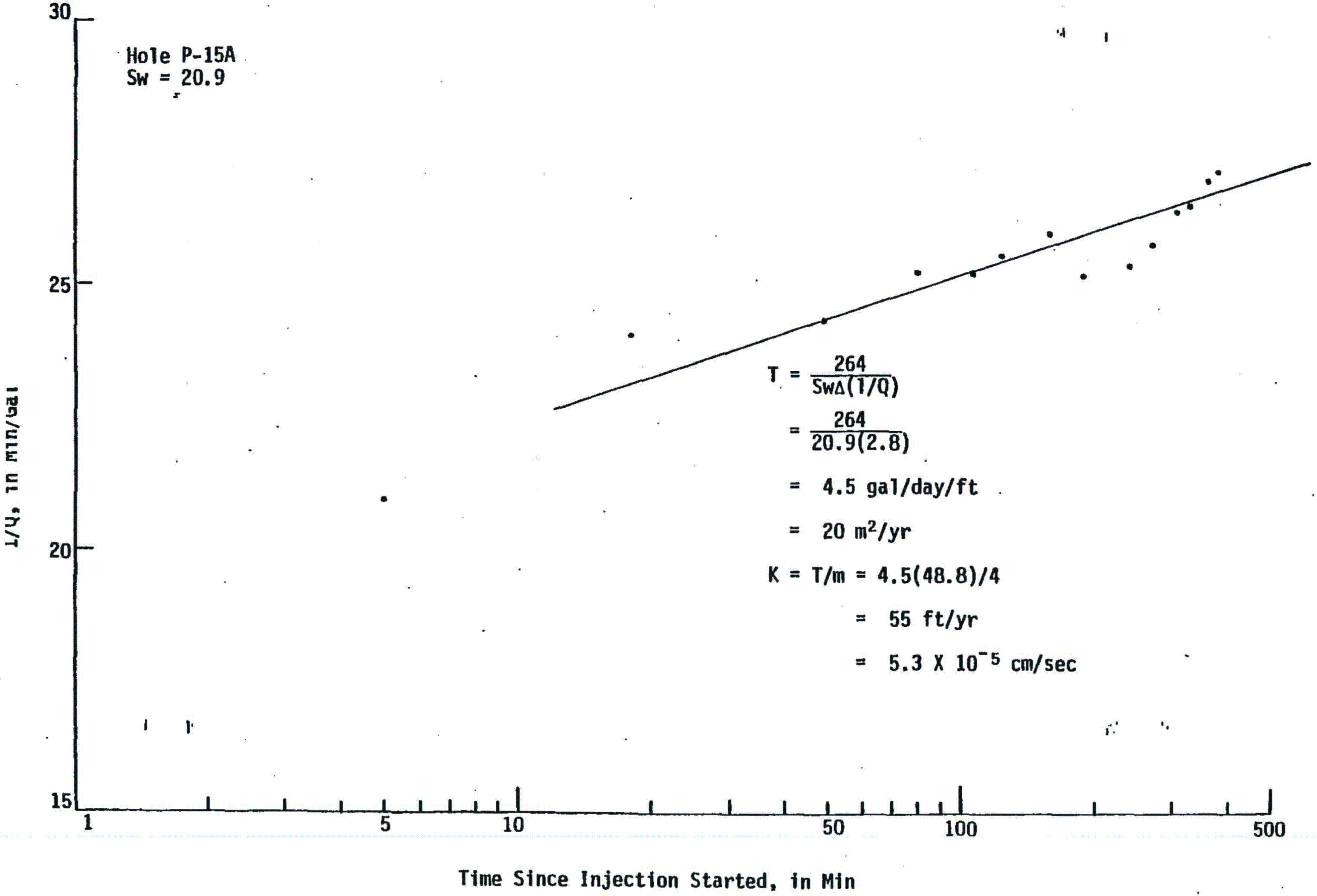
$$= 0.52 \text{ m}^2\text{/yr}$$

$$K = T/m = (0.12)(48.8)/8$$

$$= 0.71 \text{ ft/yr}$$

$$= 6.8 \times 10^{-7} \text{ cm/sec}$$

FIGURE A-1.19 CONSTANT HEAD TEST FOR HOLE P-15 (LOWER MUDSTONE AND E COAL)



$$T = \frac{264}{S_w \Delta(1/Q)}$$

$$= \frac{264}{20.9(2.8)}$$

= 4.5 gal/day/ft

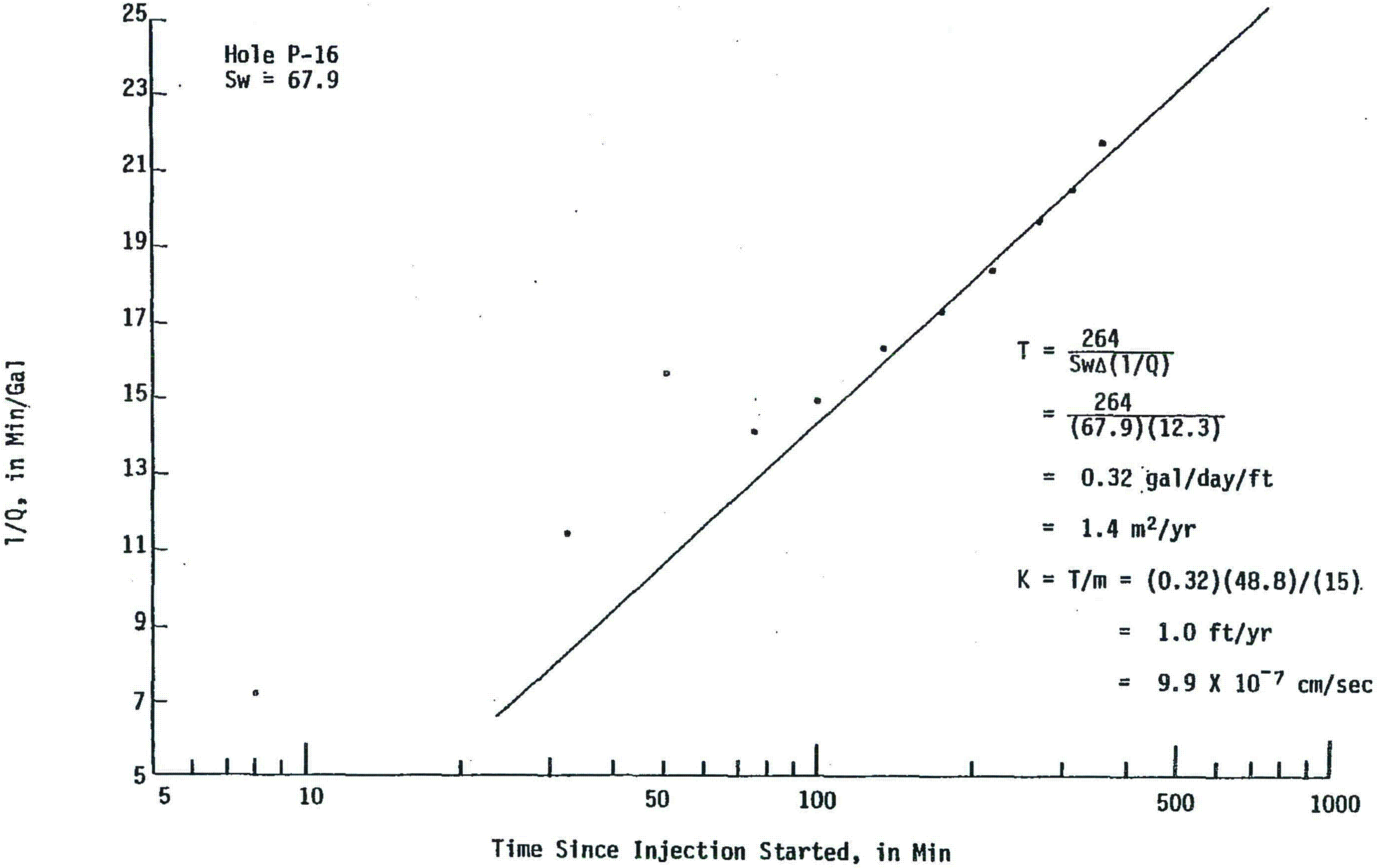
= 20 m^2/yr

K = T/m = 4.5(48.8)/4

= 55 ft/yr

= 5.3×10^{-5} cm/sec

FIGURE A-1.20 CONSTANT HEAD TEST FOR HOLE P-15A (UPPER MUDSTONE)



$$T = \frac{264}{S_w\Delta(1/Q)}$$

$$= \frac{264}{(67.9)(12.3)}$$

$$= 0.32 \text{ gal/day/ft}$$

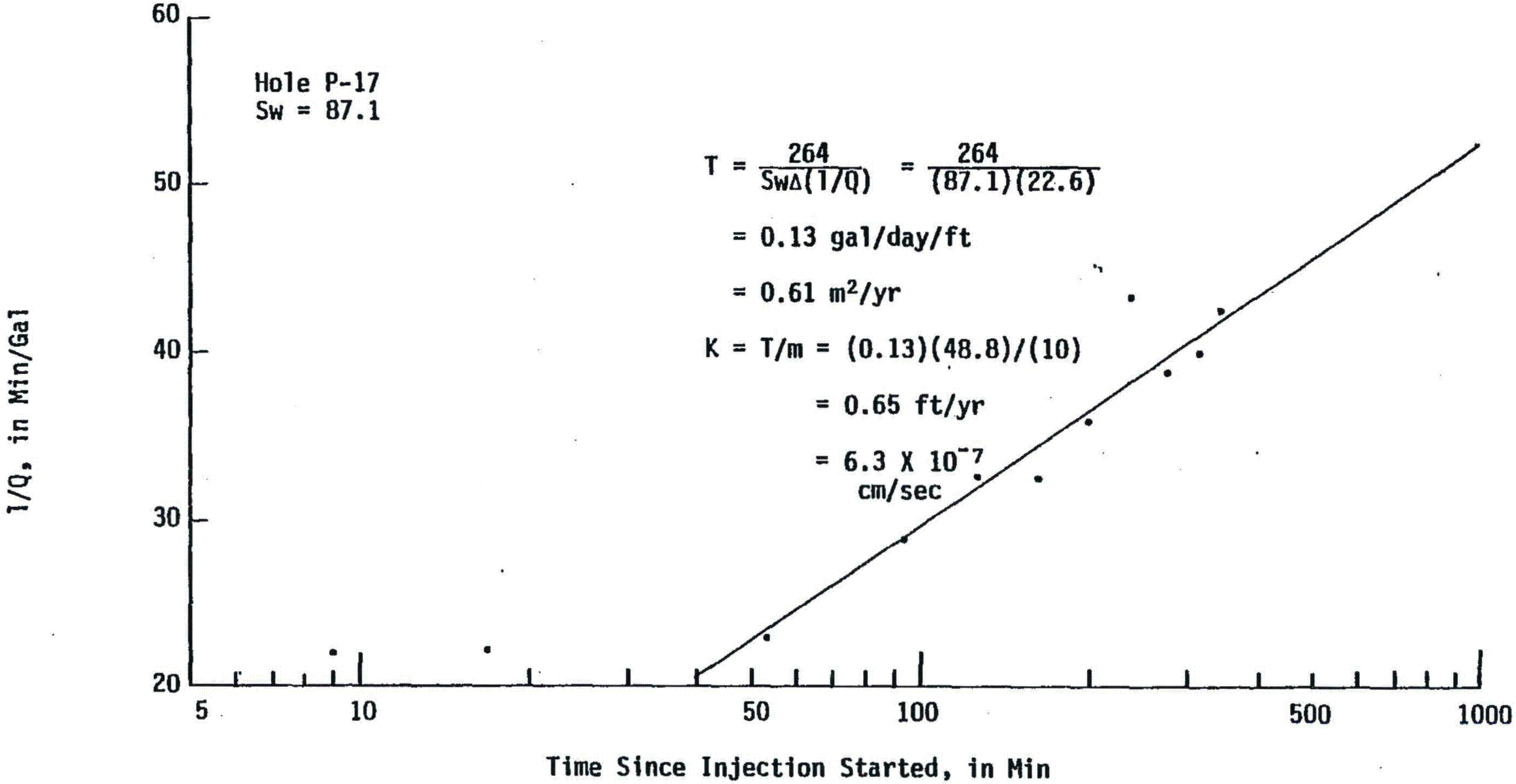
$$= 1.4 \text{ m}^2\text{/yr}$$

$$K = T/m = (0.32)(48.8)/(15)$$

$$= 1.0 \text{ ft/yr}$$

$$= 9.9 \times 10^{-7} \text{ cm/sec}$$

FIGURE A-1.21 CONSTANT HEAD TEST FOR HOLE P-16 (UPPER 70 SAND)



Hole P-17
Sw = 87.1

$$T = \frac{264}{Sw\Delta(1/Q)} = \frac{264}{(87.1)(22.6)}$$

= 0.13 gal/day/ft

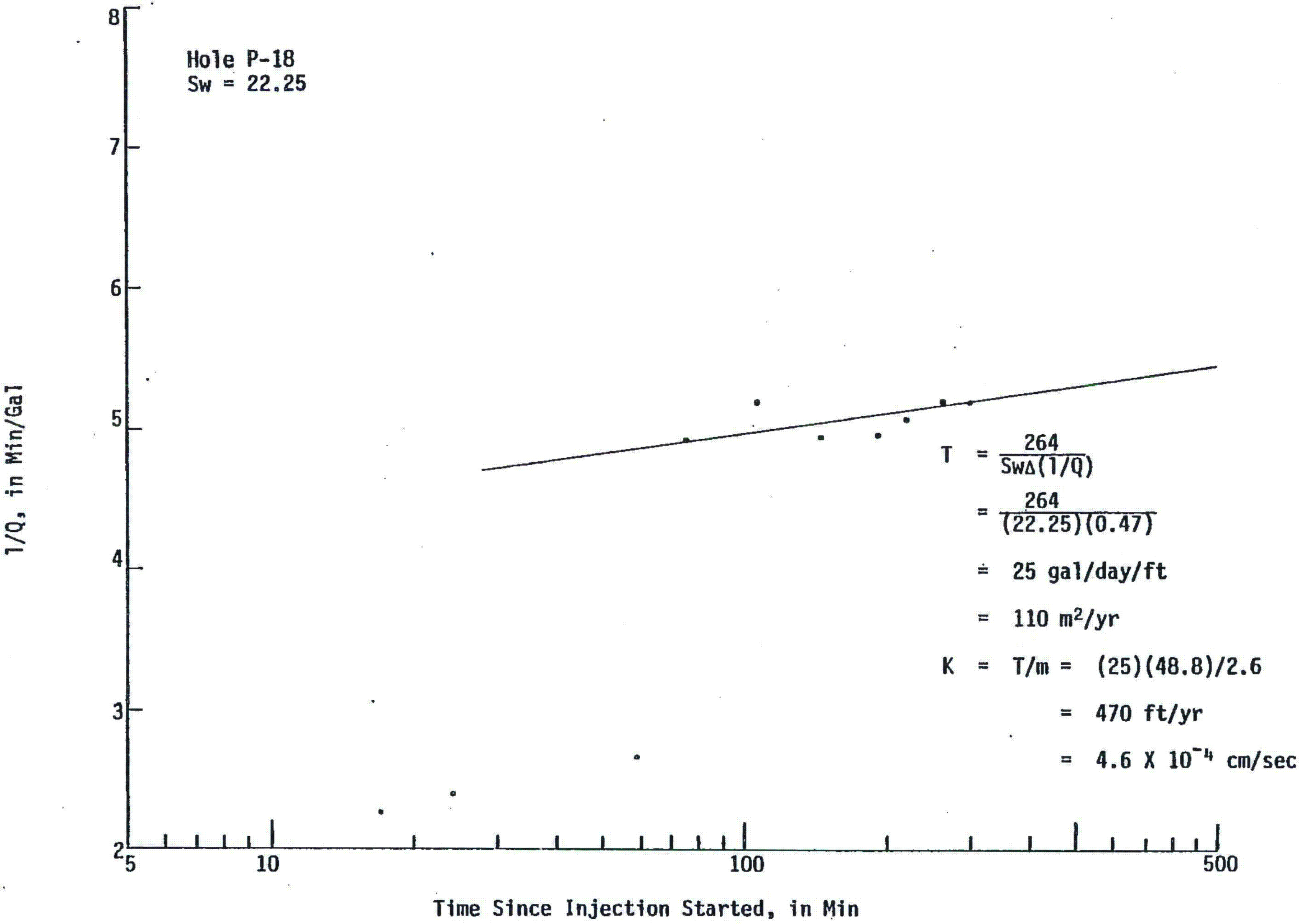
= 0.61 m^2/yr

K = T/m = (0.13)(48.8)/(10)

= 0.65 ft/yr

= 6.3 X 10^{-7} cm/sec

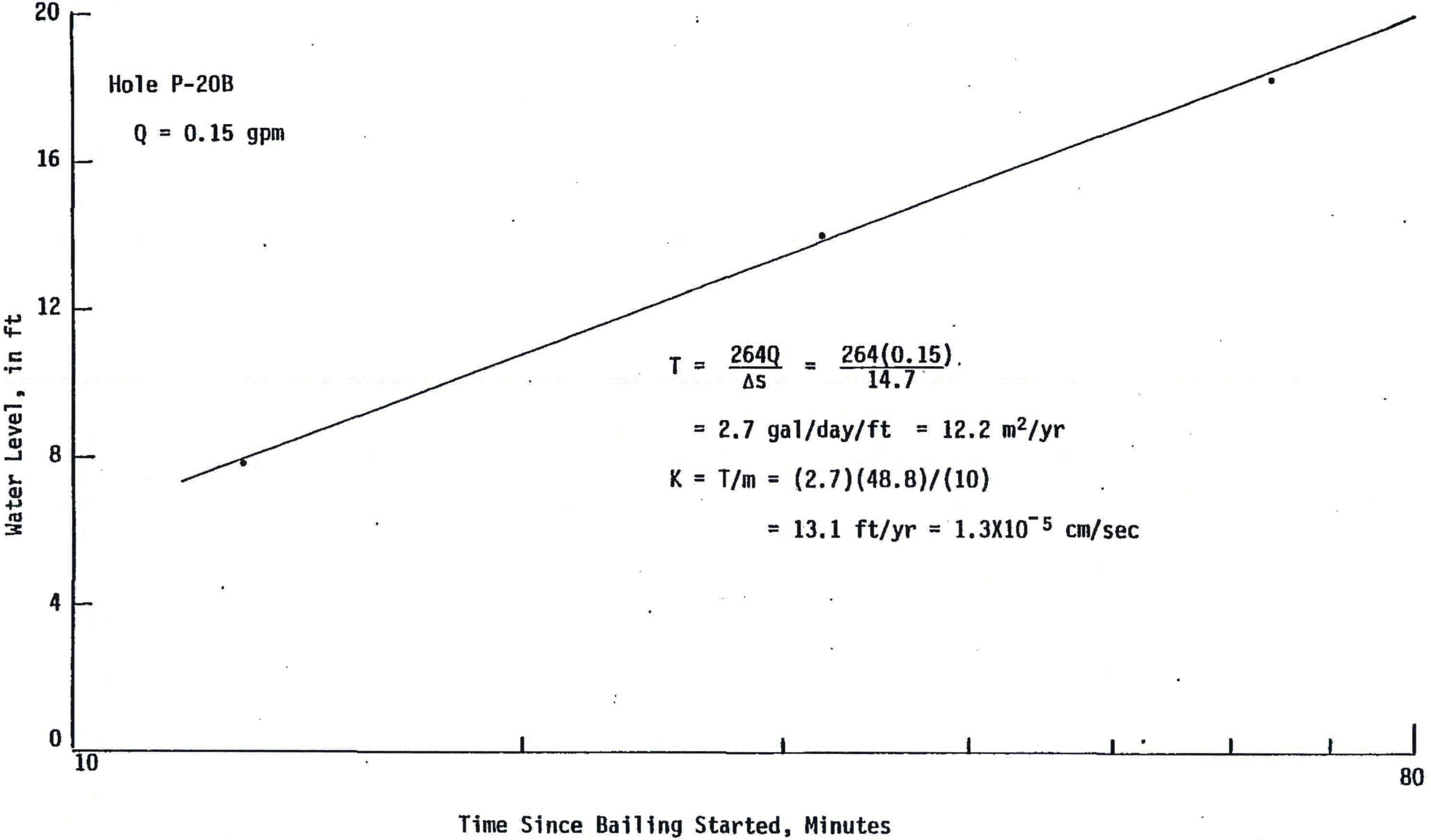
FIGURE A-1.22 CONSTANT HEAD TEST FOR HOLE P-17 (UPPER 70 SAND)



$$T = \frac{264}{S_w \Delta(1/Q)} = \frac{264}{(22.25)(0.47)} \doteq 25 \text{ gal/day/ft} = 110 \text{ m}^2\text{/yr}$$

$$K = T/m = (25)(48.8)/2.6 = 470 \text{ ft/yr} = 4.6 \times 10^{-4} \text{ cm/sec}$$

FIGURE A-1.23 CONSTANT HEAD TEST FOR HOLE P-18 (ALLUVIUM)



Hole P-20B

$Q = 0.15$ gpm

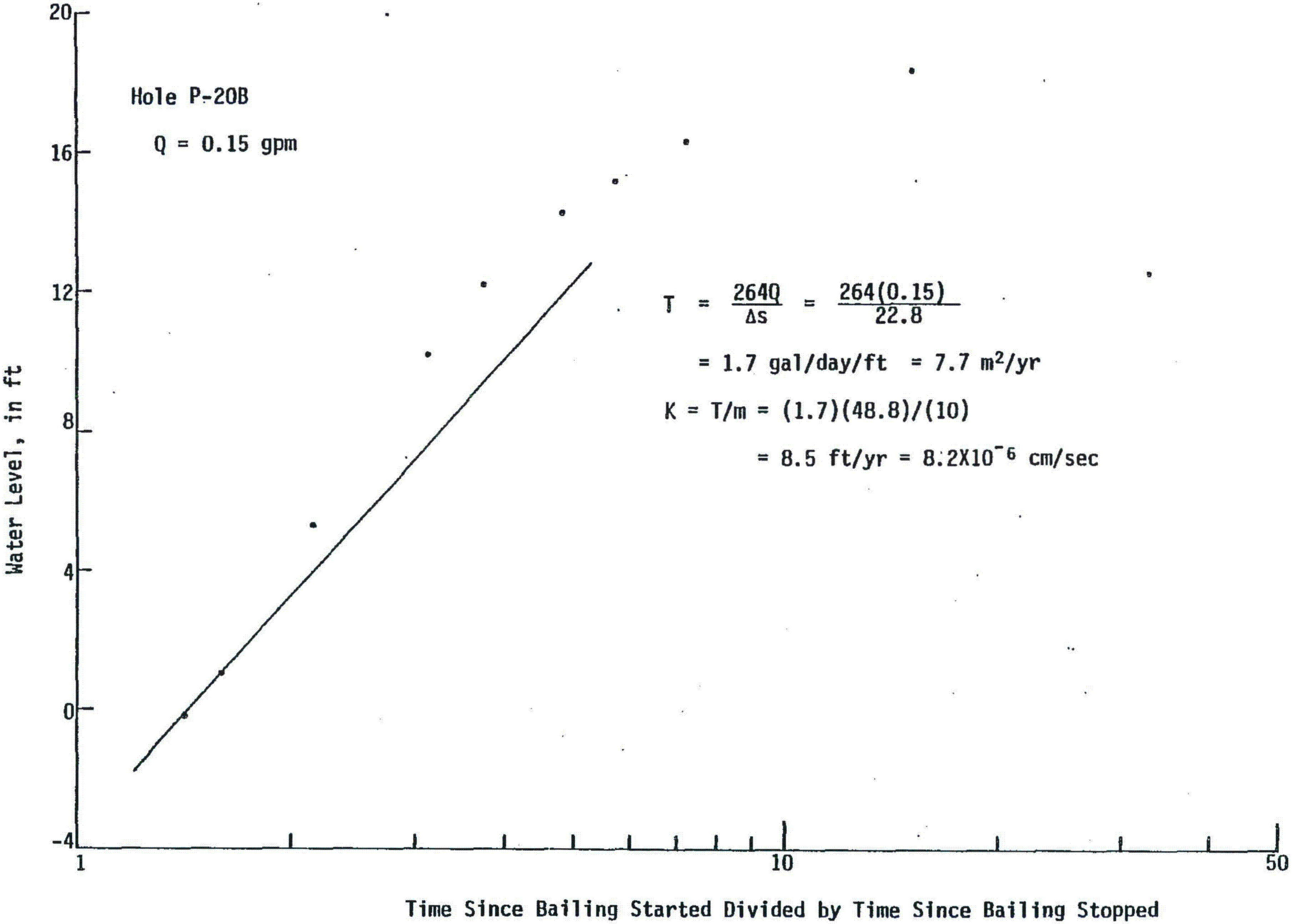
$$T = \frac{264Q}{\Delta s} = \frac{264(0.15)}{14.7}$$

$$= 2.7 \text{ gal/day/ft} = 12.2 \text{ m}^2\text{/yr}$$

$$K = T/m = (2.7)(48.8)/(10)$$

$$= 13.1 \text{ ft/yr} = 1.3\text{X}10^{-5} \text{ cm/sec}$$

FIGURE A-1.23A. DRAWDOWN TEST FOR HOLE P-20B



Hole P-20B

Q = 0.15 gpm

$$T = \frac{264Q}{\Delta s} = \frac{264(0.15)}{22.8}$$

$= 1.7$ gal/day/ft $= 7.7$ m^2/yr

$K = T/m = (1.7)(48.8)/(10)$

$= 8.5$ ft/yr $= 8.2X10^{-6}$ cm/sec

FIGURE A-1.23B. RECOVERY TEST FOR HOLE P-20B (70 SAND)

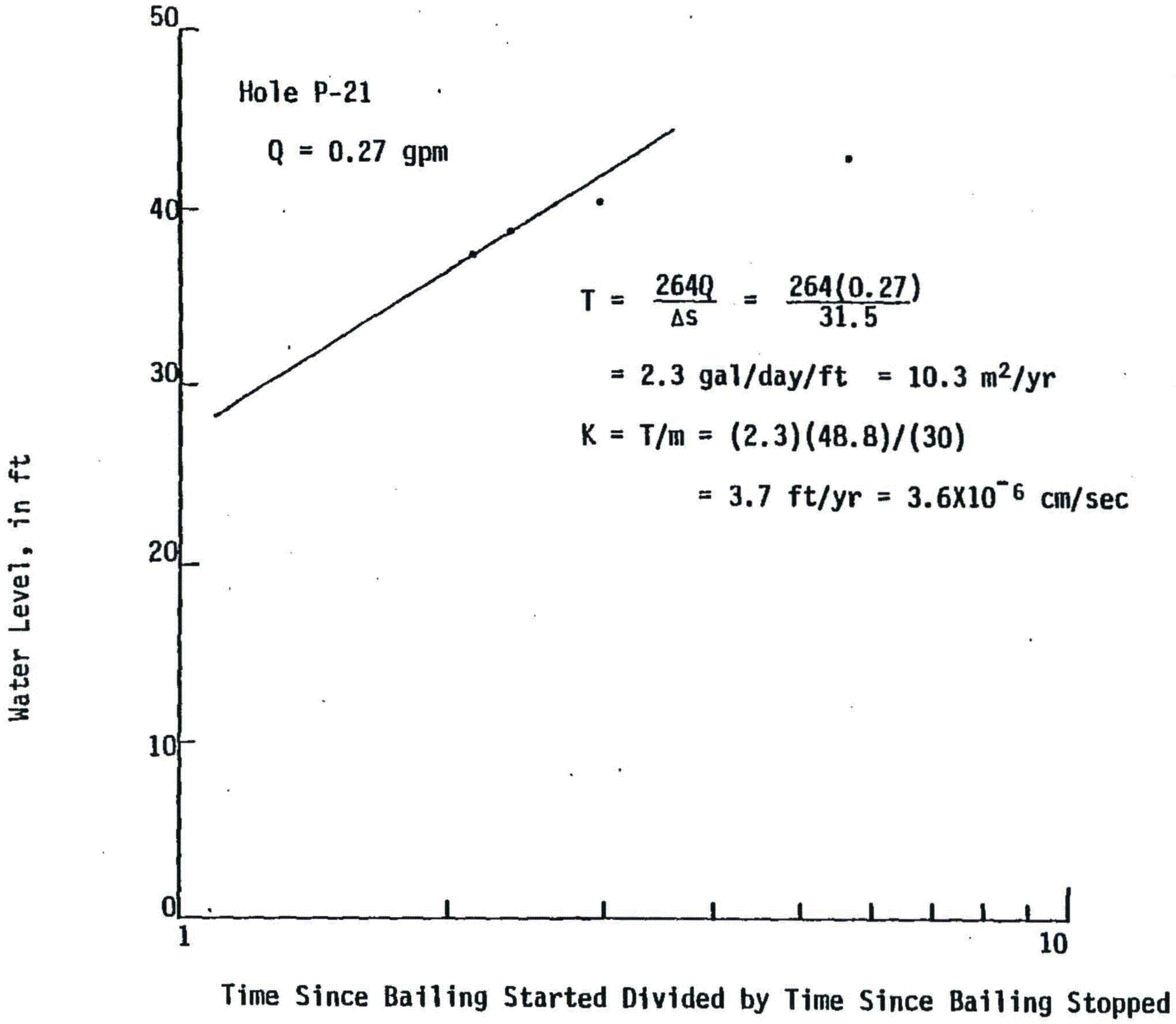
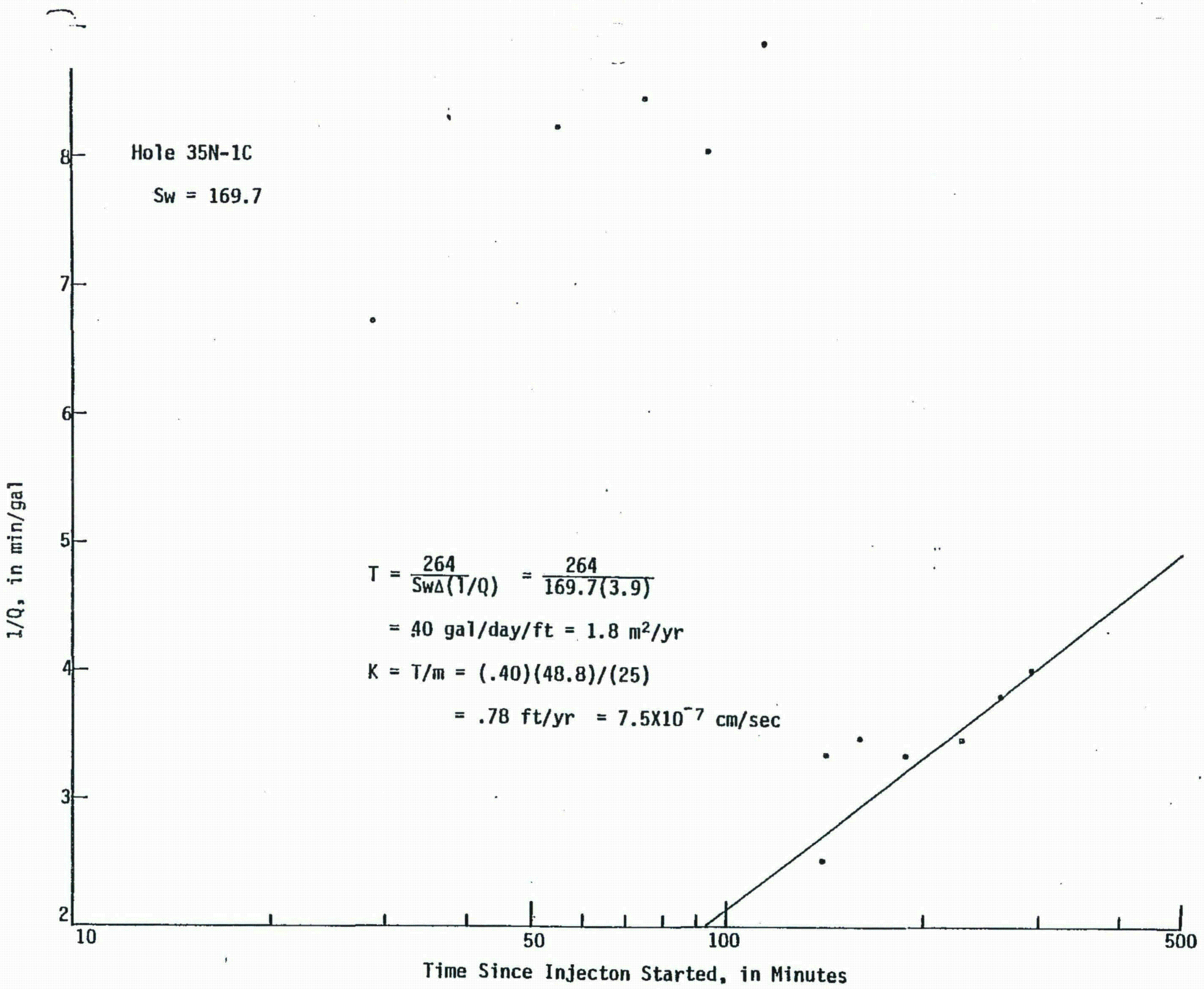


FIGURE A-1.23C. RECOVERY TEST FOR HOLE P-21 (70 SAND)



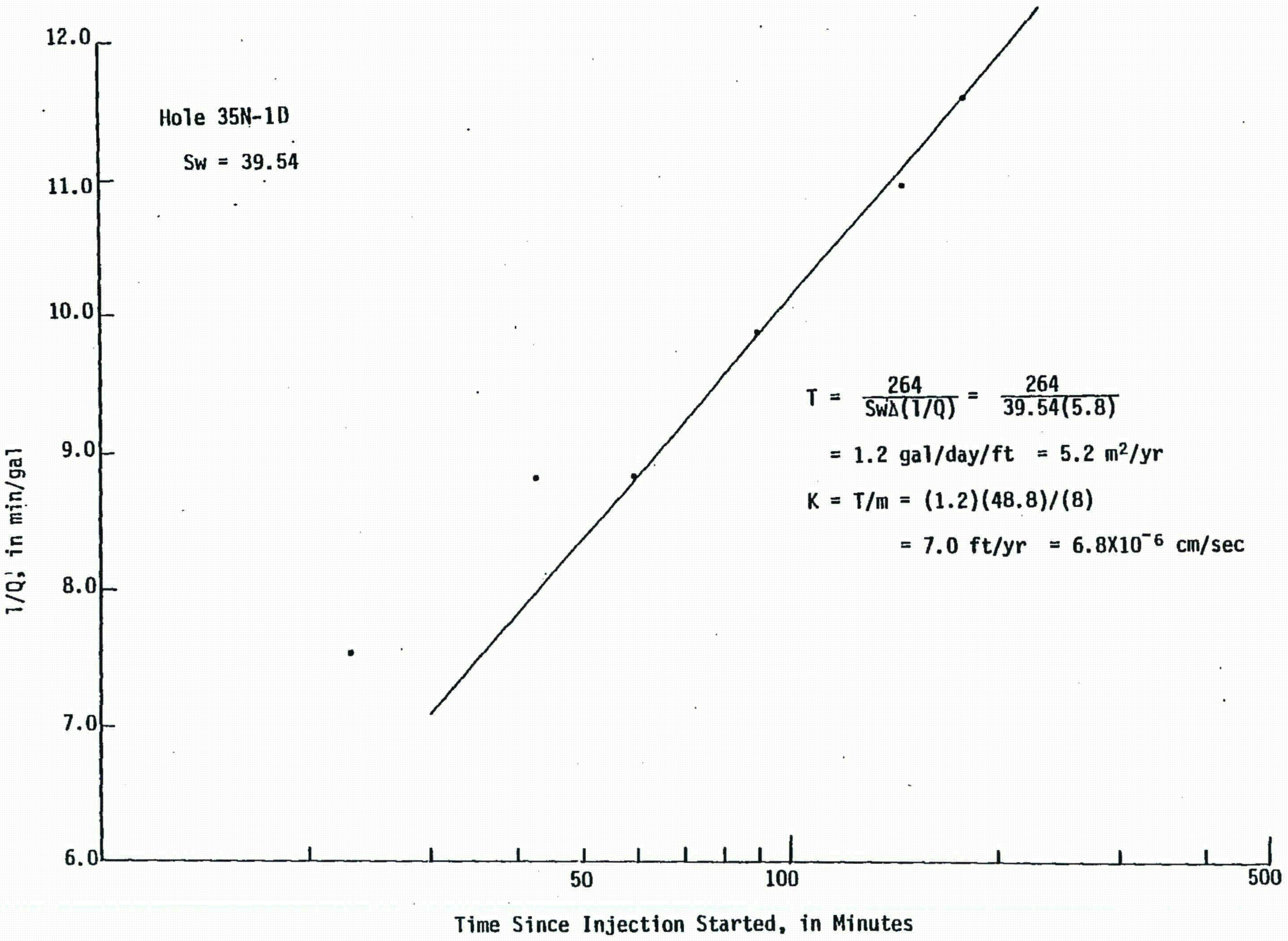
$$T = \frac{264}{Sw\Delta(1/Q)} = \frac{264}{169.7(3.9)}$$

$$= 40 \text{ gal/day/ft} = 1.8 \text{ m}^2\text{/yr}$$

$$K = T/m = (.40)(48.8)/(25)$$

$$= .78 \text{ ft/yr} = 7.5\text{X}10^{-7} \text{ cm/sec}$$

FIGURE A-1.24. CONSTANT HEAD TEST FOR HOLE 35N-1C (UPPER 70 SANDSTONE)



Hole 35N-1D

Sw = 39.54

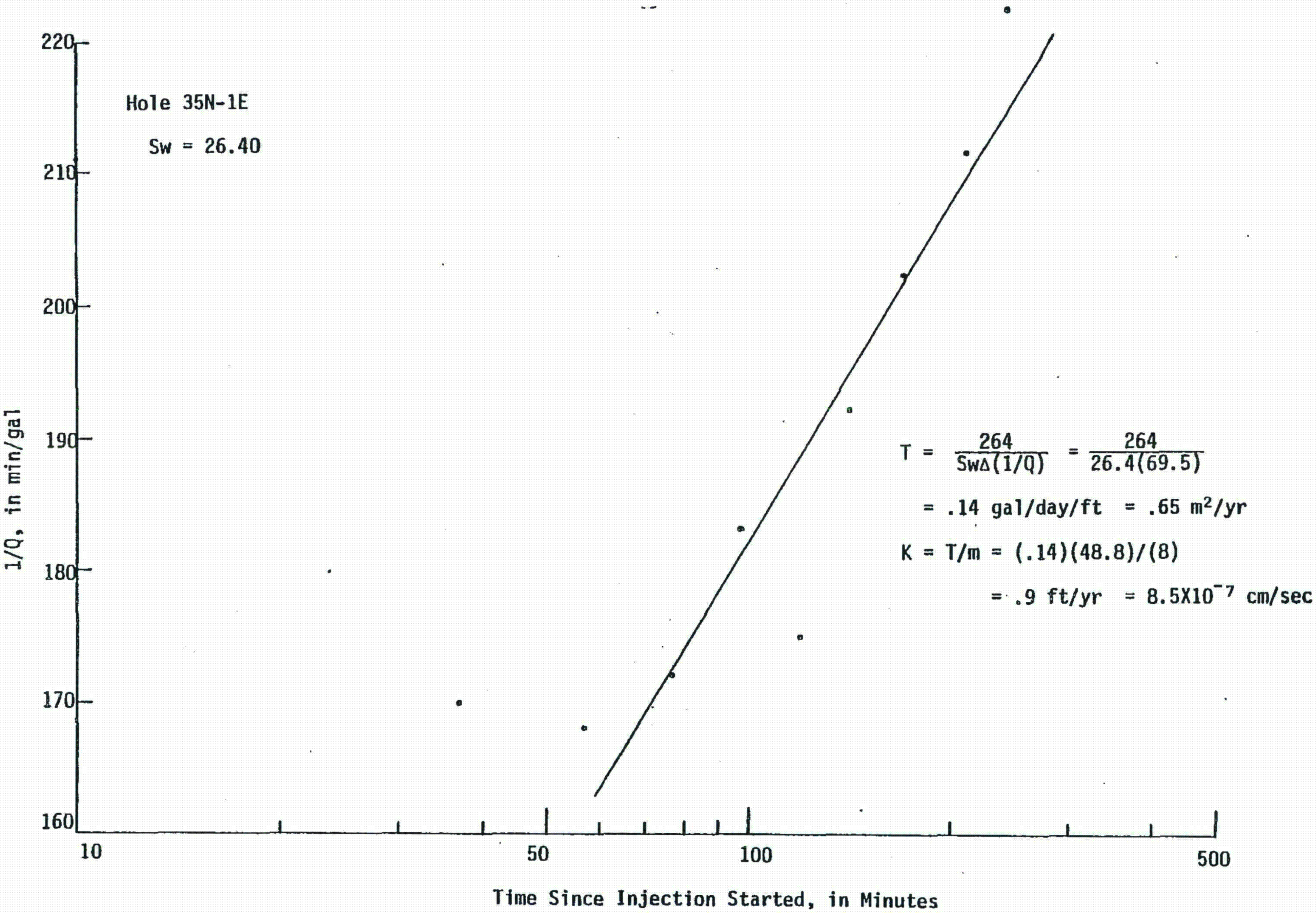
$$T = \frac{264}{Sw\Delta(1/Q)} = \frac{264}{39.54(5.8)}$$

$= 1.2$ gal/day/ft $= 5.2\ m^2/yr$

$K = T/m = (1.2)(48.8)/(8)$

$= 7.0$ ft/yr $= 6.8X10^{-6}$ cm/sec

FIGURE A-1.25. CONSTANT HEAD TEST FOR HOLE 35N-1D (SANDSTONE)



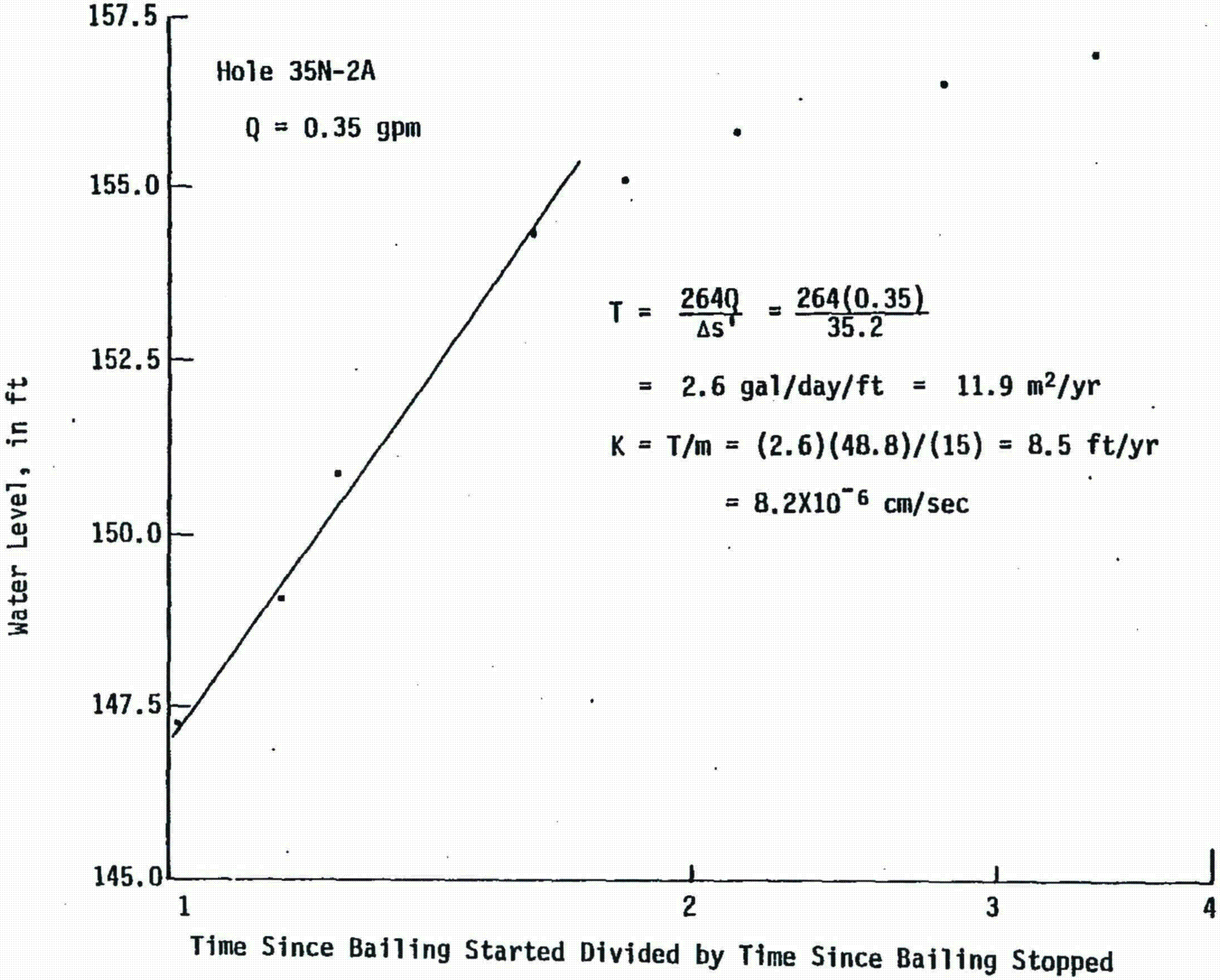
$$T = \frac{264}{Sw\Delta(1/Q)} = \frac{264}{26.4(69.5)}$$

$= .14$ gal/day/ft $= .65\ m^2/yr$

$K = T/m = (.14)(48.8)/(8)$

$= .9$ ft/yr $= 8.5X10^{-7}$ cm/sec

FIGURE A-1.26. CONSTANT HEAD TEST FOR HOLE 35N-1E (MUDSTONE)



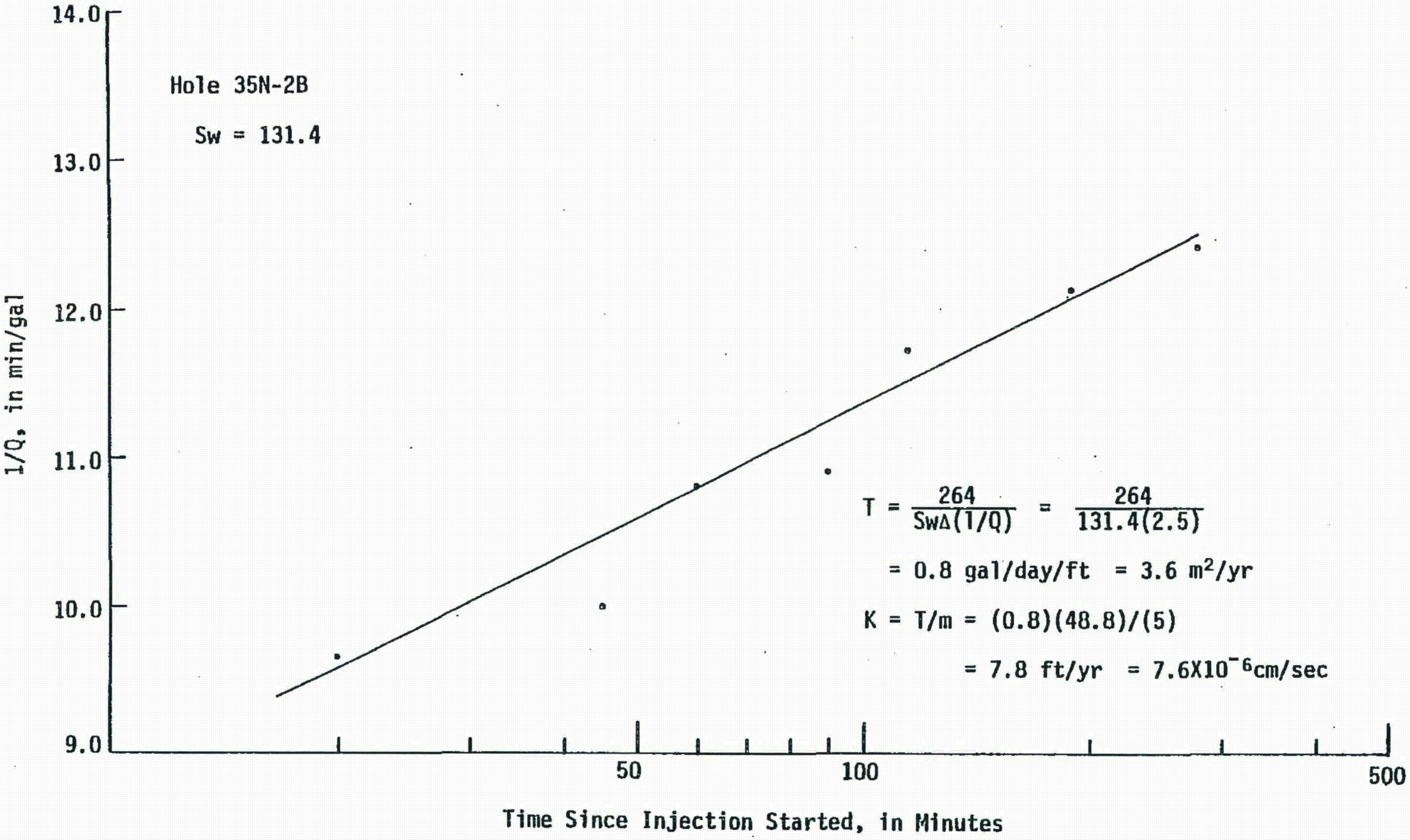
$$T = \frac{264Q}{\Delta s'} = \frac{264(0.35)}{35.2}$$

$$= 2.6 \text{ gal/day/ft} = 11.9 \text{ m}^2\text{/yr}$$

$$K = T/m = (2.6)(48.8)/(15) = 8.5 \text{ ft/yr}$$

$$= 8.2\text{X}10^{-6} \text{ cm/sec}$$

FIGURE A-1.27 RECOVERY TEST FOR HOLE 35N-2A (UPPER 70 SANDSTONE)



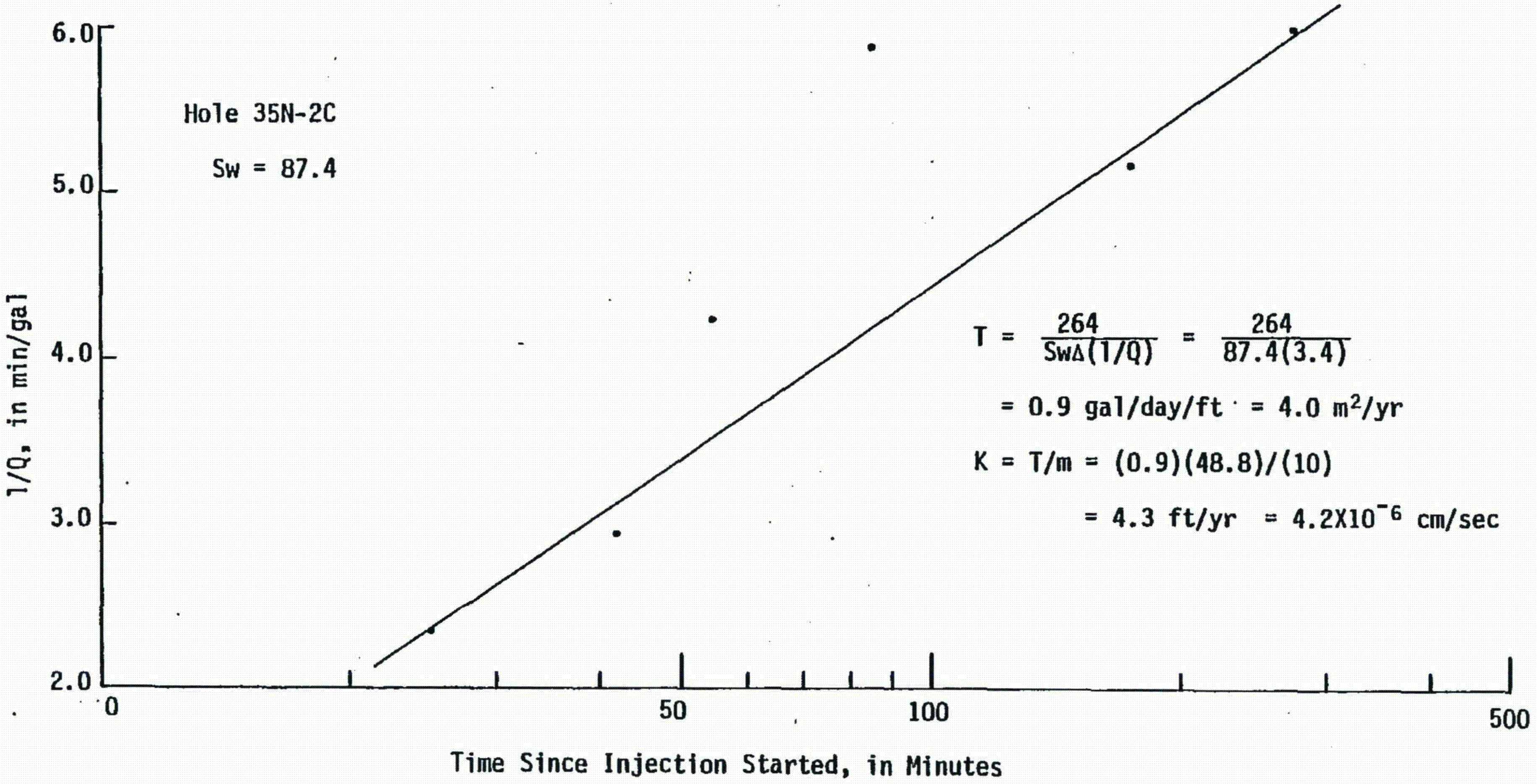
$$T = \frac{264}{Sw\Delta(1/Q)} = \frac{264}{131.4(2.5)}$$

$= 0.8$ gal/day/ft $= 3.6$ m^2/yr

$K = T/m = (0.8)(48.8)/(5)$

$= 7.8$ ft/yr $= 7.6\text{X}10^{-6}$cm/sec

FIGURE A-1.28. CONSTANT HEAD TEST FOR HOLE 35N-2B (SANDSTONE)



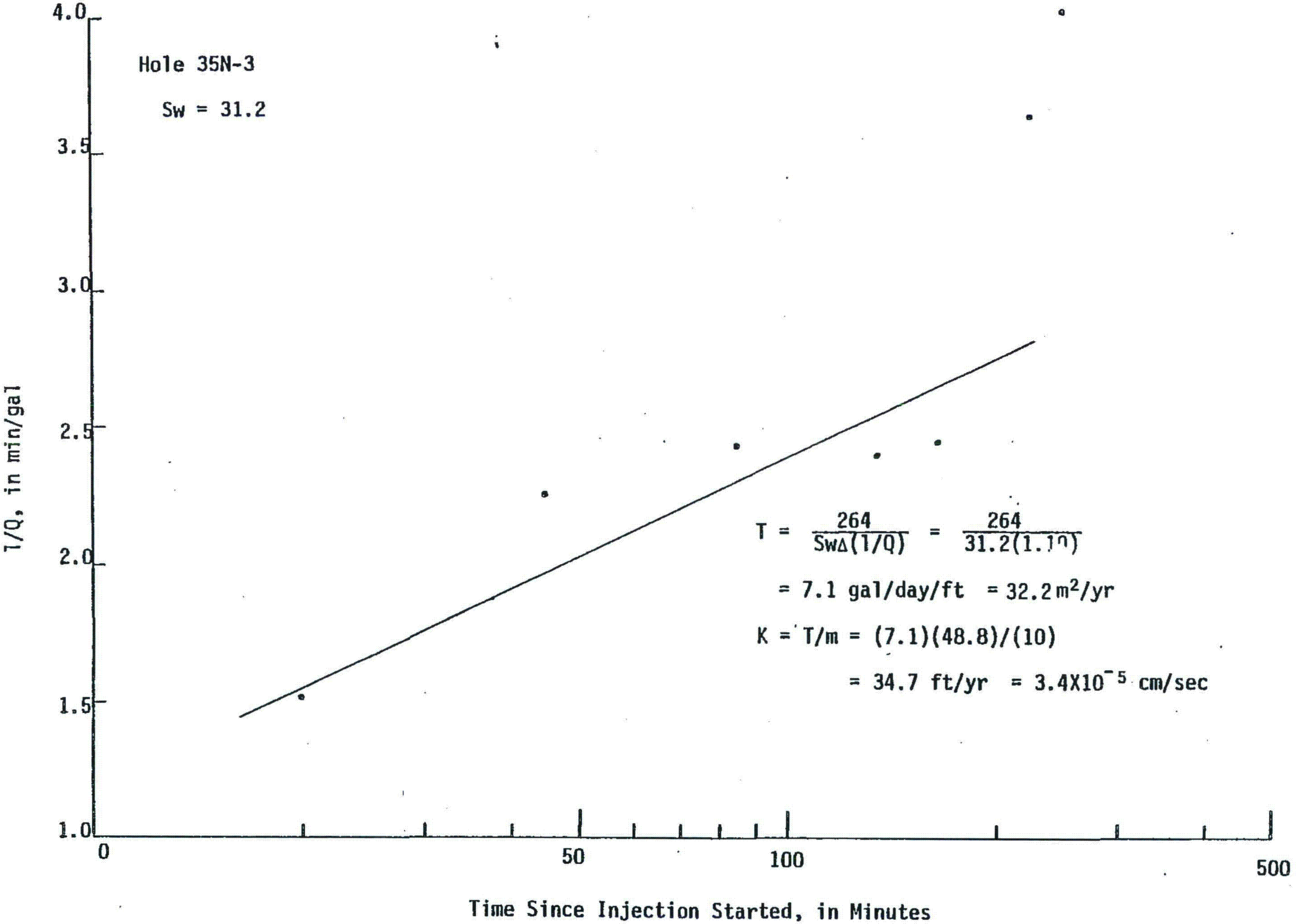
$$T = \frac{264}{Sw\Delta(1/Q)} = \frac{264}{87.4(3.4)}$$

$= 0.9$ gal/day/ft $= 4.0$ m^2/yr

$K = T/m = (0.9)(48.8)/(10)$

$= 4.3$ ft/yr $= 4.2\text{X}10^{-6}$ cm/sec

FIGURE A-1.29. CONSTANT HEAD TEST FOR HOLE 35N-2C (MUDSTONE)



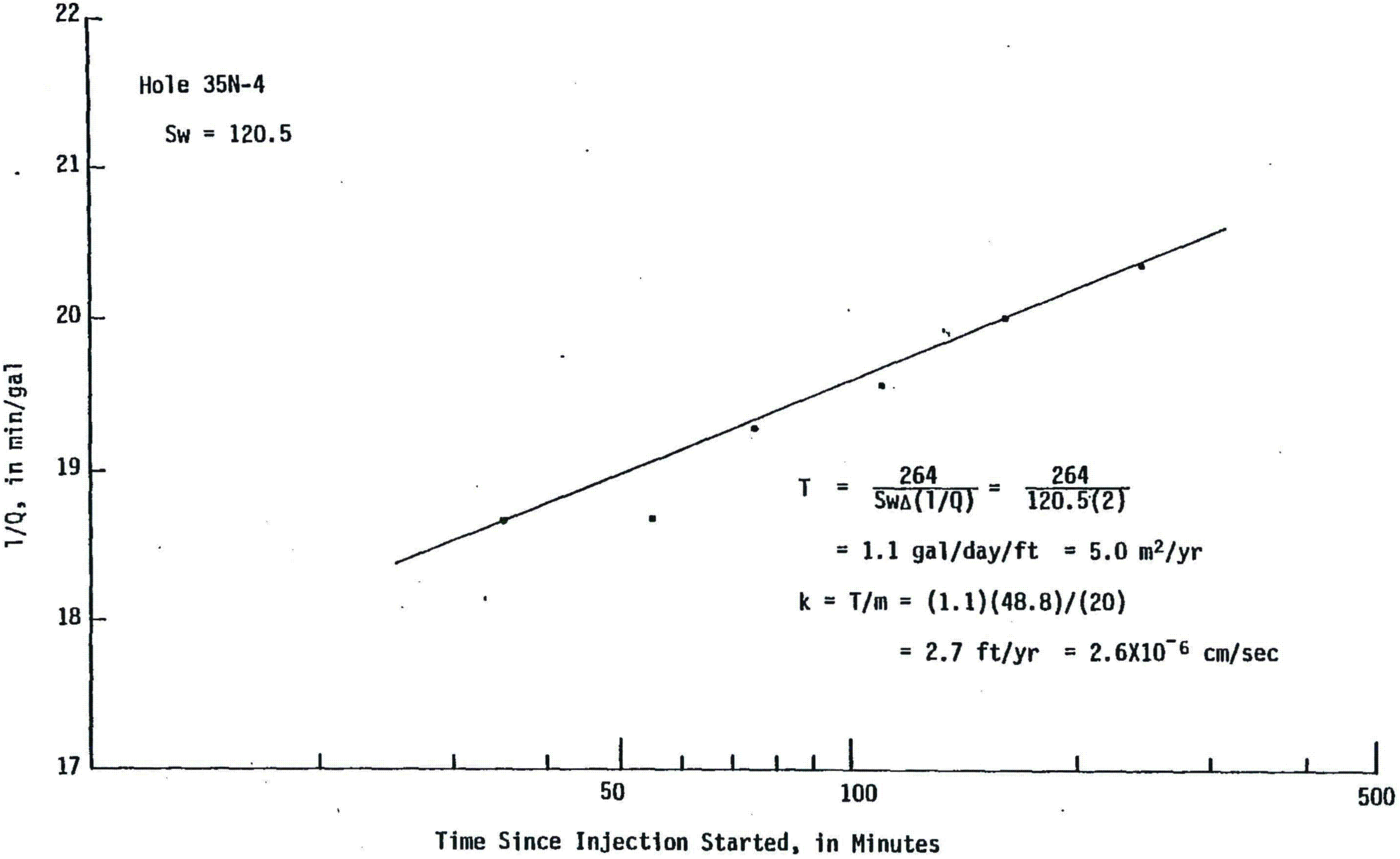
$$T = \frac{264}{Sw\Delta(1/Q)} = \frac{264}{31.2(1.19)}$$

$$= 7.1 \text{ gal/day/ft} = 32.2 \text{ m}^2\text{/yr}$$

$$K = T/m = (7.1)(48.8)/(10)$$

$$= 34.7 \text{ ft/yr} = 3.4 \times 10^{-5} \text{ cm/sec}$$

FIGURE A-1.30. CONSTANT HEAD TEST FOR HOLE 35N-3 (SANDSTONE)



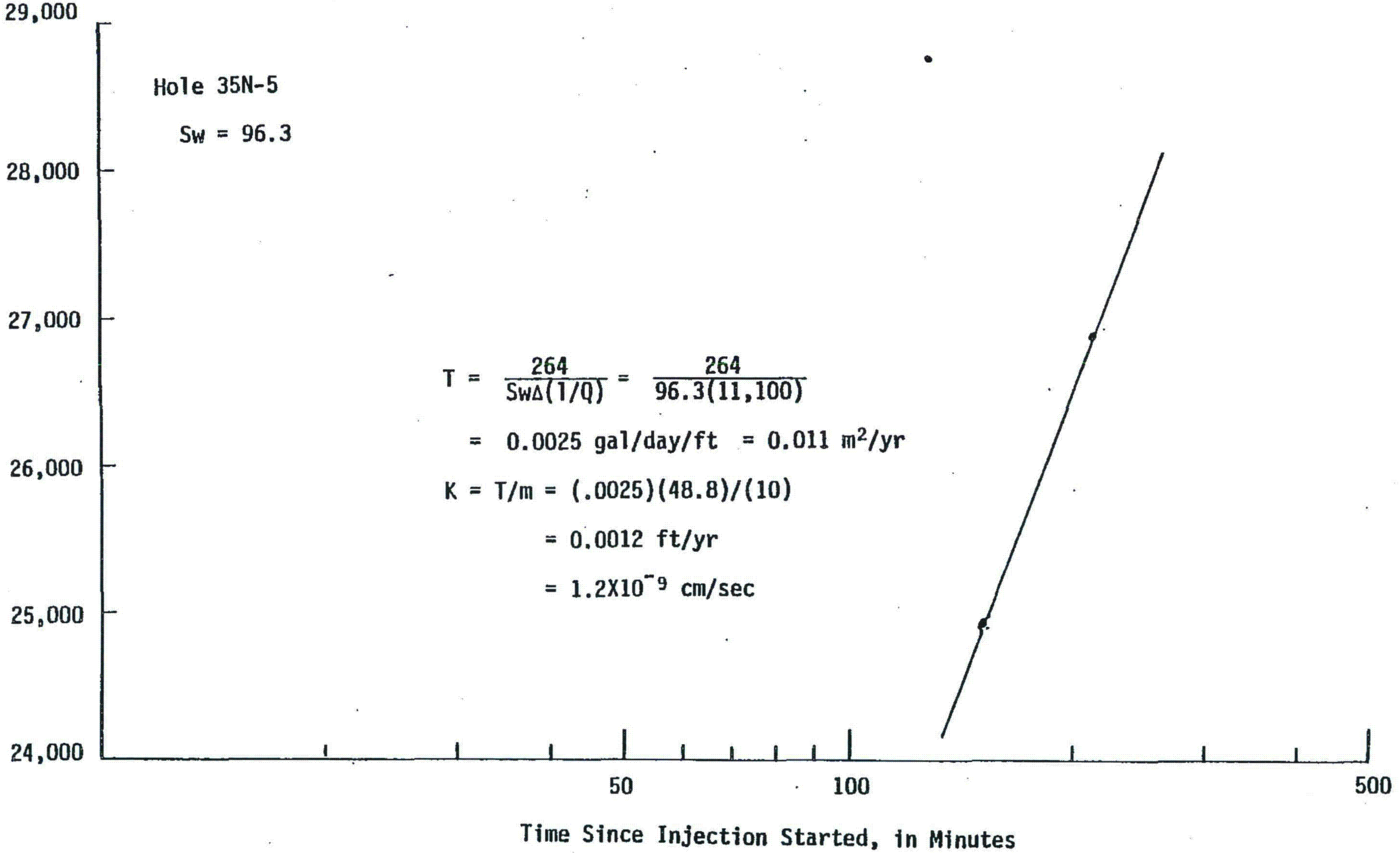
$$T = \frac{264}{Sw\Delta(1/Q)} = \frac{264}{120.5(2)}$$

$= 1.1$ gal/day/ft $= 5.0\ m^2/yr$

$k = T/m = (1.1)(48.8)/(20)$

$= 2.7$ ft/yr $= 2.6X10^{-6}$ cm/sec

FIGURE A-1.31. CONSTANT HEAD TEST FOR HOLE 35N-4 (MUDSTONE)



$$T = \frac{264}{Sw\Delta(1/Q)} = \frac{264}{96.3(11{,}100)}$$

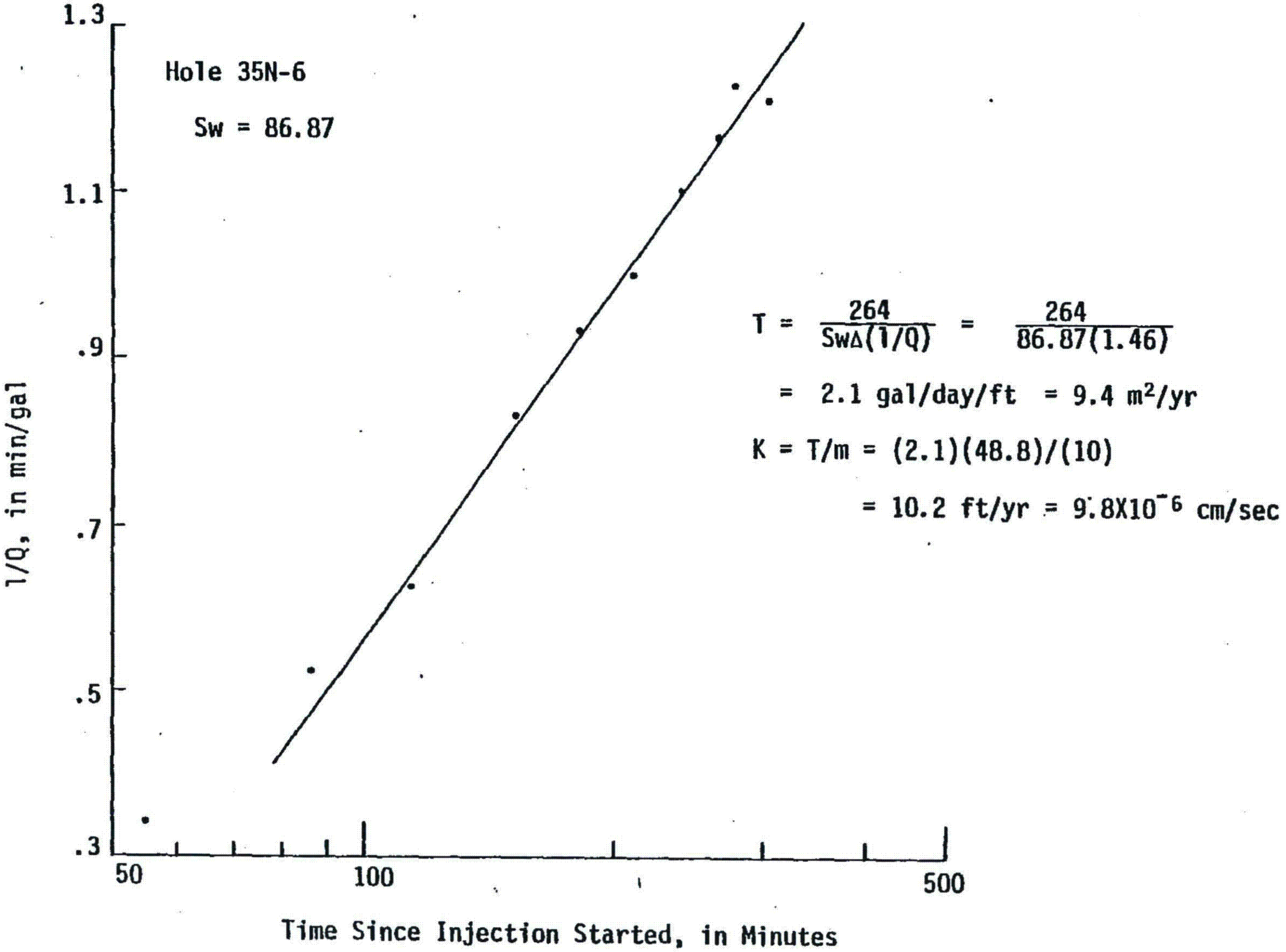
$$= 0.0025 \text{ gal/day/ft} = 0.011 \text{ m}^2\text{/yr}$$

$$K = T/m = (.0025)(48.8)/(10)$$

$$= 0.0012 \text{ ft/yr}$$

$$= 1.2\text{X}10^{-9} \text{ cm/sec}$$

FIGURE A-1.32. CONSTANT HEAD TEST FOR HOLE 35N-5 (SANDSTONE)



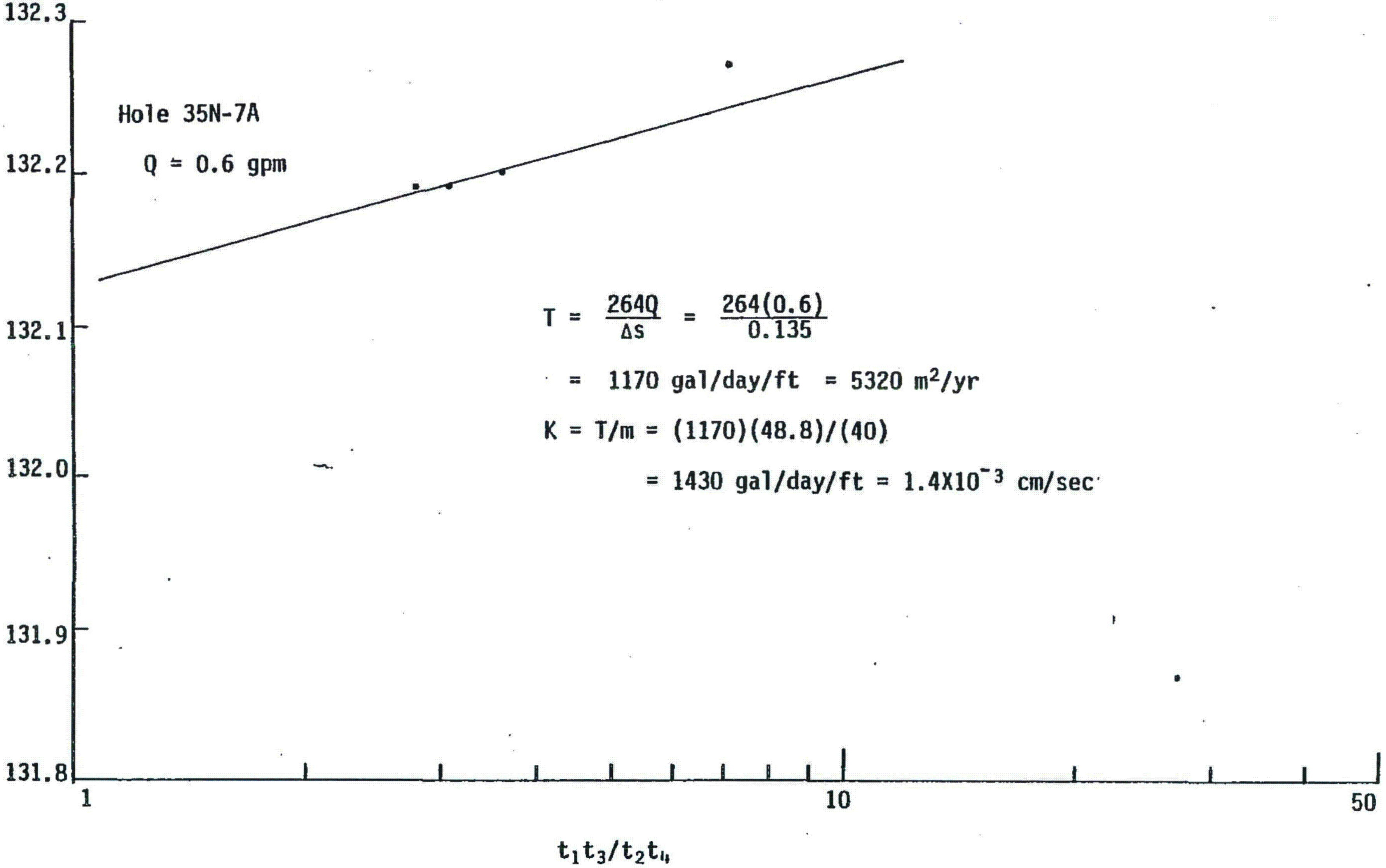
$$T = \frac{264}{Sw\Delta(1/Q)} = \frac{264}{86.87(1.46)}$$

$= 2.1$ gal/day/ft $= 9.4\ m^2/yr$

$K = T/m = (2.1)(48.8)/(10)$

$= 10.2$ ft/yr $= 9.8X10^{-6}$ cm/sec

FIGURE A-1.33. CONSTANT HEAD TEST FOR HOLE 35N-6 (SANDSTONE)



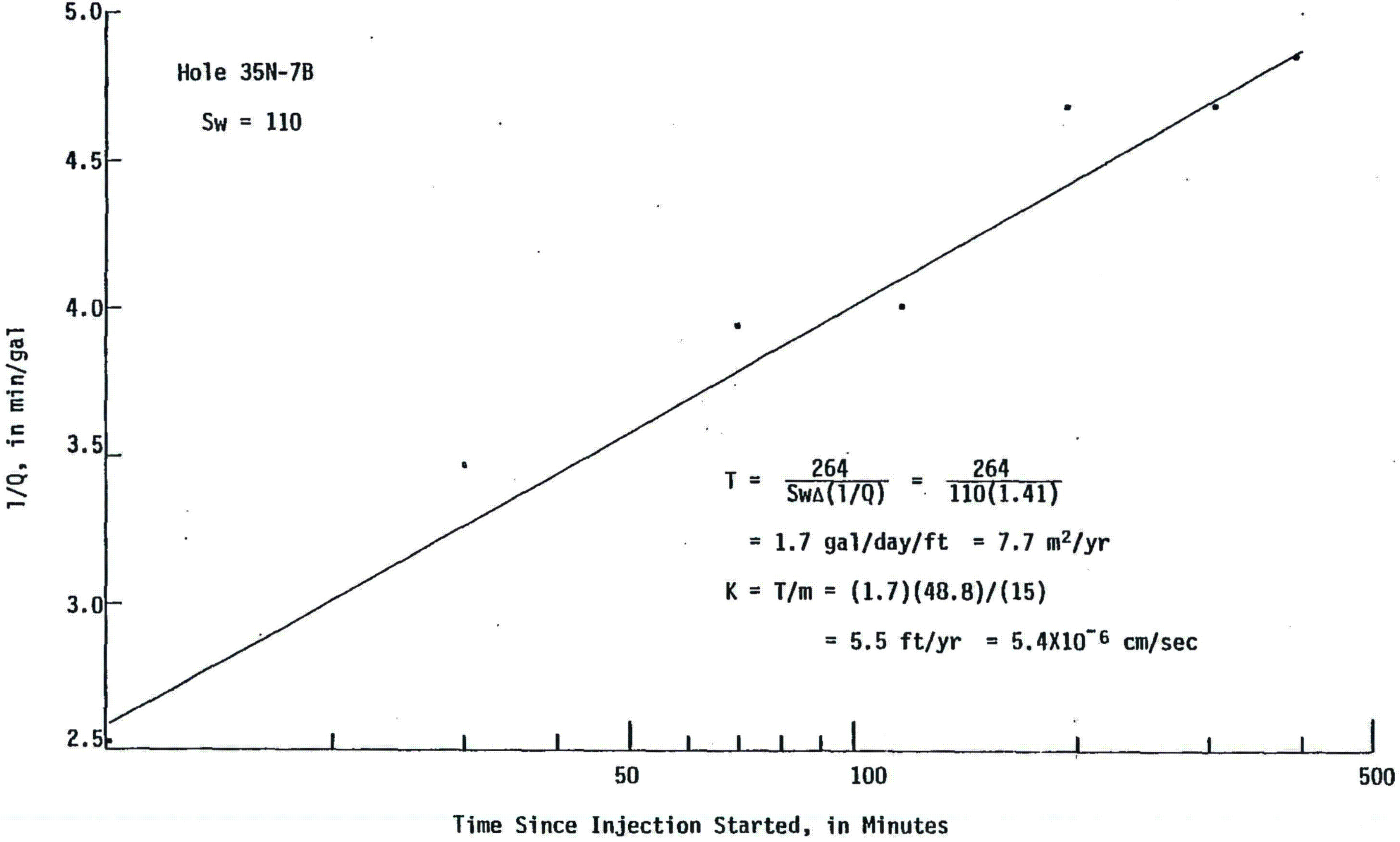
$$T = \frac{264Q}{\Delta s} = \frac{264(0.6)}{0.135}$$

$$= 1170 \text{ gal/day/ft} = 5320 \text{ m}^2\text{/yr}$$

$$K = T/m = (1170)(48.8)/(40)$$

$$= 1430 \text{ gal/day/ft} = 1.4\text{X}10^{-3} \text{ cm/sec}$$

FIGURE A-1.34. RECOVERY TEST FOR HOLE 35N-7A (70 SANDSTONE)



Hole 35N-7B

Sw = 110

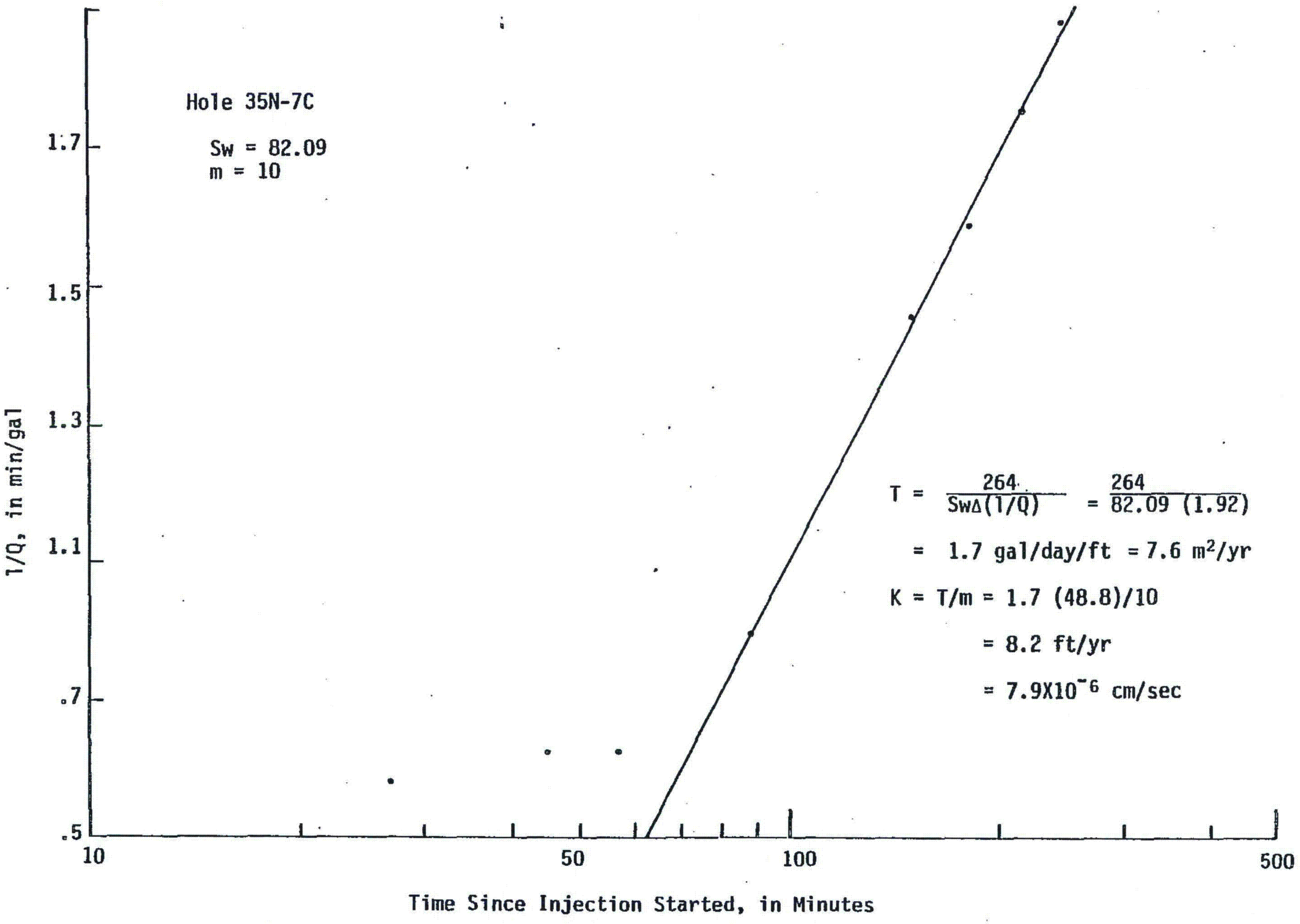
$$T = \frac{264}{Sw\Delta(1/Q)} = \frac{264}{110(1.41)}$$

$= 1.7$ gal/day/ft $= 7.7\ m^2/yr$

$K = T/m = (1.7)(48.8)/(15)$

$= 5.5$ ft/yr $= 5.4X10^{-6}$ cm/sec

FIGURE A-1.35. CONSTANT HEAD TEST FOR HOLE 35N-7B (UPPER 70 SANDSTONE)



Hole 35N-7C

Sw = 82.09
m = 10

$$T = \frac{264}{Sw\Delta(1/Q)} = \frac{264}{82.09\ (1.92)}$$

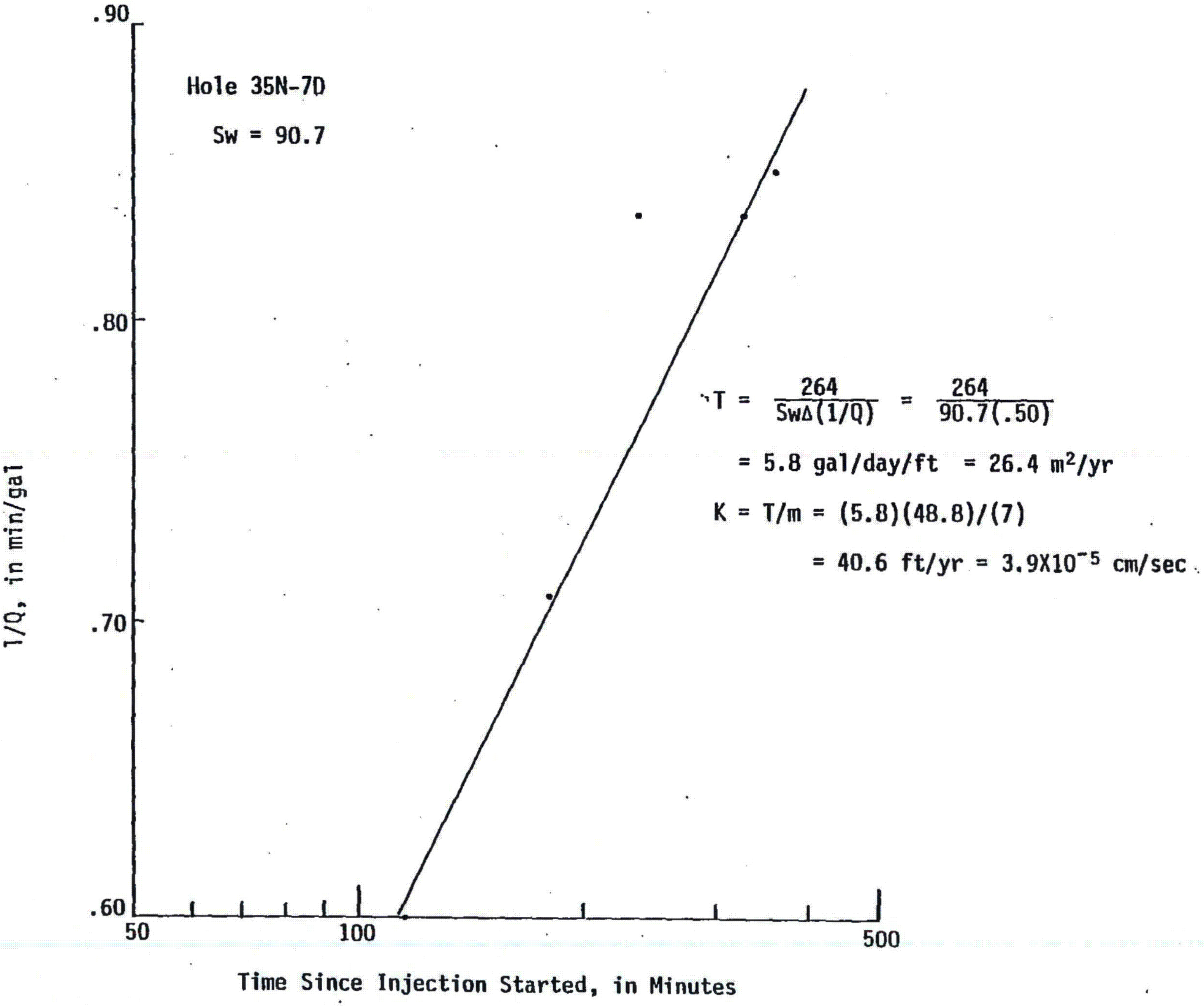
= 1.7 gal/day/ft = 7.6 m^2/yr

K = T/m = 1.7 (48.8)/10

= 8.2 ft/yr

= $7.9X10^{-6}$ cm/sec

FIGURE A-1.36. CONSTANT HEAD TEST FOR HOLE 35N-7C (SANDSTONE)



Hole 35N-7D

Sw = 90.7

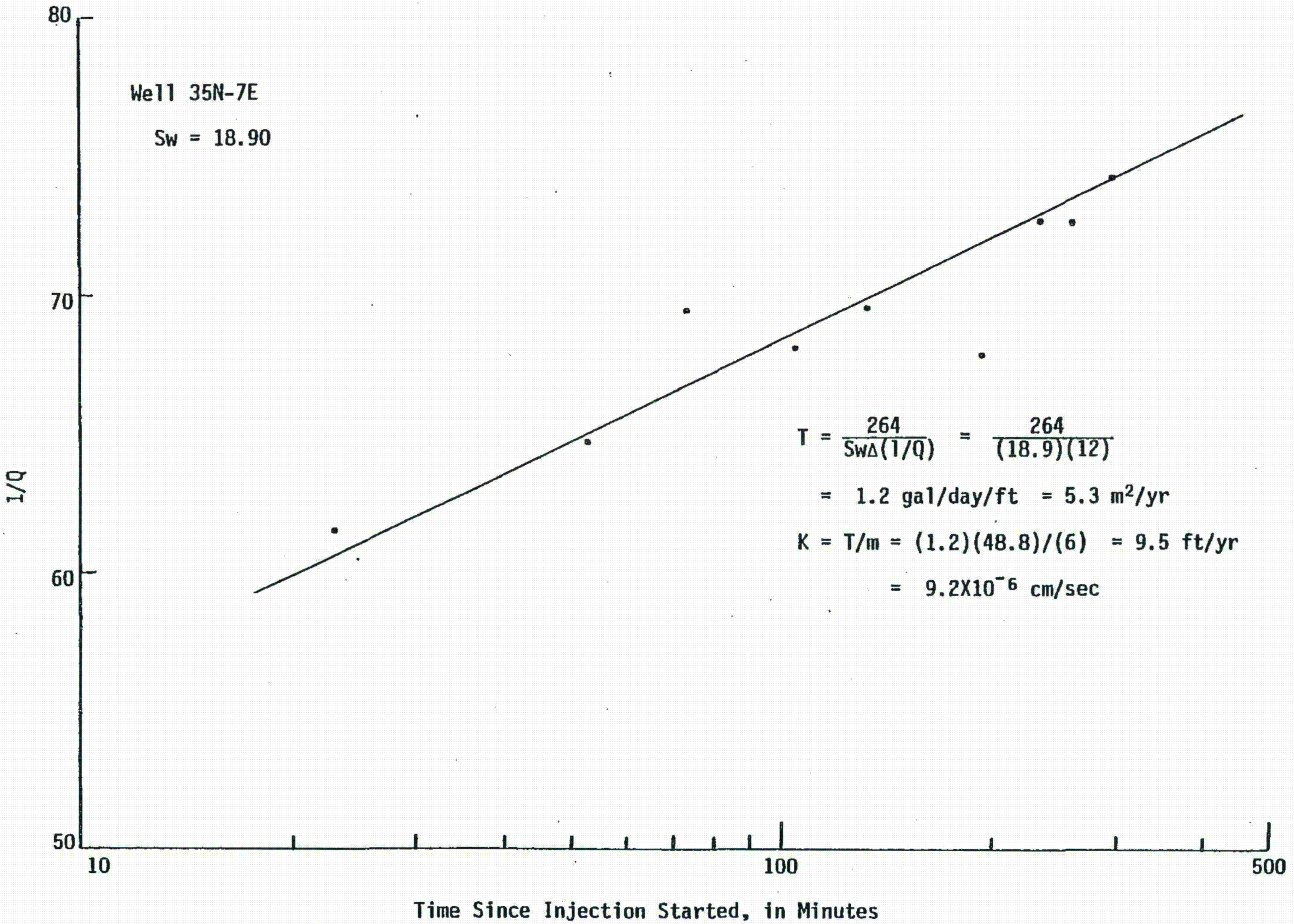
$$T = \frac{264}{Sw\Delta(1/Q)} = \frac{264}{90.7(.50)}$$

$$= 5.8 \text{ gal/day/ft} = 26.4 \text{ m}^2\text{/yr}$$

$$K = T/m = (5.8)(48.8)/(7)$$

$$= 40.6 \text{ ft/yr} = 3.9\text{X}10^{-5} \text{ cm/sec}$$

FIGURE A-1.37. CONSTANT HEAD TEST FOR HOLE 35N-7D (E COAL)



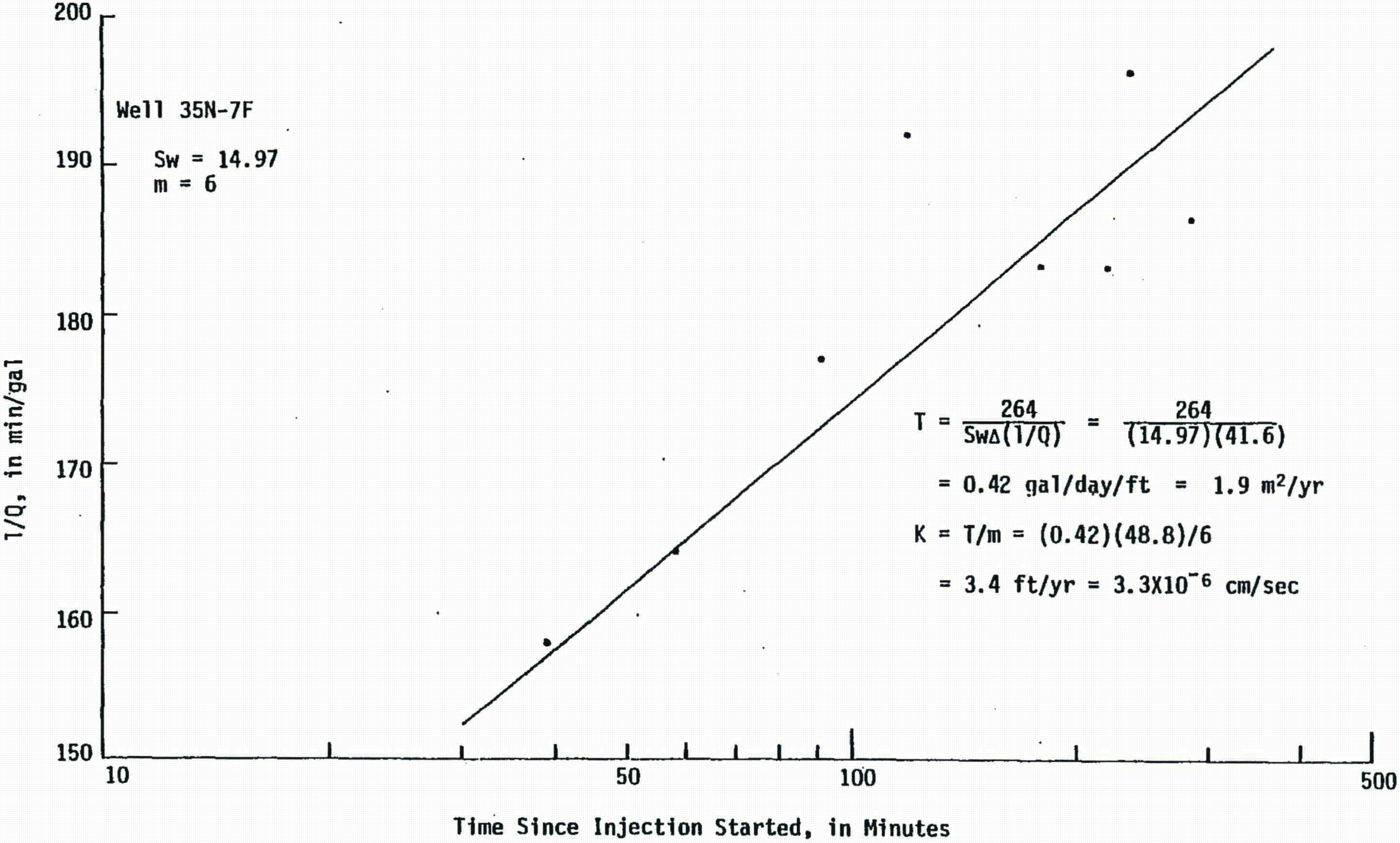
$$T = \frac{264}{Sw\Delta(1/Q)} = \frac{264}{(18.9)(12)}$$

$$= 1.2 \text{ gal/day/ft} = 5.3 \text{ m}^2\text{/yr}$$

$$K = T/m = (1.2)(48.8)/(6) = 9.5 \text{ ft/yr}$$

$$= 9.2\text{X}10^{-6} \text{ cm/sec}$$

FIGURE A-1.38. CONSTANT HEAD TEST FOR HOLE 35N-7E (SANDSTONE)



Well 35N-7F

$S_w = 14.97$
$m = 6$

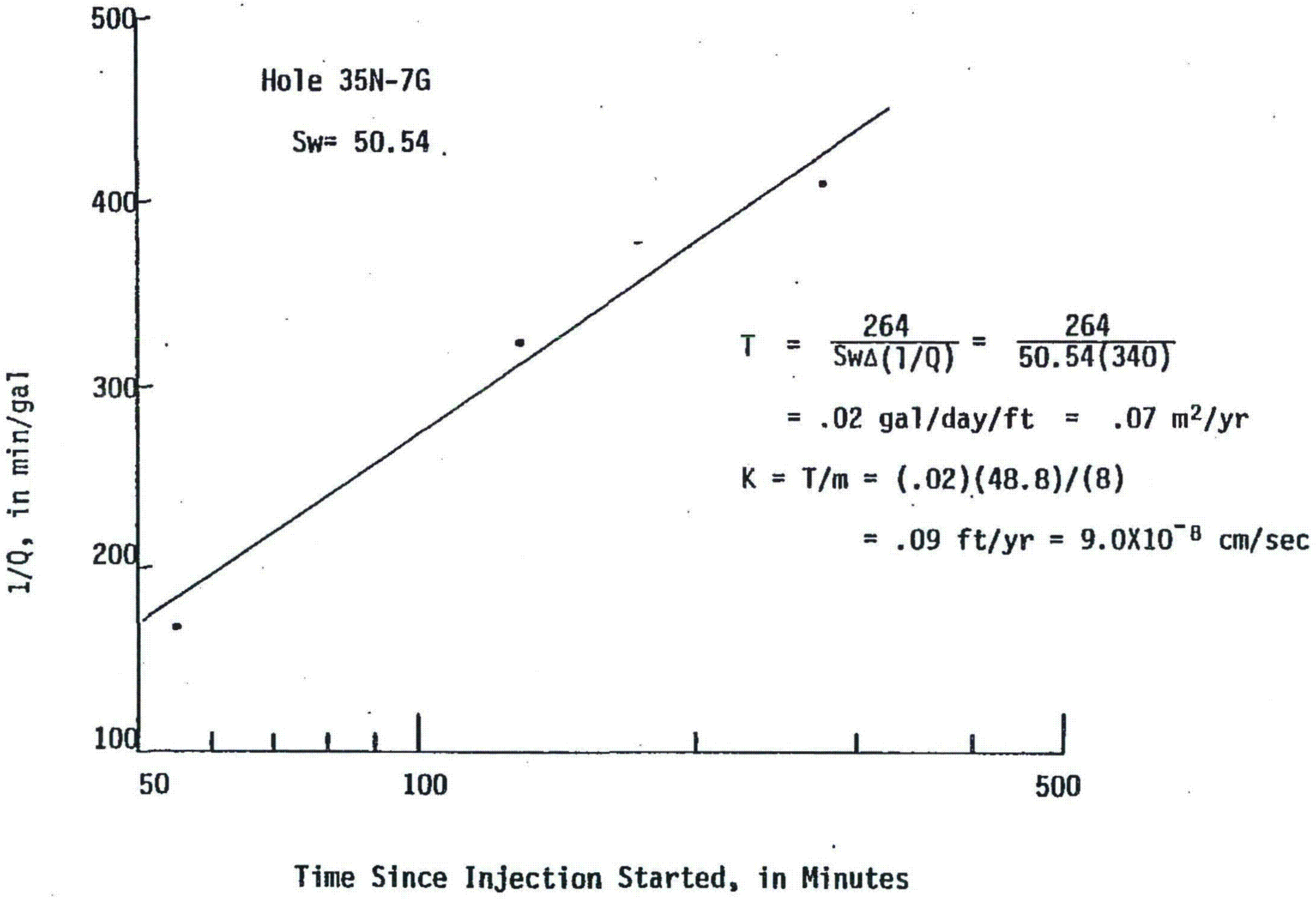
$$T = \frac{264}{S_w\Delta(1/Q)} = \frac{264}{(14.97)(41.6)}$$

$$= 0.42 \text{ gal/day/ft} = 1.9 \text{ m}^2\text{/yr}$$

$$K = T/m = (0.42)(48.8)/6$$

$$= 3.4 \text{ ft/yr} = 3.3\times10^{-6} \text{ cm/sec}$$

FIGURE A-1.39. CONSTANT HEAD TEST FOR HOLE 35N-7F (MUDSTONE)



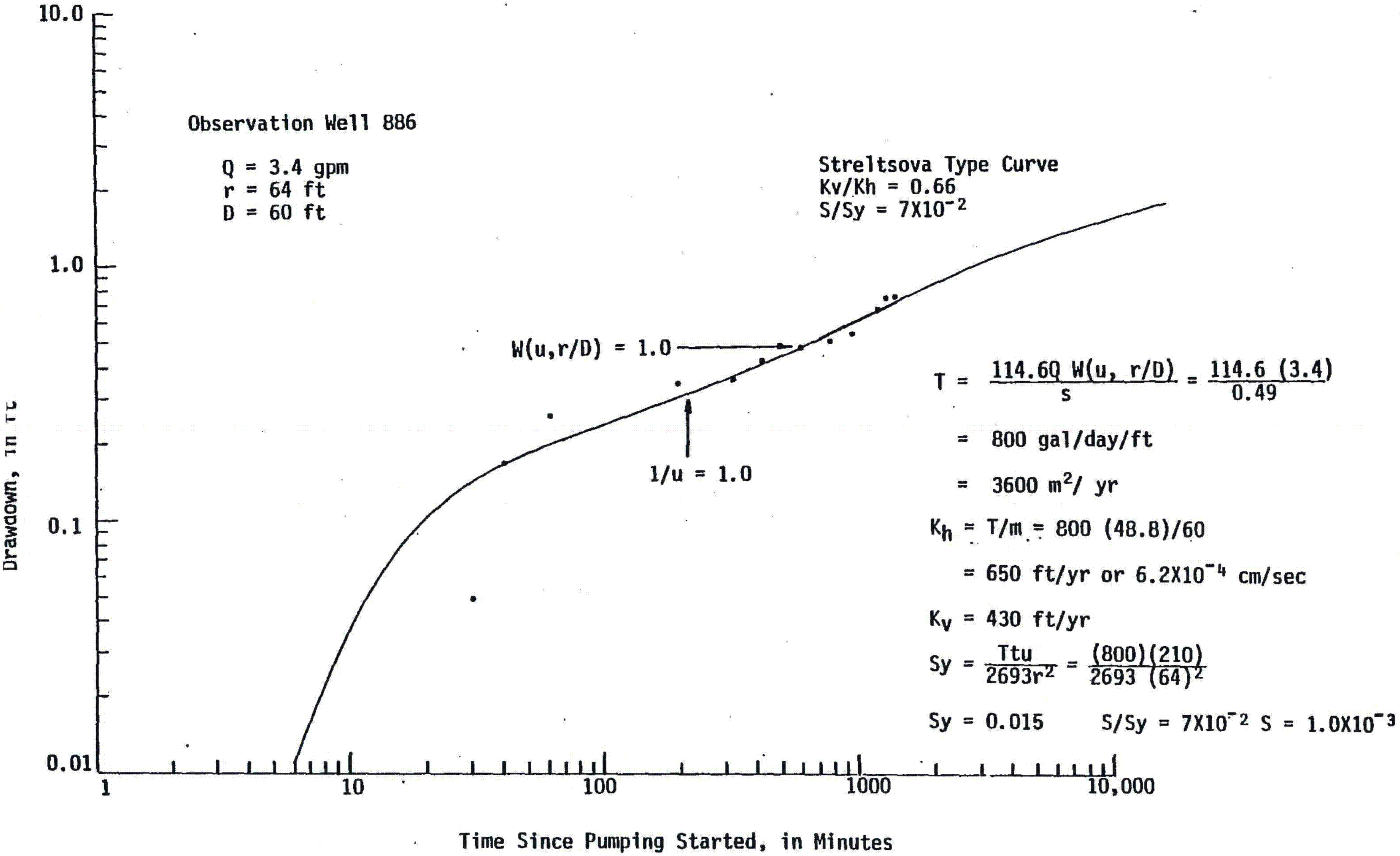
$$T = \frac{264}{Sw\Delta(1/Q)} = \frac{264}{50.54(340)}$$

$$= .02 \text{ gal/day/ft} = .07 \text{ m}^2\text{/yr}$$

$$K = T/m = (.02)(48.8)/(8)$$

$$= .09 \text{ ft/yr} = 9.0\text{X}10^{-8} \text{ cm/sec}$$

FIGURE A-1.40. CONSTANT HEAD TEST FOR HOLE 35N-7G (U COAL)



$$T = \frac{114.6Q\ W(u,\ r/D)}{s} = \frac{114.6\ (3.4)}{0.49}$$

$$= 800\ \text{gal/day/ft}$$

$$= 3600\ \text{m}^2/\ \text{yr}$$

$$K_h = T/m = 800\ (48.8)/60$$

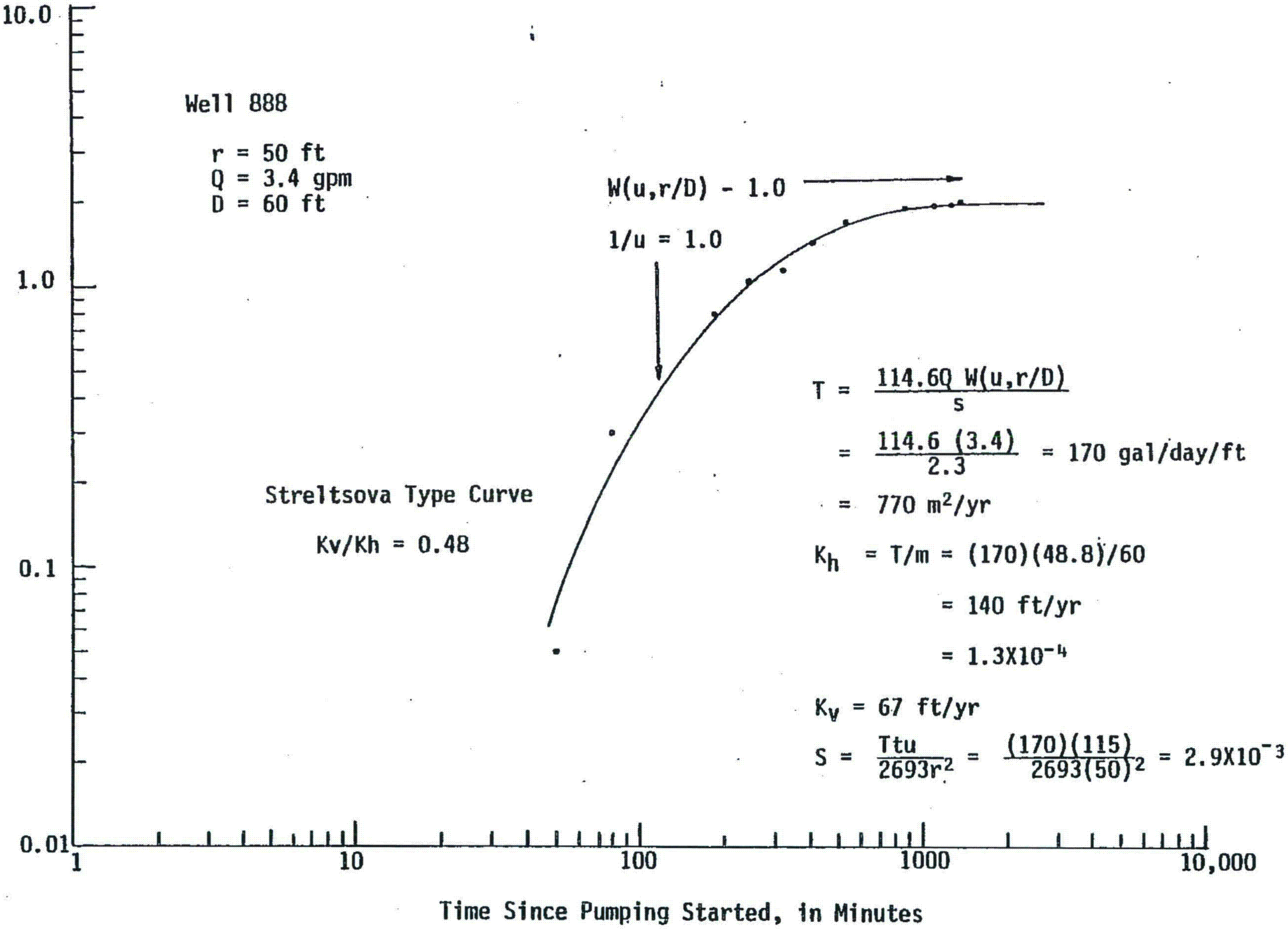
$$= 650\ \text{ft/yr or}\ 6.2\text{X}10^{-4}\ \text{cm/sec}$$

$$K_v = 430\ \text{ft/yr}$$

$$Sy = \frac{Ttu}{2693r^2} = \frac{(800)(210)}{2693\ (64)^2}$$

$$Sy = 0.015 \qquad S/Sy = 7\text{X}10^{-2}\ S = 1.0\text{X}10^{-3}$$

FIGURE A-1.41. DRAWDOWN IN OBSERVATION WELL 886 FROM PUMPING WELL 885 (70 SAND)



Well 888

r = 50 ft
Q = 3.4 gpm
D = 60 ft

$$T = \frac{114.6Q\ W(u,r/D)}{s}$$

$$= \frac{114.6\ (3.4)}{2.3} = 170\ \text{gal/day/ft}$$

$$= 770\ \text{m}^2/\text{yr}$$

$$K_h = T/m = (170)(48.8)/60$$

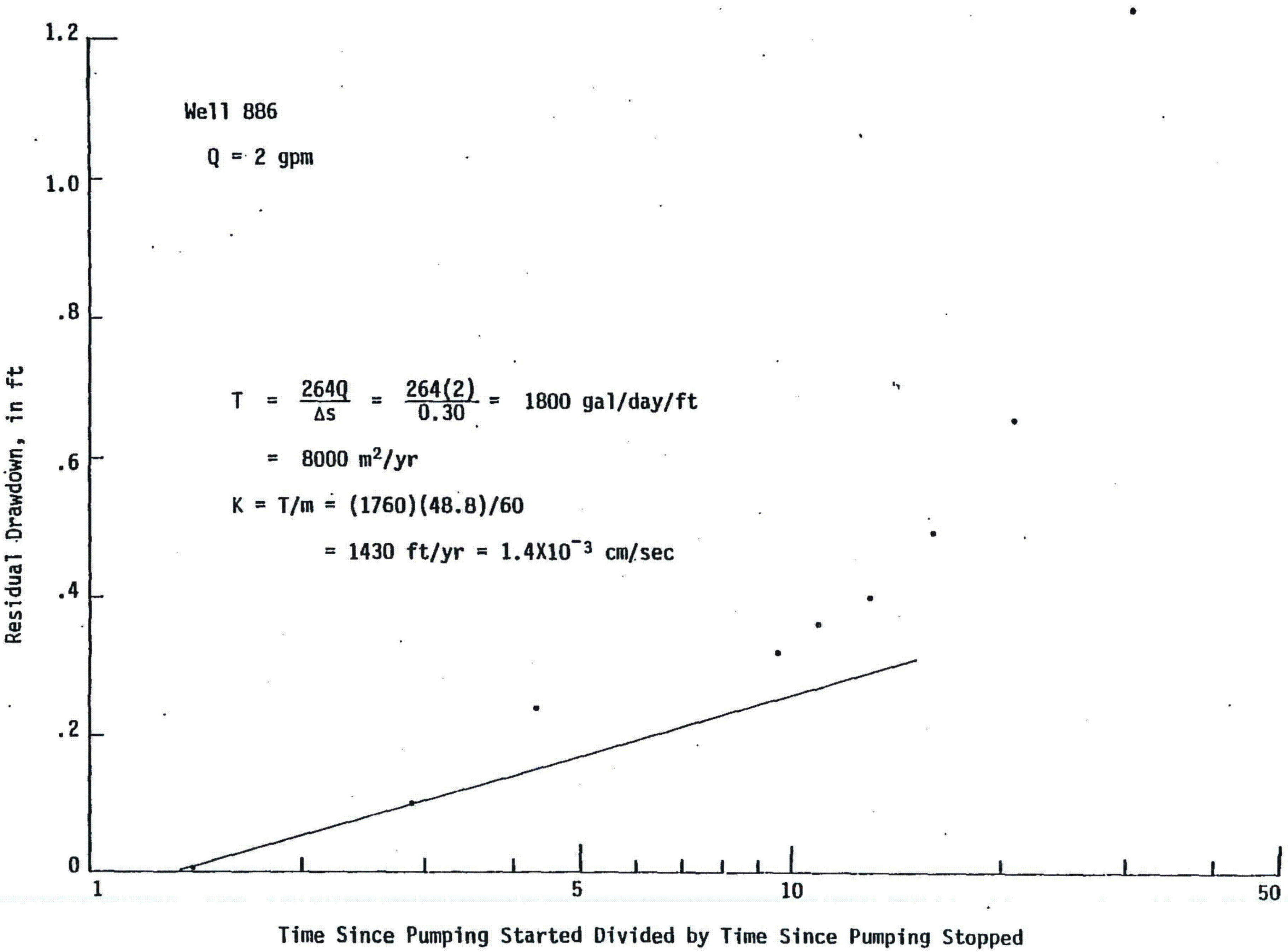
$$= 140\ \text{ft/yr}$$

$$= 1.3\text{X}10^{-4}$$

$$K_v = 67\ \text{ft/yr}$$

$$S = \frac{Ttu}{2693r^2} = \frac{(170)(115)}{2693(50)^2} = 2.9\text{X}10^{-3}$$

FIGURE A-1.42. DRAWDOWN IN OBSERVATION WELL 888 FROM PUMPING WELL 885 (70 SAND)



Well 886

Q = 2 gpm

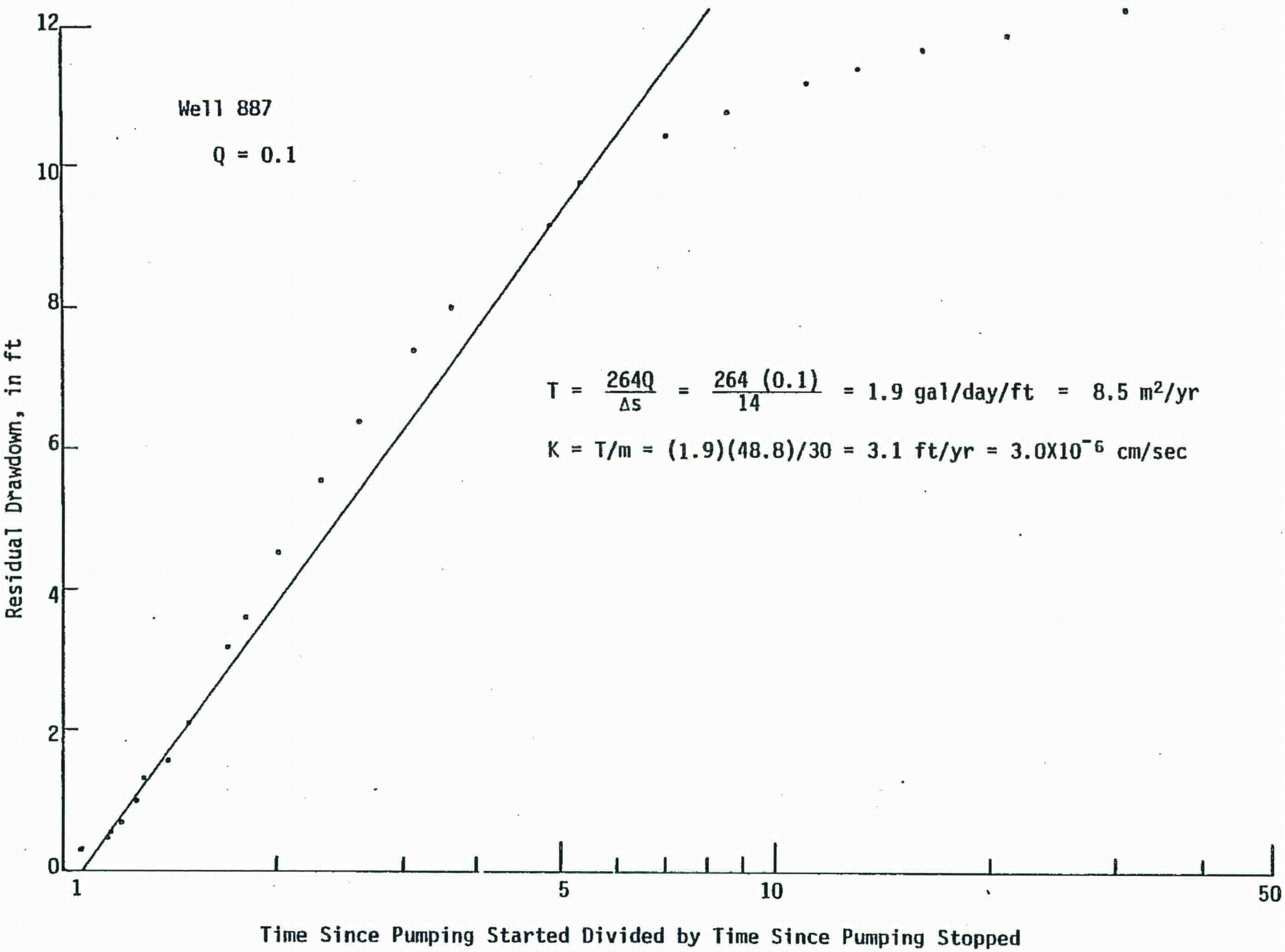
$$T = \frac{264Q}{\Delta s} = \frac{264(2)}{0.30} = 1800 \text{ gal/day/ft}$$

$$= 8000 \text{ m}^2\text{/yr}$$

$$K = T/m = (1760)(48.8)/60$$

$$= 1430 \text{ ft/yr} = 1.4X10^{-3} \text{ cm/sec}$$

FIGURE A-1.43. RECOVERY OF PUMPING WELL 886 (70 SAND)



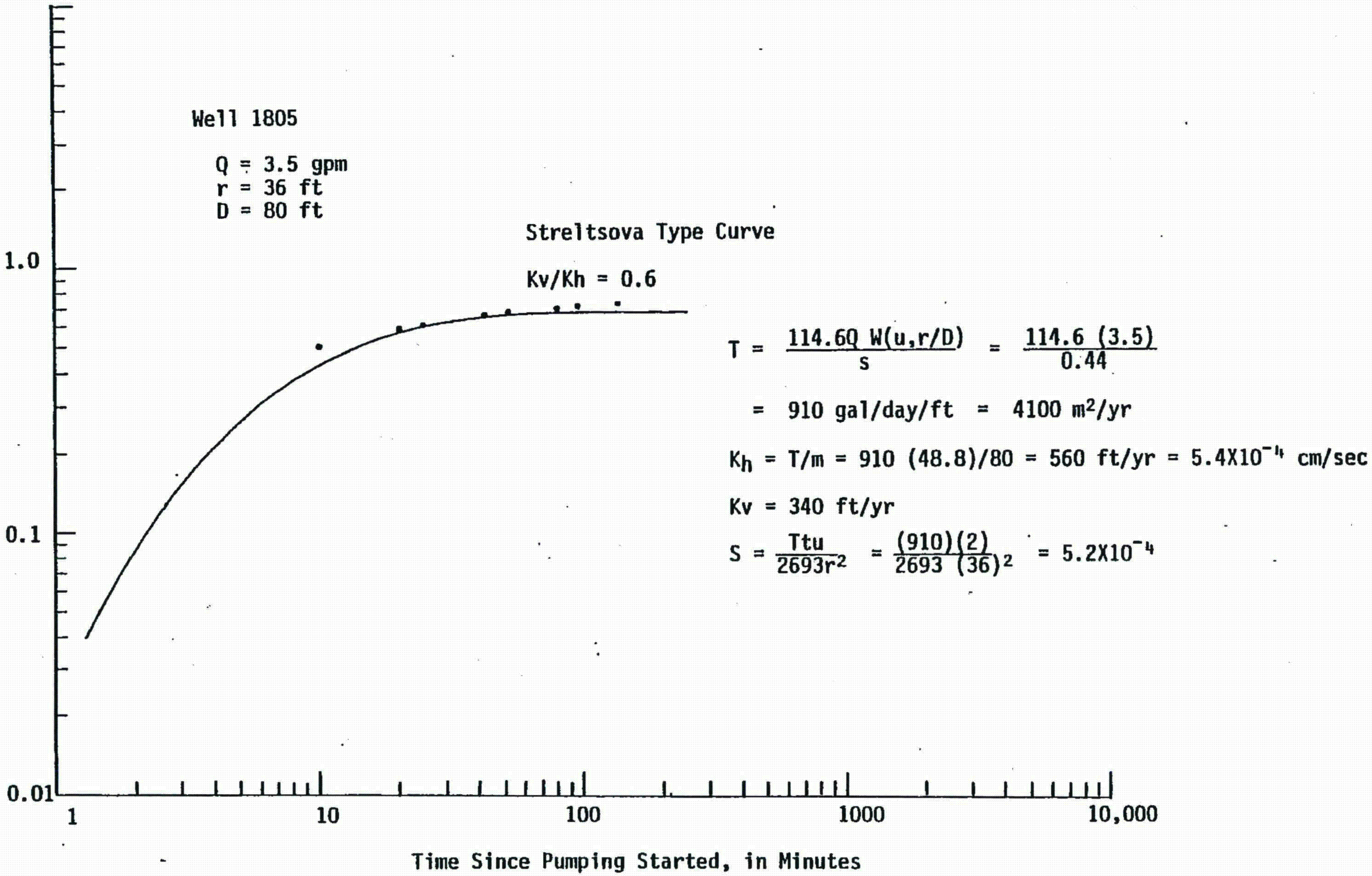
Well 887

Q = 0.1

$T = \frac{264Q}{\Delta s} = \frac{264\ (0.1)}{14} = 1.9$ gal/day/ft $= 8.5$ m^2/yr

$K = T/m = (1.9)(48.8)/30 = 3.1$ ft/yr $= 3.0 \mathrm{X} 10^{-6}$ cm/sec

FIGURE A-1.44. RECOVERY OF PUMPING WELL 887 (68 SAND)



$$T = \frac{114.6Q\ W(u,r/D)}{s} = \frac{114.6\ (3.5)}{0.44}$$

$$= 910\ \text{gal/day/ft} = 4100\ \text{m}^2\text{/yr}$$

$$K_h = T/m = 910\ (48.8)/80 = 560\ \text{ft/yr} = 5.4\text{X}10^{-4}\ \text{cm/sec}$$

$$Kv = 340\ \text{ft/yr}$$

$$S = \frac{Ttu}{2693r^2} = \frac{(910)(2)}{2693\ (36)^2} = 5.2\text{X}10^{-4}$$

FIGURE A-1.45. DRAWDOWN IN OBSERVATION WELL 1805 FROM PUMPING WELL 1 (70 SAND)

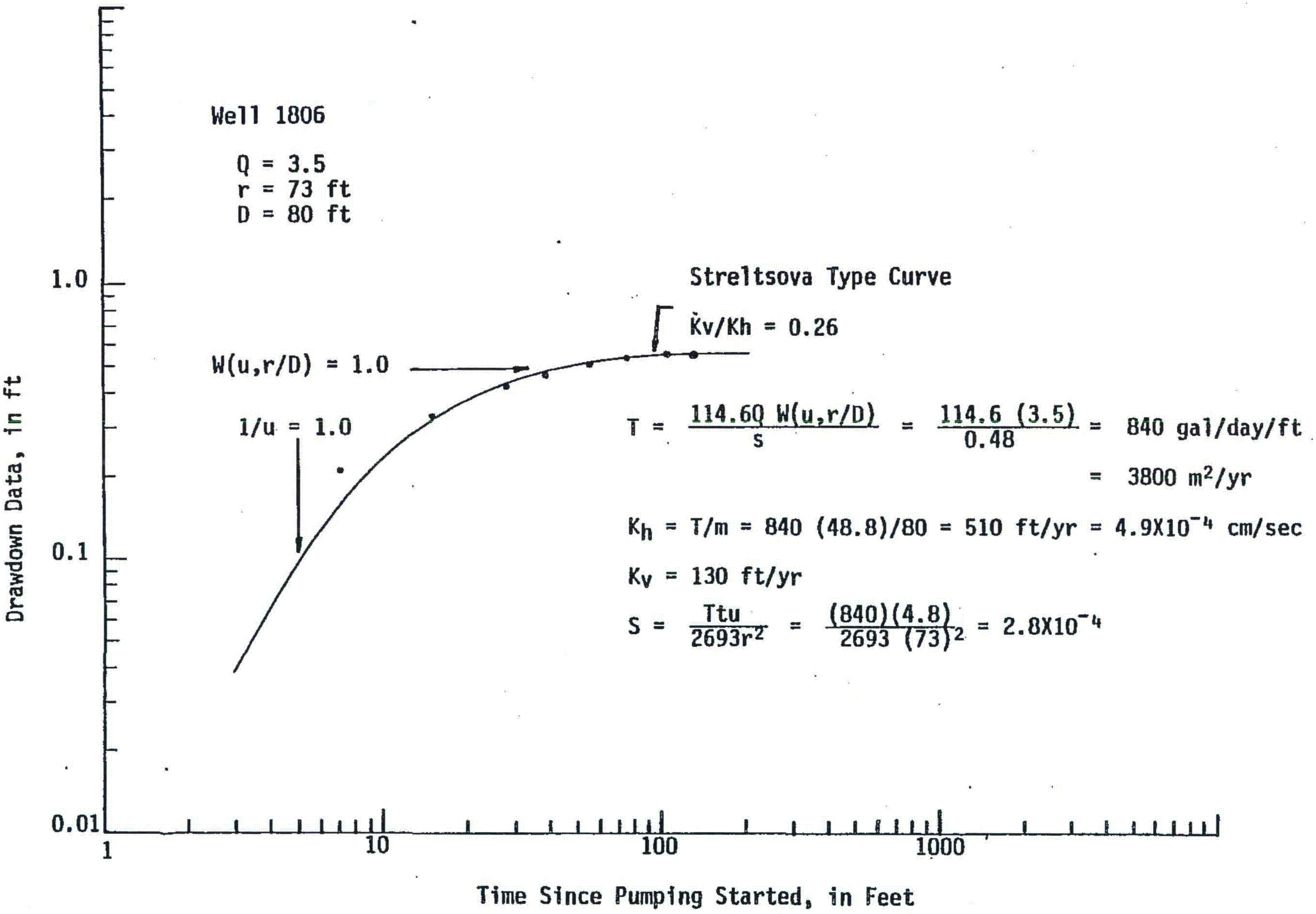


FIGURE A-1.46. DRAWDOWN IN OBSERVATION WELL 1806 FROM PUMPING WELL 1 (70 SAND)

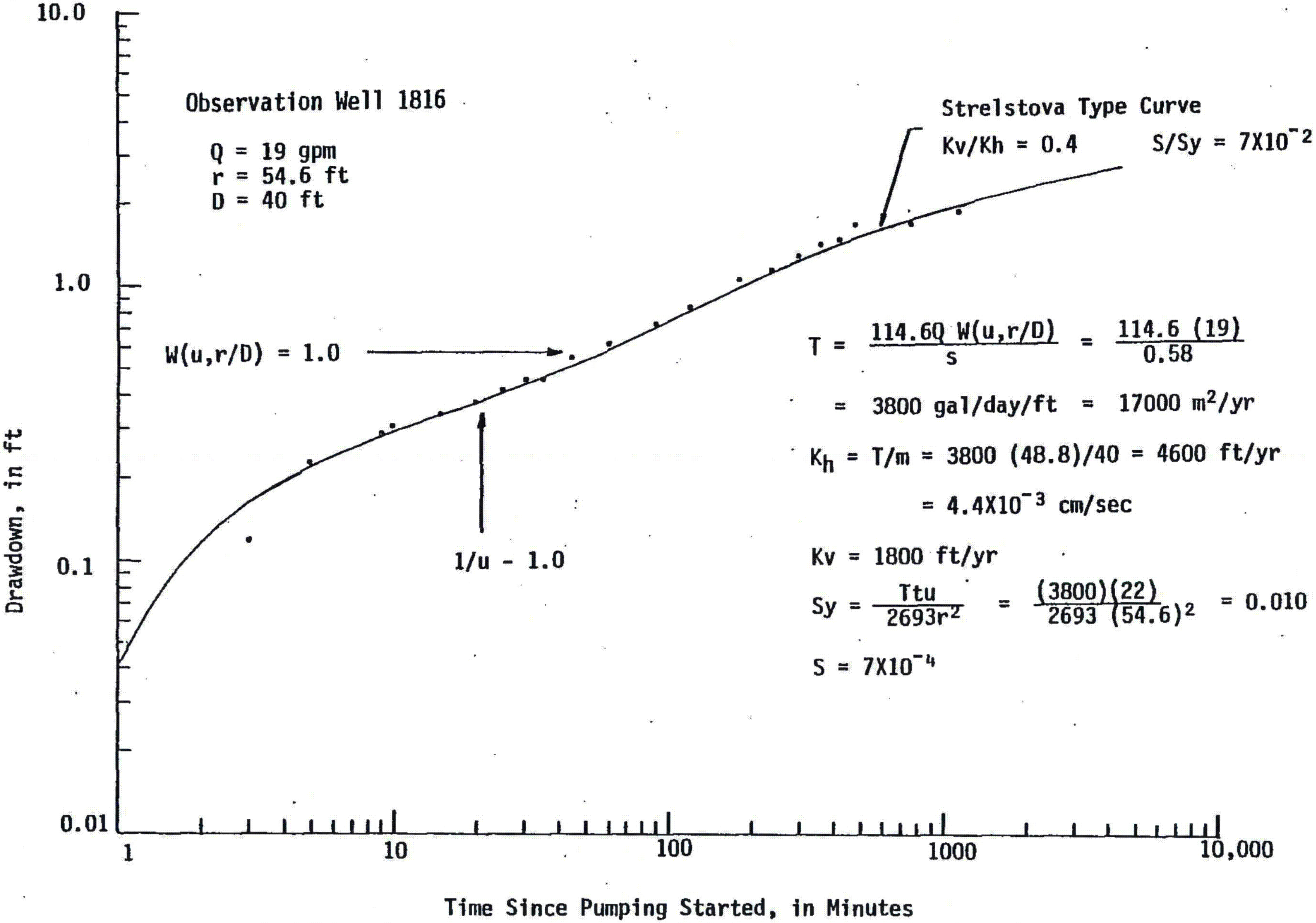
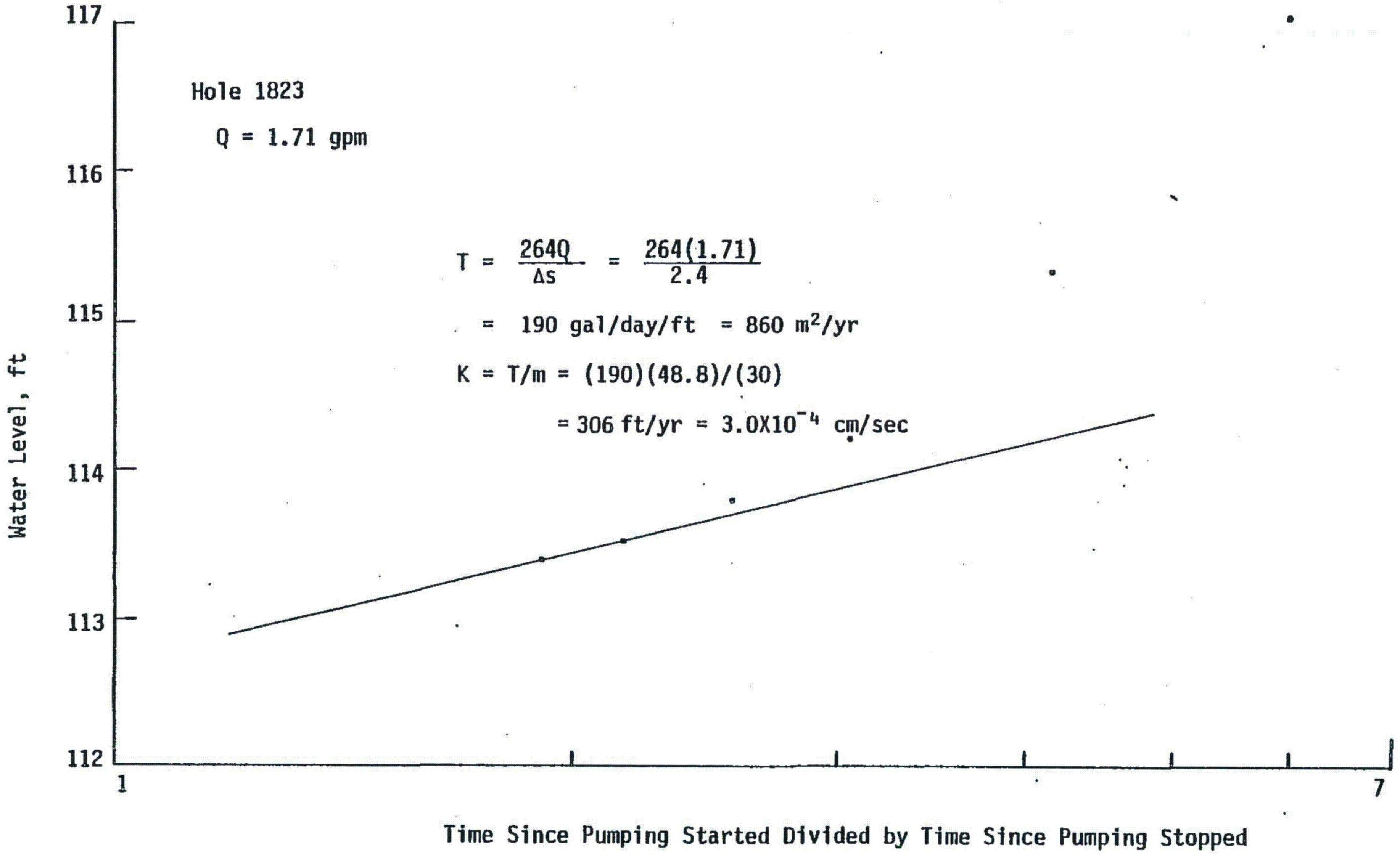


FIGURE A-1.47. DRAWDOWN IN OBSERVATION WELL 1816 FROM PUMPING WELL 1814 (70 SAND)



$$T = \frac{264Q}{\Delta s} = \frac{264(1.71)}{2.4}$$

$$= 190 \text{ gal/day/ft} = 860 \text{ m}^2\text{/yr}$$

$$K = T/m = (190)(48.8)/(30)$$

$$= 306 \text{ ft/yr} = 3.0\text{X}10^{-4} \text{ cm/sec}$$

FIGURE A-1.48. RECOVERY OF PUMPING WELL 1823

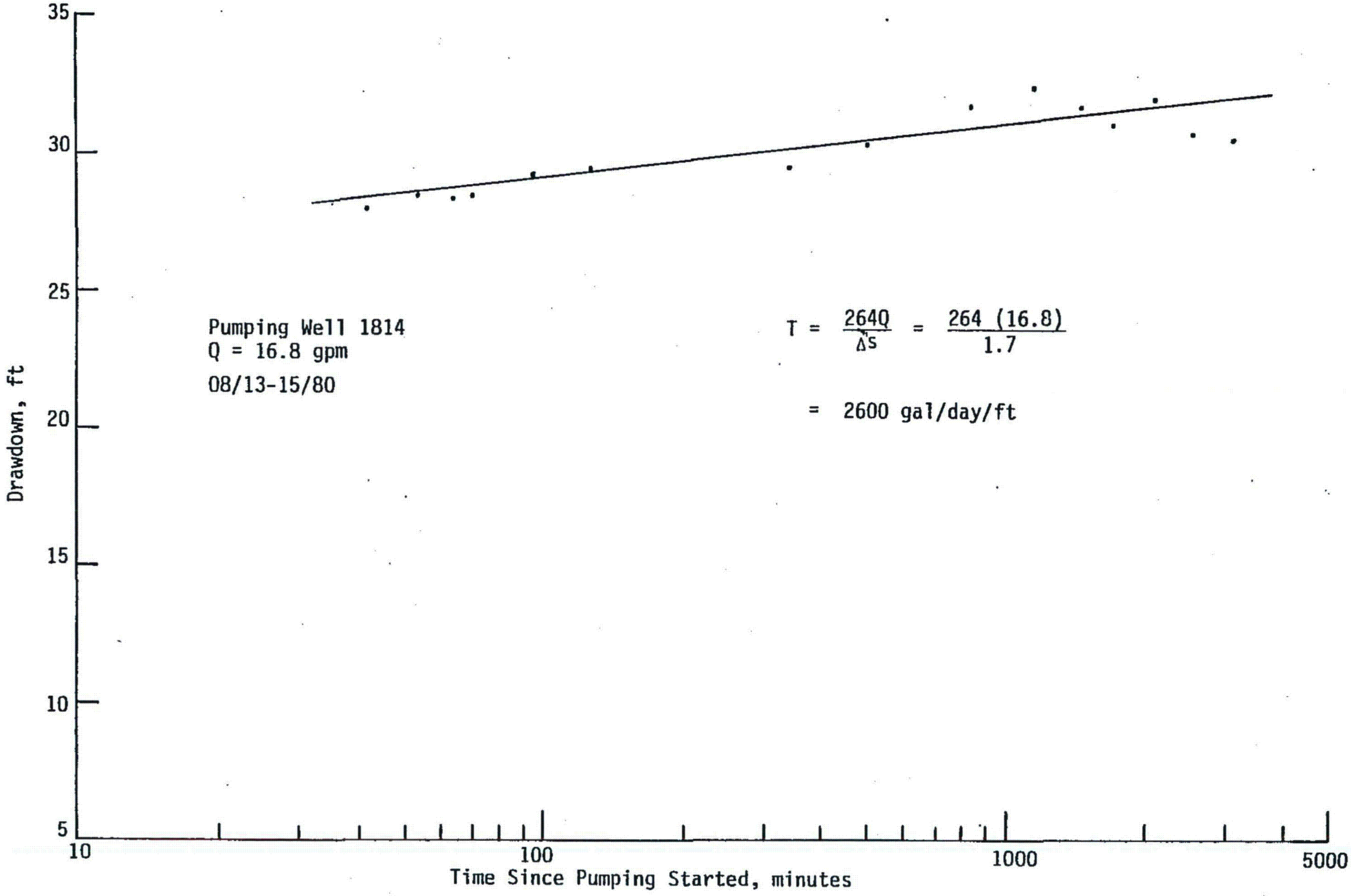


FIGURE A-1.49 DRAWDOWN DATA FOR PUMPING WELL 1814 (70 SAND)

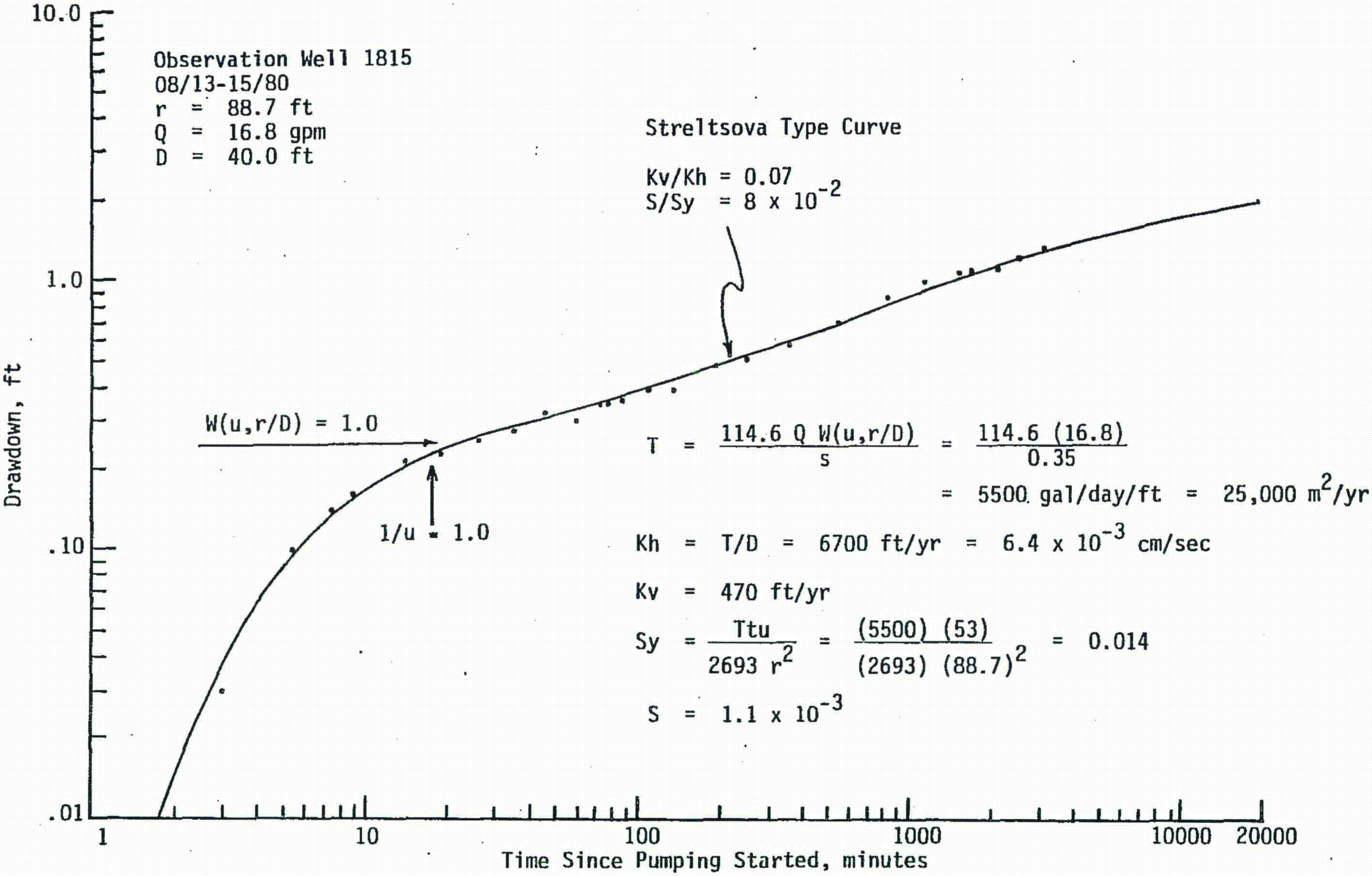
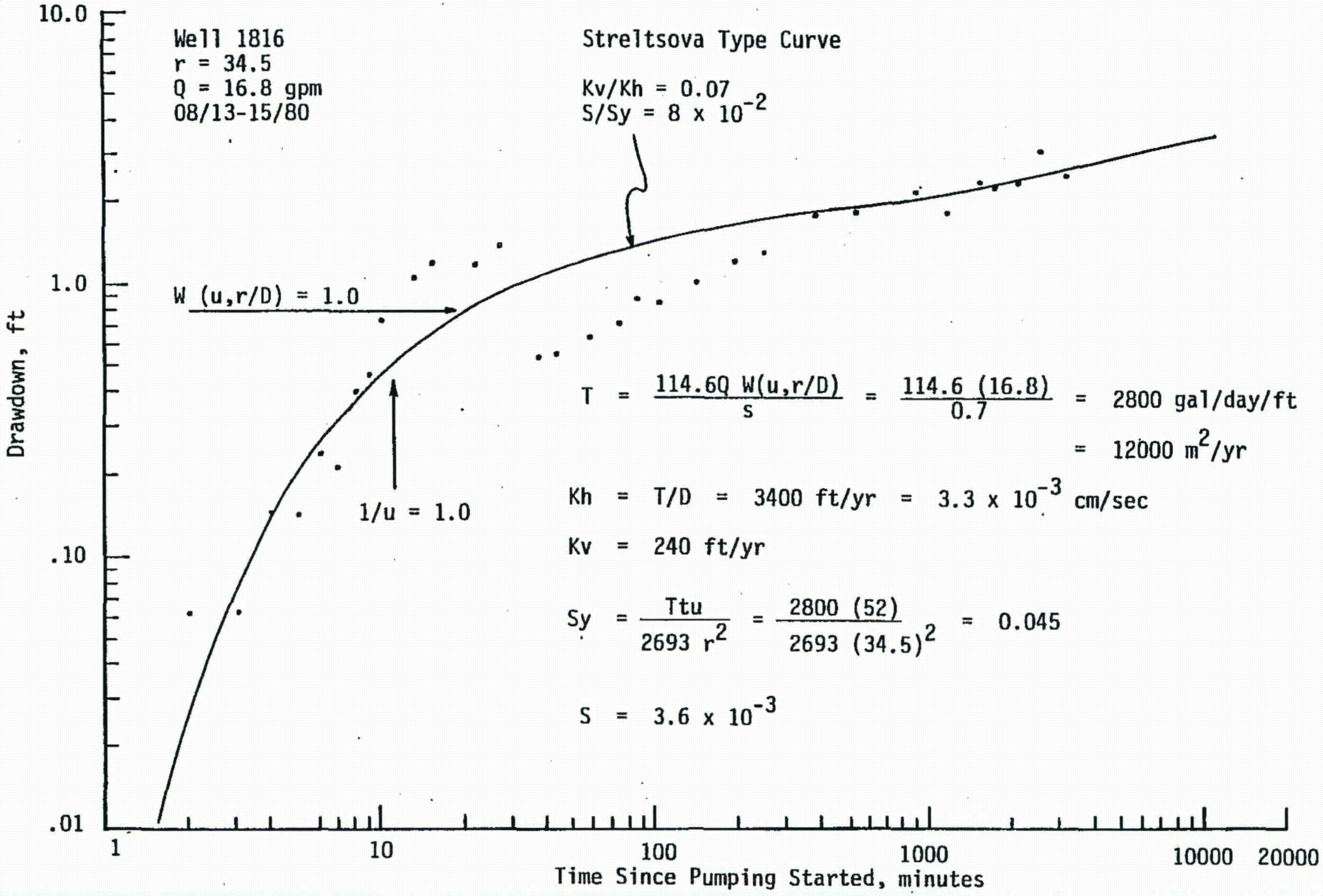


FIGURE A-1.50 DRAWDOWN DATA FOR WELL 1815 FROM PUMPING WELL 1814 (70 SAND)



Well 1816
r = 34.5
Q = 16.8 gpm
08/13-15/80

Streltsova Type Curve

Kv/Kh = 0.07
$S/Sy = 8 \times 10^{-2}$

$$T = \frac{114.6Q\ W(u,r/D)}{s} = \frac{114.6\ (16.8)}{0.7} = 2800 \text{ gal/day/ft}$$

$$= 12000 \text{ m}^2\text{/yr}$$

$$Kh = T/D = 3400 \text{ ft/yr} = 3.3 \times 10^{-3} \text{ cm/sec}$$

$$Kv = 240 \text{ ft/yr}$$

$$Sy = \frac{Ttu}{2693\ r^2} = \frac{2800\ (52)}{2693\ (34.5)^2} = 0.045$$

$$S = 3.6 \times 10^{-3}$$

FIGURE A-1.51 DRAWDOWN DATA FOR WELL 1816 FROM PUMPING WELL 1814 (70 SAND)

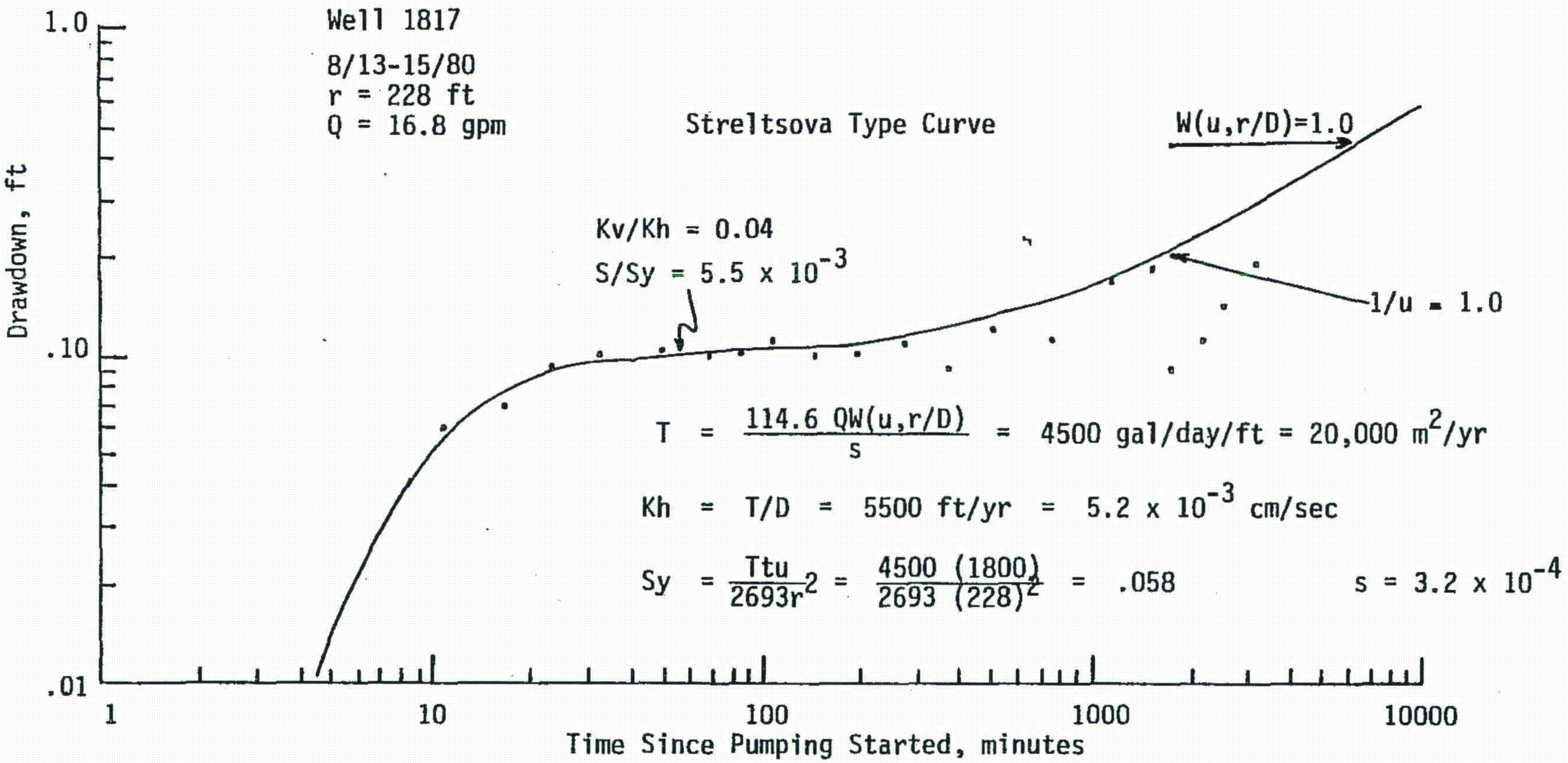


FIGURE A-1.52 DRAWDOWN DATA FOR WELL 1817 FROM PUMPING WELL 1814 (70 SAND)

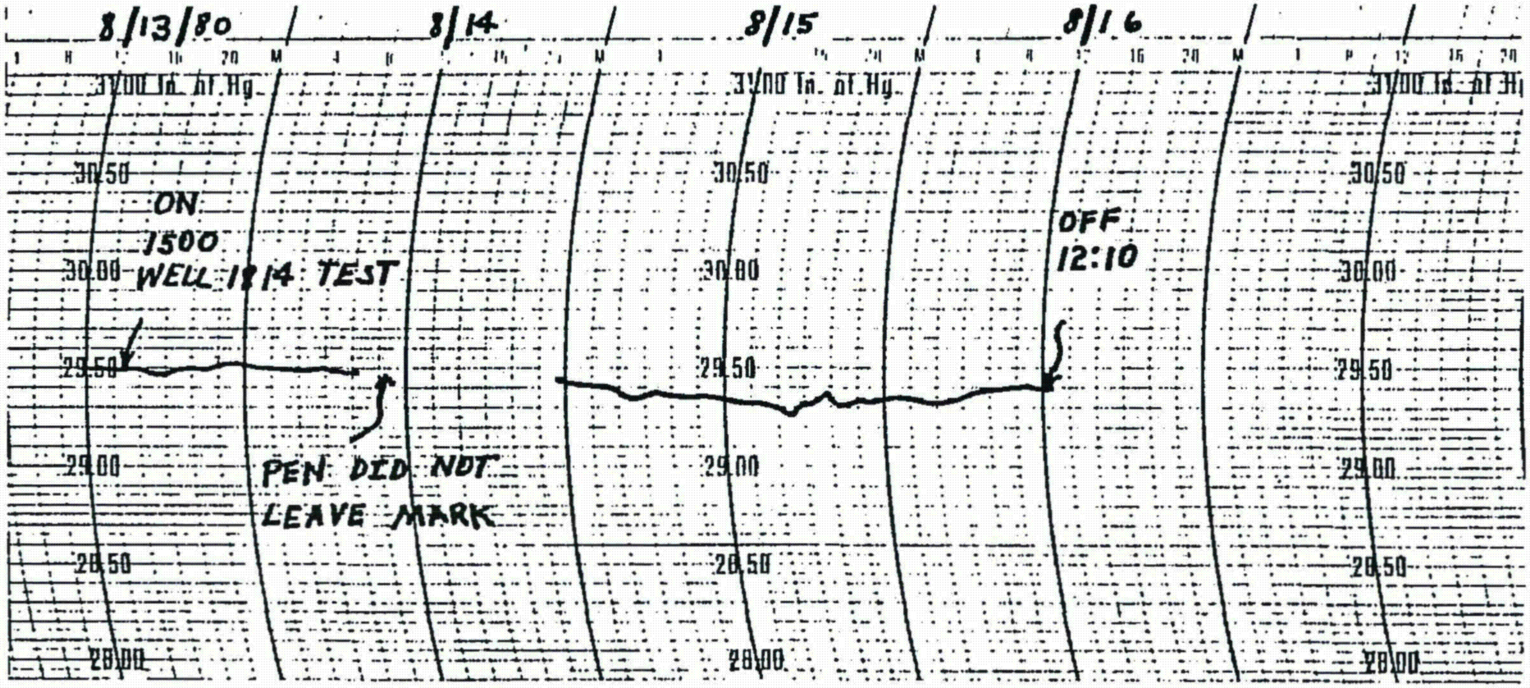


FIGURE A-1.53 BAROMETRIC PRESSURE DURING THE 8/13-15/80 PUMP TEST

APPENDIX A-2

PUMP TEST

THEORY AND ANALYSES

APPENDIX A-2

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TEST ANALYSES

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APPENDIX A-2

TEST ANALYSES

Pump and Constant Head Test Theories

The theory used to analyze transmissivities and hydraulic conductivities from nonpumped wells is presented first. Theories used to evaluate aquifer properties from the pump tests are given last.

Hydraulic conductivities (permeabilities) in wells which yield only small amounts of water were determined by constant head injection tests. Dry drill holes were also tested using this method after saturating the rock unit outside the perforated casing interval. Lohman (1972, pages 23-29) presents the theory for a constant-head drawdown or injection test. Briefly, this technique utilizes a form of Jacob's straight-line semi-log plot method and the equation:

$$T = \frac{264}{\Delta(sw/Q/\Delta \log_{10}(t/r_w^2)}$$

$$= \frac{264}{sw\Delta(1/Q)} \quad \text{change in } 1/Q \text{ for one log cycle of } \log_{10} t$$

where Q = discharge, in gpm

sw = constant drawdown, or head, in ft

T = transmissivity, in gal/day/ft

t = elapsed time, in min

r = effective well radius, in ft

The inverse of the injection rate was plotted against elapsed time since injection started on semi-log paper with time on the log scale. The inverse of the injection rate should gradually increase with time and form a straight line. The change in the injection rate from the straight line over one log cycle is used with the above equation to compute the transmissivity of the unit. The hydraulic conductivity was obtained by dividing the transmissivity by the test interval. Theis, in 1935, introduced his equation which describes a nonleaky confined aquifer. The following is a general definition of the Theis equation:

$$T = 114.6QW(u)/s$$

$$u = 2693r^2S/Tt$$

where: s = drawdown, in ft

Q = discharge in gallon per minute (gpm)

$W(u)$ = well function

T = transmissivity in gallons (gal)/day/ft

u = well function variable

r = observation well radius from pumping well, in ft

S = storage coefficient

t = time since pumping started in minutes (min)

Pump test data are analyzed by matching the log-log plot of drawdown versus time to Theis' type curve (W(u) vs. 1/u) and applying the above equations to the match. Pages 92-98 of Ferris and others (1962) present a more thorough discussion of the Theis equation.

Theis' equation can be modified to handle recovery of a well or multiple pumping periods by summation of the well functions. The following equation in the solution of Theis' equation for one pumping and recovery cycle (Recovery equation).

$$T = 264\ Q \log_{10} (t/t')/s$$

or $$264Q/\ s'$$

where: t = time since pumping started, in min

t' = time since pumping stopped, in min

s = residual drawdown, in ft

s' = change in residual drawdown over one log cycle of time on a semi-log plot, in ft

Therefore, when residual drawdown is plotted on an arithmetic scale versus t/t' on a logarithmic scale, the above equation can be used for the straight line fit. Pages 100-102 of Ferris and others (1962) should be consulted for a discussion of Theis' recovery method. Theis' recovery equation is for a nonleaky confined aquifer also.

Theis' equation with Jacob's (1944) correction for aquifer thinning has been used extensively to analyze unconfined aquifer tests. However, this equation does not take into account the free surface boundary of the water table. Theories of unconfined aquifers are more complicated than Theis' equation with the moving boundary at the phreatic surface. Boulton

(1954) presented an unconfined flow equation for drawdown at the free surface. This equation has not been used very extensively, because drawdowns at the phreatic surface and from a well which penetrates the aquifer are considerably different. Stallman (1963, 1965) developed some type curves for an unconfined aquifer from an electric analog, but these curves have not been used extensively because they are for limited well conditions. Dagan (1967) and Neuman (1972, 1974) have developed computer programs which compute type curve values for unconfined aquifer conditions. Neuman showed that unconfined aquifers have some storage from compression of the aquifer structure and the expansion of the fluid. His equation, therefore, has both a storage coefficient and a specific yield term. Dagan's equation considers only the specific yield for storage. All of these unconfined aquifer equations produce equal type curves for the same conditions except Neuman's curves, which depart from the other curves at early pumping times. The confining nature of most unconfined aquifers is only significant at early pumping times. Some of the pump tests on the 70 sand were conducted long enough to define only the early time drawdown. Neuman's pump test theory was selected for our pump test analyses because it defines the early drawdown also.

Development of Neuman (1974) type curves requires an execution of a computer program for each individual pump test. Streltsova (1972, 1973) developed an approximation of the vertical flow equation and has shown this approximation is the same as Boulton's (1963) flow equation. Streltsova's approximation allows Boutlon's type curves to be used to analyze an unconfined aquifer with consideration of vertical flow if all wells are fully penetrating. The following form of Steltsova's equation will be used in this report:

$T = 114.6\ Q\ W(u,r/D)/s$

$S_y = Ttu/2693r^2$

The relationship between this equation and Boulton's equation is as follows:

$r/B = r/D \sqrt{3K_v k_h}$

where: T = Transmivsivity, in gal/day/ft

Q = Discharge, in gpm

s = Drawdown, in feet

$W(u,r/D)$ = Streltsova well function

S_y = Specific yield

t = Time since pumping started, in minutes

u = Well function variable

r = Distance from pumping well, in feet

D = Aquifer thickness, in feet

$B = \sqrt{\alpha S_u/T}$ (Boulton's equation)

$\alpha = 3K_v/S_y/D$ (Boulton's equation)

K_v = Vertical hydraulic conductivity, in ft/day

K_h = Horizontal hydraulic conductivity, in ft/day

Test Results

The results of the permeability tests from the low yielding wells and dry piezometers in the evaporation pond area will be presented first with the 70 sand tests from this area given second. The permeability and transmissivity results from the 35N area will be given last.

Twenty-one constant head injection and three recovery tests were conducted to determine the saturated hydraulic conductivity (permeability) of the subsoil materials in the evaporation pond area (see Figure D-6-2) for a schematic of lihologic units). Fifteen constant head injection tests and two recovery tests were conducted in the 35N tailings area.

Several pump tests were conducted on the 70 and 68 sands in the mine area. The injection rates necessary to maintain the water level at the top of the casing were measured. Most of the injection tests were conducted approximately three to four hours. The constant head used in the permeability computation was static water level for previously saturated units, or the depth to the center of the perforations for unsaturated rock units. These two depths were measured from the top of the well casing. Dry piezometers were filled with water for one or two days prior to the tests to saturate the perforated unit.

Table A-1.1 presents the basic data for the constant head test conducted on hole P-1, a Lower mudstone (claystone) and E coal piezometer. This test was conducted for a period slightly less than three hours. This piezometer was developed by bailing and filling with water prior to the tests. The injection rate (discharge) for piezometer P-1 started at approximately one-fourth gallon per minute and gradually decreased to 0.158 gpm at the end of the test. The inverse of the injection rate was plotted versus time since the injection started on semi-log paper with time on the log scale. The straight line fit of the inverse injection rate produced a transmissivity of 3.1 gal/day/ft for the Lower mudstone and E coal near hole P-1. A permeability of 15 ft/yr was computed from this transmissivity.

The constant head test for piezometer P-2 is presented in Table A-1.2 and Figure A-1.2. The test data for this hole shows that the piezometer would take only .0095 gpm at the end of the 229 minute injection period. A permeability of 0.7 ft/yr was computed for the Lower mudstone and E coal formations near hole P-2.

The test results for another Lower mudstone test hole, P-3, are presented in Table A-1.3 and Figure A-1.3. This hole was saturated the day before the test because only a small amount of water was present in the bottom of this piezometer. A permeability of 7.7 ft/yr was computed from this test for the Lower mudstone near hole P-3.

Piezometer P-4 is perforated in the Lower mudstone and E coal. A constant head test on this hole was conducted on April 3, 1980. This piezometer would take only a small injection rate of .0023 gpm after 343 minutes of injection. Transmitting properties of 0.14 gal/day/ft and .70 ft/yr were computed for the Lower mudstone and E coal near P-4 for the transmissivity and permeability, respectively.

Piezometer P-4B was injected at a constant head while the water level in piezometer P-4B1 was observed. Both wells are completed in the Upper mudstone and E coal. Table A-1.5 presents the injection rate data for hole P-4B. A gradual water level rise in piezometer P-4B1 was observed during the injection test after approxiately 30 minutes with a total drawdown of greater than one-tenth of a meter at 275 minutes. Well P-4B1 is approximately 5 feet from well P-4B. A permeability of 16 ft/yr was computed from the injection test.

An Upper mudstone piezometer, P-4CA, was tested by injecting water to maintain a constant head at the top of the casing. Table A-1.7 gives the basic test data for piezometer P-4CA, which was taking .0076 gpm after 398 minutes of injection. The straight line fit of this data produced a permeability of 4.6 ft/yr for the Upper mudstone near piezometer P-4CA. Figure A-1.7 presents the plot of this data, which is considerably scattered.

The test on piezometer P-5, an E coal well, yielded a permeability of 6.2 ft/yr. Figure A-1.8 gives the straight line fit of this data, and Table A-1.8 contains the test data.

Piezometer P-6 is completed in the Upper sandstone, which is saturated only in the bottom few feet of the formation. The data plot, which is shown in Figure A-1.9, does not follow a good straight line. The initial partial saturation of this sandstone unit could have caused some of the variation in the injection rate. The best fit of the data produced a permeability of 7.1 ft/yr for the sandstone. This test shows that the permeability of the Upper sandstone is low at this interval in this area.

Piezometer P-8 is completed in the Lower mudstone and E coal and was tested on April 2, 1980, with questionable results. Table A-1.11 presents the basic test data, while Figure A-1.11 gives the semi-log plot. This plot shows a large scatter in the injection rates, indicating that factors in addition to those assumed by theory are influencing the system. Results from this test should not be weighted very heavily.

An injection test on piezometer P-9 was conducted for slightly more than five hours with an ending injection rate of .004 gpm. A permeability of 0.38 ft/yr was obtained from this test for the Lower mudstone and E coal.

A second piezometer was completed at the P-9 site in the Upper mudstone. The test on this piezometer, P-9A, indicates that the Upper mudstone at this site has a permeability of 2.5 ft/yr.

The permeability test information for piezometer P-10 is given in Table A-1.14 and Figure A-1.14. The straight line fit produced a permeability of 1.2 ft/yr for the Lower mudstone and E coal in this area.

The injection rate for the constant head test on piezometer P-11 was fairly steady for the first 200 minutes and then steadily increased with time. The pattern of these injection rates did not follow the constant head theory, and, therefore, results from this test are questionable.

The constant head test data for piezometer P-12, which is perforated in the E coal, is presented in Table A-1.16 and Figure A-1.16. The static water level in P-12 is near the top of the E coal, which is approximately three feet thick at this location. A permeability of 6.7 ft/yr was obtained for the E coal near piezometer P-12.

The injection test on piezometer P-13 produced a reasonable semilog plot for the first 40 minutes of injection. Then a steady increase in the injection rate occurred contrary to theoretical expectation.

The constant head test for hole P-13A produced a transmissivity and permeability for the E coal of 1.8 gal/day/ft and 14.8 ft/yr respectively. Figure A-1.18 gives the plot for this test.

Two piezometers were completed at the P-15 site, one in the Lower mudstone and E coal and one in the Upper mudstone. Constant head tests conducted on these piezometers produced permeabilities of 0.71 ft/yr and 55 ft/yr for the Lower mudstone - E coal and Upper mudstone respectively.

Well P-18, which is an alluvial well in the evaporation pond area, produced a permeability of 470 ft/yr for the alluvium in this area. Figure A-1.23 gives the plot of this test.

The upper portion of the 70 sand is not saturated and was tested for permeability at two sites in the evapotation pond area. Permeabilities of 1.0 ft/yr and 0.65 ft/yr were determined for the unsaturated portion of the 70 sand. The low permeabilities from these tests are reflective of the large amount of cementation present within this sandstone above the water table.

Recovery tests were conducted on the three 70 sand wells in the evaporation pond area. Well P-20B was pumped but went dry very quickly. Recovery tests after bailing wells were conducted because the wells would not yield a sustained flow. Permeabilities of 15.8 ft/yr and 3.7 ft/yr were calculated for wells P-7, P-20B and P-21 respectively. Figures A-1.10, A-1.23B and A-1.23C give the recovery plots for these three wells.

Table A-1.24 presents the basic data for the constant head test conducted on hole 35N-1C, an upper 70 sandstone well. This test was conducted slightly less than five hours. This piezometer was developed by bailing and filling with water prior to the tests. The inverse of the injection rate was plotted versus time since injection started on semi-log paper with time on the log scale. Figure A-1.24 shows the graphical representation of the data. The straight line fit of the inverse injection rate produced a transmissivity of 0.40 gal/day/ft. A permeability of 0.78 ft/yr was computed from this transmissivity.

The constant head test data for hole 35N-10 is presented in Table A-1.25. The test for this hole shows that the piezometer would take 0.086 gpm at the end of the 177 minute injection period. A permeability of 7.0 ft/yr was computed for the sandstone formation near hole 35N-1D.

Table A-1.26 presents the data for the constant head test for hole 35N-1E, a mudstone formation. This piezometer was prepared for the constant head test by bailing the hole dry then saturating the hole the day prior to the test. The piezometer would take only .0045 gpm over the 242 minute injection period. The permeability computed for this mudstone formation was 0.9 ft/yr. Refer to Figure A-1.26 for the graphical representation of the constant head test.

Table A-1.27 presents the data for the recovery test conducted on hole 35N-2A. The piezometer was bailed for 34 minutes and the water level was measured over a 133 minute period after bailing had stopped. The water level versus the ratio of time since pumping started to time since pumping stopped was plotted on semi-log paper with the ratio of times on the log scale. Figure A-1.27 shows the graphical representation of the data. A transmissivity of 2.6 gal/day/ft was computed by using an average flow rate of 0.35 gpm. A permeability of 8.5 ft/yr was computed from this transmissivity.

The constant head test data for hole 35N-2B, which is completed in sandstone, is shown in Table A-1.28. The hole was developed prior to the test by bailing and then by saturating. The piezometer took .0806 gpm over the 280 minute injection period. The transmissivity computed for this hole was 0.82 gal/day/ft. Figure A-1.28 shows the straight line fit of the inverse injection rate. A permeability of 7.8 ft/yr was computed from the transmissivity.

Table A-1.29 shows the data for the constant head test for hole 35N-2C, a mudstone piezometer. The injection period was 275 minutes with an injection rate of 0.168 gpm at the end of the test. The transmissivity was computed to be 0.9 gal/day/ft. From this transmissivity a permeability of 4.3 ft/yr was computed.

Table A-1.30 shows the data for the constant head test for hole 35N-3, a sandstone piezometer. The piezometer was developed by bailing and then by saturating prior to the test. The permeability was computed to be 34.7 ft/yr.

The constant head test data for hole 35N-4 is presented in Table A-1.31. The piezometer took .049 gpm over the 242 minute injection period. The transmissivity was computed to be 1.1 gal/day/ft. Figure A-1.31. shows a graphical representation of the constant head data. From the computed transmissivity, a permeability of 2.7 ft/yr was computed.

The data for the constant head test for hole 35N-5 can be found in Table A-1.32. The piezometer was developed prior to the test by bailing and then by saturating. The transmissivity was computed to be 0.0025 gal/day/ft. From this transmissivity a permeability of 10.2 ft/yr was computed.

Table A-1.33 shows the data for the constant head test for hole 35N-6, a sandstone formation. This test was conducted over a five-hour period. The inverse of the injection rate was plotted versus time since injection started on semi-log paper with time on the log scale. Figure A-1.33 shows the graphical representation of the data. The straight line fit of the inverse injection rate produced a transmissivity of 2.1 gal/day/ft. A permeability of 10.2 ft/yr was computed from this transmissivity.

Table A-1.34 presents the data for the recovery test conducted on hole 35N-7A (70 sand well). The data shows that the recovery was measured after two different intervals (bailing cycles). Figure A-1.34 shows the graphical representation of the data. The permeability was computed to be 1,430 ft/yr.

The constant head test data for hole 35N-7B, an upper 70 sandstone, is presented in Table A-1.35. The test for this hole shows that the piezometer took 0.207 gpm at the end of the 395 minute injection period. A permeability of 5.5 ft/yr was computed for this formation.

Table A-1.36 presents the constant head test data for hole 35N-7C, a sandstone formation. The hole was developed prior to the test by bailing and then by saturating. The transmissivity was computed to be 1.7 gal/day/ft. From this transmissivity the permeability was computed to be 8.3 ft/yr.

Table A-1.37 presents the constant head test data for hole 35N-7D, an E coal piezometer. This piezometer was developed by bailing and filling with water prior to the tests. The inverse of the injection rate was plotted versus time since injection started on semi-log paper with time on the log scale. Figure A-1.37 shows the graphical representation of the data. The straight line fit of the inverse injection rate produced a transmissivity of 5.8 gal/day/ft. A permeability of 40.6 ft/yr was computed from this transmissivity.

The constant head test data for hole 35N-7E is presented in Table A-1.38. This piezometer took 0.014 gpm over a 300 minute period. The permeability was computed to be 42.1 ft/yr.

Table A-1.39 presents the constant head test data for hole 35N-7F, a mudstone formation. The transmissivity was computed to be 0.37 gal/day/ft. Figure A-1.39 shows a graphical representation of the data. From the transmissivity a permeability of 3.0 ft/yr was computed.

The constant head test data for hole 35N-7G, an upper coal, is presented in Table A-1.40. The piezometer was developed by bailing and by saturating prior to the test. The piezometer took only 0.0025 gpm over a 275 minute injection period. The permeability was computed to be 0.09 ft/yr.

Pump tests have been conducted in each of the proposed mine pits to define the aquifer properties of the 70 sand aquifer. Well 885, which is inside the limits of Pit 34, was pumped at 3.4 gpm for approximately one day. Table A-1.41 presents the drawdown for the three obervation wells.

Wells 885, 886 and 888 are 70 sand wells, while well 887 penetrates only the 68 sand, which is the next sand below the 70 sand. The drawdown and its best fit Streltsova type curve ($Kv/Kh = 0.66$ and $S/Sy = 7 \times 10^{-2}$) in observation well 886 are shown in Figure A-1.41. This match produced a transmissivity of 800 gal/day/ft for the 70 sand aquifer in the area of pit 34. Horizontal and vertical permeabilities of 650 ft/yr and 430 ft/yr, respectively, were computed for the 70 sand aquifer. These values show that the 70 sand is only slightly anisotropic in this area. Storage values of 0.015 and 1.0×10^{-3} were computed for the specific yield and storage coefficient respectively. The shape of the drawdown curve in well 888 is considerably different that the shape of the curve for well 886. The match of the drawdown data for well 888 (see Figure A-1.42)produces a much lower transmissivity. A similar storage coefficient and anisotropic ratio (Kv/Kh) were obtained from the analysis of the drawdown from well 888 as well 886. The drawdown in observation well 887, which is perforated in the 68 sand, is given in Table A-1.41. The drawdown in this well indicates connection between the 70 and 68 sands, but this well is not analyzed because it is questionable if the well was sealed between the two sands.

Recovery tests were also conducted on wells 886 and 887 by air lifting 2 and 0.1 gpm respectively from these two wells. Tables A-1.42 and 43 give the recovery data, while the recovery plots are shown in Figures A-1.43 and 44. The straight line fit of the recovery data for wells 886 and 887 produced a transmissivity of 1800 gal/day/ft and 1.9 gal/day/ft respectively. This information indicates that the 68 sand has a low transmitting capacity in this area.

A pump test was also conducted on wells in the area of Pit 35N. Well 1 was pumped while wells 1805, 1806 and 1807 were observed for drawdown. Wells 1, 1805 and 1806 are 70 sand wells, while well 1807 is a 68 sand well. Tables A-1.44, 45 and 46 give the drawdown data for the three Pit 35N observation wells. A Streltsova type curve of Kv/Kh = 0.6 (see Figure A-1.45) was matched to the drawdown data to yield a transmissivity of 910 gal/day/ft. A horizontal permeability of 560 ft/yr was computed from the transmissivity and aquifer thickness of 80 feet, while a vertical permeability of 340 ft/yr was obtained from the anisotropic ratio. The analysis of this test also produced a storage coefficient of 5.2×10^{-4} for the 70 sand aquifer near well 1805. The results from observation well 1806 are similar to those from well 1805 and are given in Figure A-1.46. The completion of well 1807 has shown that a good seal was not obtained. The drawdown in observation well 1807 (68 sand) indicates a possible connection between the 68 and 70 sands in this area, but this test was not conclusive on the connection between these two systems.

Well 1816 was observed while well 1814 in Pit 35S was pumped. The match in Figure A-1.47 indicates the anisotropic ratio of the aquifer near well 1816 is 0.4. This test was conducted long enough to obtain a specific yield of the aquifer of 0.01. The transmissivity of 3800 gal/day/ft indicates that the 70 sand is more permeable in the area of Pit 35S.

Pumping and recovery data for well 1823 is presented in Table A-1.48. The well was pumped for 49 minutes. The water level of the well was then measured at different intervals over an 80-minute period after pumping was stopped. The water level versus the time since pumping started divided by the time since pumping stopped was then plotted on semi-log paper with time on the log scale. Figure A-1.48 shows the graphical representation of the data. The transmissivity was computed to be 190 gal/day/ft. The permeability computed from this transmissivity was 306 ft/yr. Table A-1.49 presents the water level in well 1816 during the pumping of well 1823. This data indicates no measurable connection between the 68 and 70 sands in this area.

A three day pump test was conducted on 8/13-15/80. Well 1814 was pumped at an average discharge rate of 16.8 gpm, while wells 1815, 1816, 1817 and 1823 were observed. All of these wells are 70 sand wells except well 1823, which is a 68 sand well. Table A-1.50 presents the pumping and drawdown data for the pumping well 1814, while Tables A-1.51, A-1.52 and A-1.53 present the drawdown data for observation wells 1815, 1816 and 1817, respectively. The water level measurements for well 1823 show a typical water level rise in the adjacent aquifer shortly after pumping starts. The water level in the 68 sand then returns to a level close to the static conditions. The rise at the end of the test is probably attributed to a decrease in barometric pressure. Figure A-1.53 presents the barometric pressure during the pump test.

The semi-log of the drawdown in the pumping well is given in Figure A-1.49. The fit of the straight line yields a transmissivity of 2600 gal/day/ft for the transmissivity of the 70 sand near well 1814. Streltsova's type curve for an anisotropic ratio (Kv/Kh) of 0.07 and storage ratio (S/Sy) of 8 x 10^{-2} matched the drawdown data in observation well 1815. Figure A-1.50 presents this match of the type curve to the drawdown data. Values of 5500 gal/day/ft, 6700 ft/yr and 470 ft/yr were calculated for the transmissivity, horizontal and vertical permeability, respectively. Storage values of 0.014 and 1.1×10^{-3} were computed from the type curve match for the specific yield and storage coefficient.

Drawdown in observation well 1816 reacted very strangely which questions the accuracy of results obtained from this well. Figure A-1.51 presents the match and results from this observation well.

Observation well 1817 is 228 feet from pumping well 1814, and therefore the confining portion of the unconfined aquifer is the major portion of the drawdown curve observed. Figure A-1.52 presents the results of the match for well 1817. A better fit of the late time data would probably be obtained if the drawdowns were corrected for barometric pressure changes.

Appendix A-3 to Appendix D-6 (Hydrology)

EROSION POTENTIAL OF THE SAND ROCK MILL PROJECT SITE

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1.0 INTRODUCTION

1.1 Objectives

The primary purposes of the Sand Rock Mill erosion study were to (1) identify and describe erosional processes actually or potentially active in the study area, (2) provide order of magnitude estimates of past or present erosion rates, and (3) predict future erosional conditions on the site. This information can be used as a basis for designing mitigation programs for potential erosion problems that might arise.

1.2 Methods

Estimates of past and present erosion rates were based on published geological information, analysis of existing topography and geomorphology in the area, calculations of the Universal Soil Loss Equation, discussions with USGS personnel, and limited field investigations. Section 5.0 provides detailed calculations by which quantitative estimates of erosion rates were derived. Assumptions used for each calculated rate are shown.

For the purposes of this study, three time estimates were utilized. "Past" ranges from 100 years B.P. (before present) to 26 million years B.P. The latter figure is the age of the Pumpkin Buttes erosional remnant (i.e., post-Oligocene; Sharp et al. 1964) and therefore represents a convenient starting point for dating regional erosion. "Present" includes the interval from 100 years B.P. to today. "Future" or "Long-term" erosion includes the next 1,000 years (i.e., from now until about 3000 A.D.). The 1,000 year limit was selected because it coincides with the proposed standards for long-term disposal of hazardous uranium mill tailings required by the Environmental Protection Agency (EPA).

Major erosional processes identified in the study area are sheet and rill erosion, stream erosion, gully formation, and wind erosion. The past, present, and anticipated future rates of erosion attributable to each of these processes are discussed in Sections 2.1 - 2.4 of this report.

1.3 Site Description

The Sand Rock Mill site is located in the drainage of Ninemile Creek, which is tributary to Antelope Creek and within the Cheyenne River basin. Several ephemeral washes drain southward across the site toward Ninemile Creek. This study dealt primarily with an ephemeral drainage designated as Wash #2 by Conoco. Wash #2 is of particular interest to Conoco because it crosses the proposed location of a tailing disposal site, Pit 35N (Section 35, T42N, R75W).

Wash #2 has a total drainage area of 2.42 square miles, about half of which is above Pit 35N. Present plans call for Pit 35N to be covered with 10-30 feet of overburden material, a clay cap, and soil, and then revegetation as part of the reclamation process.

The site is dominated by gently rolling terrain, with occasional sandstone outcrops and blowouts. Parent material is the Tertiary Wasatch Formation; soils are predominantly sandy and have high infiltration rates. Average annual precipitation at the site is about 12-15 inches, mostly falling in spring and summer rainstorms. Vegetation consists of mixed grassland and sagebrush steppe, with fairly well developed cover. This combination of coarse-textured soil, gentle terrain, vegetational cover, and limited rainfall results in very low runoff (1.5 acre-feet per square mile per year) and low erosional rates (Hadley and Schumm 1961).

2.0 RESULTS

2.1 Sheet and Rill Erosion

Sheet erosion is the removal of surface material by water flowing across a surface in sheets (i.e., not confined to channels). Rill erosion is the removal of surface material by water flowing in small channels, usually only a few inches in depth and width.

Present rates of sheet and rill erosion of the Wasatch Formation throughout the Cheyenne River basin are low (1.0 ft/1000 yrs), based on sediment yield studies of Hadley and Schumm (1961). This value assumes a sediment delivery rate of 20 percent and that all sediment is the result of sheet and rill erosion. The Hadley and Schumm study included a small gully-plug stock pond in Section 30, T41N, R75W, about 4 miles west-northwest of Pit 35N. Sediment yields between 1931 and 1954 indicate an erosion rate of 0.8 ft/1000 yrs (Table 1).

Future rates of sheet and rill erosion have been estimated for reclaimed areas using the Universal Soil Loss Equation (Wischmeier and Smith 1978). Assuming slopes with an average gradient of 7 percent, an erodibility factor of 0.3 (U.S. Forest Service 1978), an average density for sandy loam of 1.5 g/cm^3, and vegetation cover of 50 percent (roughly the premining average in a typical year), this method of analysis predicts a postmining erosion rate of about 0.8 ft/1000 yrs (Table 1).

2.2 Stream Erosion

Stream erosion is the cyclical process of erosion and deposition in the lower portions of a drainage basin. At present, Wash #2 appears stable, based on the meandering pattern of the active channel and the mostly vegetated sideslopes. Minor lateral cutting along the outside banks of meanders and downcutting through grassy channel bottoms occurs in a few places.

Thicknesses of alluvium in the area indicates the depth of valley cutting in Wash #2 that has occurred in the past. For example, Conoco hydrology consultant George Hoffman (personal communication, 1980) reports that the alluvium is about 7.5 ft deep in a well 500 ft west of the Pit 35N site. The well is near the edge of the lowermost terrace, and alluvium thicknesses probably are greater toward the middle of the channel. According to Conoco project geologist John Barr (personal communication, 1980), the alluvium in Wash #2 probably is about 6-10 ft deep, based on well cuttings, lithologic logs, and geophysical logs. The depth of stream erosion in Wash #2 might be controlled by bedrock in the vicinity of a sandstone outcrop in Section 2, T41N, R75W to the south.

Table 1. Summary of erosion rates estimated for the Sand Rock Mill study area.

Process	Rate (ft/1000 yrs)	Method	Interval Measured	Area Where Calculated	Source
Sheet and Rill Erosion	1.0	sediment accumulation	present	Wasatch Formation, Cheyenne River Basin, Wyoming	Hadley and Schumm (1961)
"	0.8	sediment accumulation	1931-1954 A.D.	Section 30, T41N, R75W	"
"	0.8	Universal Soil Loss Equation (USLE)	projected post-reclamation	site specific	This Study
Stream Erosion	2.0	terrace stratigraphy	5000 yrs B.P. to present	Ninemile Creek	"
"	in progress	radiocarbon (C^{14})	—	site specific	"
Wind Erosion	≤ 2.5	soil loss tolerance	present	site specific	"
Denudation	0.03	Pumpkin Buttes erosion surface	26 million years B.P. to present	South Pumpkin Butte, Wyoming	"
"	0.8	clinker bed fission track dating	0.7 million years B.P. to present	Little Thunder Creek, Wyoming	Coates (1980)
"	1.1-2.4	sediment accumulation	130-580 yrs B.P., 2500-4000 yrs B.P.	Powder River Basin, Wyoming	Leopold and Miller (1954)

Based on correlation of terrace stratigraphy at Ninemile Ranch (Merith Reheis, USGS, personal communication, 1980), valley cutting of Ninemile Creek has proceeded at an average rate of about 2 ft/1000 yrs (Table 1) during the last 5,000 years.

An estimate of stream erosion rates in Wash #2 currently is being obtained using a radiocarbon (C^{14}) dating method. The C^{14} age date is being calculated for organic matter collected from a buried soil A horizon in a low terrace adjacent to the active channel. The low terrace represents the most recent stage of alluvial deposition in Wash #2, and the C^{14} date represents the minimum age of the terrace. The height of the terrace divided by the minimum age of the terrace will indicate the maximum rate of recent stream cutting (Table 1).

2.3 Gully Formation

Gullies are deep, steep-sided channels, generally formed by ephemeral streams in areas of occasionally high runoff and readily erodible substrate. Gullies are common throughout the West, where steep slopes, sparse vegetation, and intense thunderstorm precipitation events combine to produce short-duration episodes of rapid downcutting.

At present, none of the washes in the Sand Rock Mill area shows signs of gully formation, nor is gullying a common feature of drainages on Wasatch Formation substrate elsewhere in the Cheyenne River basin. The scarcity of gullies in the area probably is attributable to the preponderance of sandy materials, which have higher infiltration rates and typically support fairly dense plant cover.

Because gullying does not appear to be a significant problem on the site at present, no attempt was made to quantify rates of gully formation in the region. Susceptibility of Wash #2 to future gullying probably is low. It is possible that sandstone outcrops near the confluence of Wash #2 and Simmons Draw will provide a bedrock control of downcutting in the area of Pit 35N.

2.4 Wind Erosion

Wind (aeolian) processes generally fall into two categories. Sand-sized particles are moved short distances and deposited as dunes. Finer particles are lifted to considerable heights and may be transported out of the area entirely.

The relatively sparse vegetation and high average wind speeds characteristic of the region have resulted in a long history of erosional and depositional aeolian processes. The Casper Distributary Current is a wind corridor that flows north and east from Casper across the site (Johnson and Bryant 1979). Aeolian deposits occur throughout the wind belt, often as sandy areas on the leeward slopes of hills or, less frequently, as dune fields.

Deflation hollows or "blowouts" are fairly common on the site, usually less than 0.25 acres in extent and 1 to 3 feet deep. Most blowouts on the site are located along and above stream banks on slopes facing the prevalent wind direction (i.e., west). Hollows as much as 10 feet deep occur along the eastern side of Wash #2.

Present wind erosion rates on the site are estimated to be less than 2.5 ft/1000 yrs, based on soil and vegetation conditions. This figure is based on the assumption that wind erosion currently is below 5 tons per acre per year, the level above which the effects of soil loss would be obvious and widespread. It must be emphasized that this value is a maximum, and that actual rates probably are less.

Future rates of wind erosion are expected to be no greater than present, assuming that reclamation procedures will re-establish vegetation cover comparable to premining conditions.

3.0 CONCLUSIONS

Denudation is the overall lowering of a land surface and therefore represents the total of all erosional and depositional processes active in an area. Past rates of denudation in the Pumpkin Buttes region have been very slow (0.03 ft/1000 yrs) (Table 1). This figure was derived by dividing the average relief of South Pumpkin Butte (693 feet) by the maximum age of its erosional surface (26 million years).

More recent denudation rates apparently are higher than the long-term mean. For example, Coates (1980) estimated regional denudation at 0.8 ft/ 1000 yrs for the past 0.7 million years (Table 1), based on fission track dating of clinker (burned coal) deposits in the Little Thunder Creek area. Hadley and Schumm (1961) arrived at similar values for sheet and rill erosion (see Section 2.1, page 3).

Leopold and Miller (1954) calculated volumes of alluvium deposited during the intervals 130-580 and 2500-4000 years B.P. Assuming a sediment delivery ratio of 20 percent (Schumm 1971), erosion rates averaged 1.1 ft/ 1000 yrs and 2.4 ft/1000 yrs (Table 1), respectively, during those intervals.

In summary, a number of techniques for quantifying erosional processes were used to estimate past and present rates in the area, mostly ranging from 0.8 to 2.5 feet per 1000 years. These figures may be used to extrapolate erosion rates after decommissioning and reclamation are complete; however, they should be considered as approximations. The reliability of these estimates is based on the accuracy of assumptions inherent in each calculation, and the continuation of environmental conditions active in shaping the present landscape.

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5.0 CALCULATIONS

Sheet and Rill Erosion

Method: Direct measurement of sediment accumulation, divided by source area.

Assumptions:

1. Annual sediment accumulation rate calculated by Hadley and Schumm (1961) to be 0.13 acre-feet per square mile per year for four reservoirs in the region and 0.10 acre-feet per square mile per year for a small pond in Section 30, T41N, R75W.
2. Average delivery ratio is 20 percent (Schumm 1977).
3. All sediment delivered to the reservoirs comes from sheet and rill erosion (rate therefore a maximum).

Calculation:

(0.13 ac-ft/mi^2/yr)(1.56 x 10^{-3} mi^2/ac)(1000 yrs) ÷ 20 percent = 1.0 ft/1000 yrs

(0.10 ac-ft/mi^2/yr)(1.56 x 10^{-3} mi^2/ac)(1000 yrs) ÷ 20 percent = 0.8 ft/1000 yrs

Method: Universal Soil Loss Equation (USLE).

Assumptions:

1. See Wischmeier and Smith (1978) for a discussion of assumptions and conditions associated with use of the USLE.
2. Erodibility factor (K) = 0.30; Gradient factor (LS, length/slope) = 1.6; Rainfall factor (R) = 50; Crop factor (C) = 0.07, based on typical premining cover of 50 percent; Practice factor (P) = 1, based on typical rangeland methods. See U.S. Forest Service (1978).
3. Average density of soil lost is 1.5 g/cm^3, the value for sandy loams.

Calculation:

$$A = K \times LS \times R \times C \times P$$

$$A = 0.30 \times 1.6 \times 50 \times 0.07 \times 1 = 1.7 \text{ tons/acre/year}$$

$$1.5 \text{ g/cm}^3 = (4.8 \text{ tons/acre})(907.18 \text{ kg/ton})(2.47 \times 10^{-4} \text{ ac/m}^2) = 0.4 \text{ kg/m}^2$$

$$(0.4 \text{ kg/m}^2)(0.67 \text{ cm}^3\text{/g})(10^3 \text{ g/kg})(10^{-4} \text{ m}^2\text{/cm}^2) = 0.02 \text{ cm}$$

$$(0.02 \text{ cm})(0.3937 \text{ in/cm})(0.08 \text{ ft/in})(1000 \text{ yrs}) = 0.8 \text{ ft/1000 yrs}$$

Stream Erosion

Method: Height of first terrace along Ninemile Creek, divided by approximate age.

Assumptions:

1. Age of first terrace is about 5000 years B.P. (Reheis, USGS geologist, personal communication, 1980).
2. Average height of first terrace is about 10 feet above the active floodplain.
3. No episodes of downcutting below present levels have occurred during past 5000 years.

Calculation:

$$10 \text{ ft} \div 5000 \text{ yrs} = 2 \text{ ft}/1000 \text{ yrs}$$

Wind Erosion

Method: Maximum soil loss on vegetated hillslopes converted to erosion rate.

Assumptions:

1. Owing to absence of active wind erosion features, present soil loss is below the SCS tolerance level of 5 tons per acre per year.
2. Average density of soils on the site is 1.5 g/cm^2.

Calculation:

$$(5\ \text{tons/acre})(907.18\ \text{kg/ton})(2.47 \times 10^{-4}\ \text{ac/m}^2) = 1.12\ \text{kg/m}^2$$

$$(1.12\ \text{kg/m}^2)(0.67\ \text{cm}^3\text{/g})(10^3\ \text{g/kg})(10^{-4}\ \text{m}^2\text{/cm}^2) = 0.08\ \text{cm}$$

$$(0.08\ \text{cm/yr})(0.3937\ \text{in/cm})(0.08\ \text{ft/in})(1000\ \text{yrs}) = 2.5\ \text{ft/1000 yrs}^{*}$$

*This value is a maximum; actual rates probably are lower.

APPENDIX B7

Moore Ranch Supplemental Hydrologic Testing