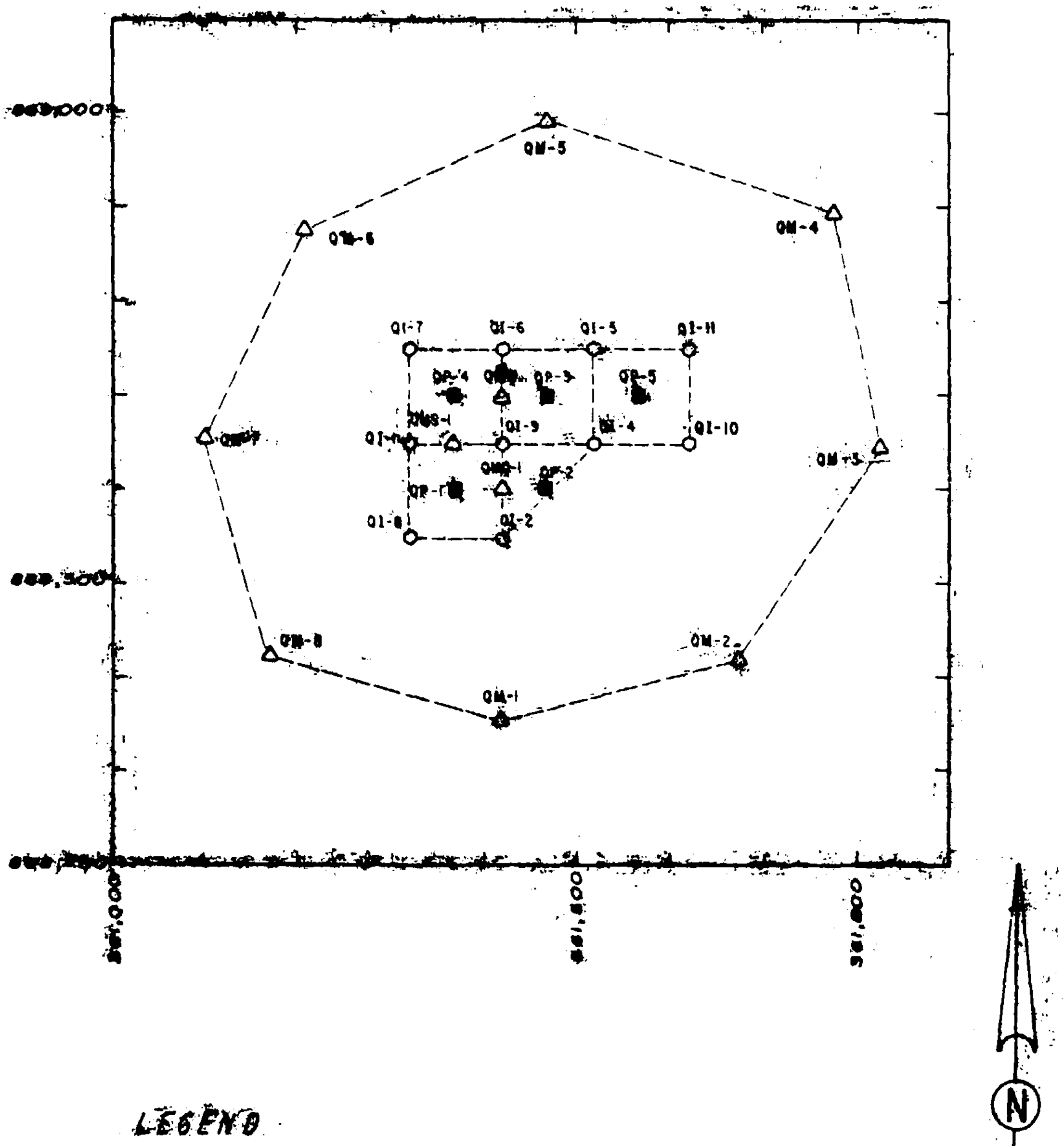
IN SITU R&D PROJECT WELL PATTERN
"Q" SAND DEPOSIT
SECTION 36-T36N, R74W
CONVERSE COUNTY, WYOMING



LEGEND
- △ MONITOR WELL
- ■ PRODUCTION WELL
- ○ INJECTION WELL

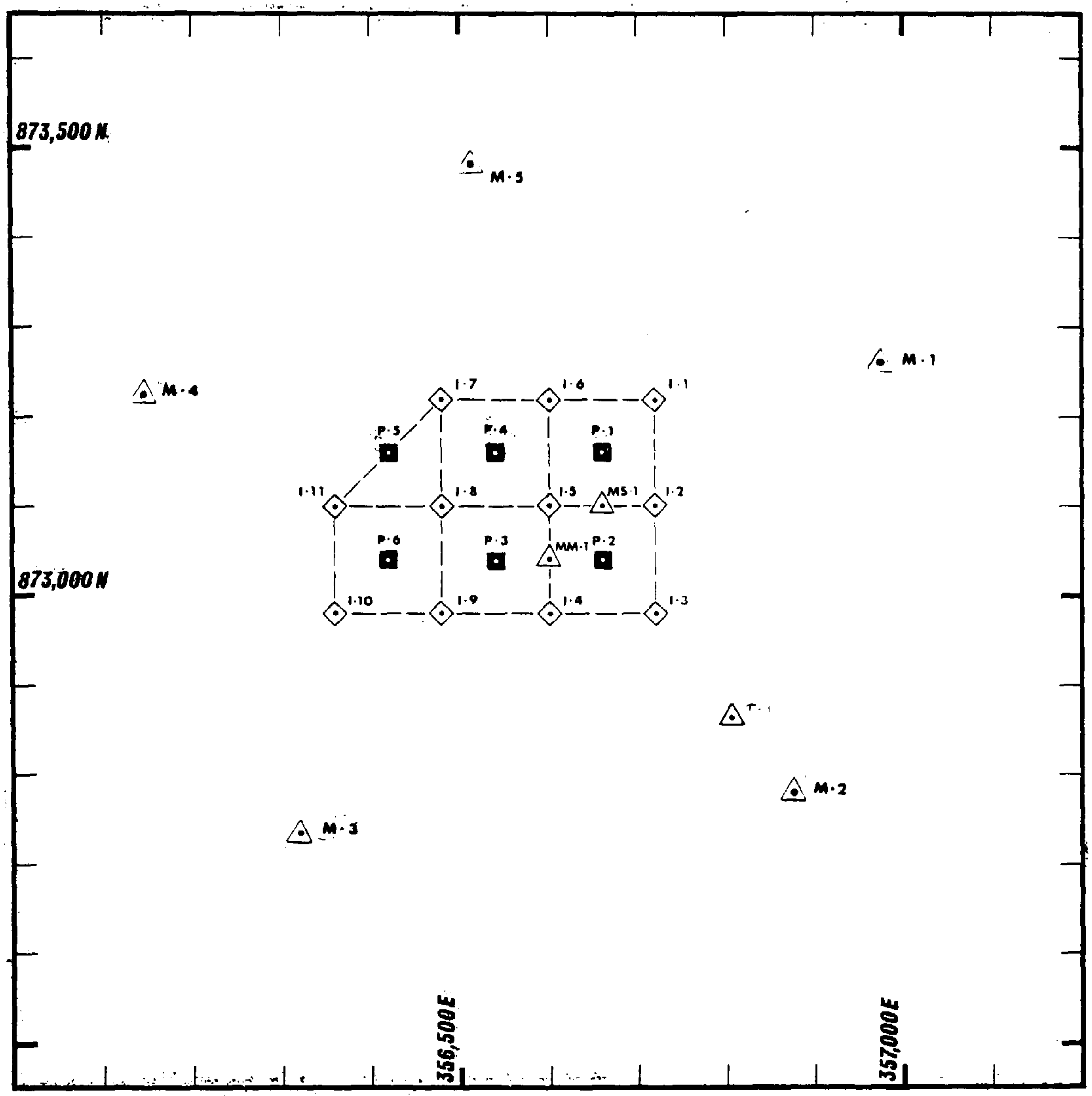
SCALE 1" = 200'

FEB 1980
REV. JULY 1980

FIGURE D-6.6

"O" SAND WELL PATTERN

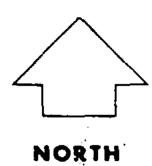
Section 26, T-36N; R-74W



Legend

- Monitor Well
- Production Well
- Injection Well
- MS-1 Upper Zone Monitor Well
- MM-1 Lower Zone Monitor Well

120 ft. Spacing Between Injection Wells



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SURFACE WATER

Surface flow in the permit area is intermittent, the result of both the relatively low average annual precipitation in the region (about 12 inches) and the fact that most stream channels in the area are underlain by Quaternary deposits of high transmissivity.

Most of the high flow rates in the streams of the permit area result from high-intensity convective storms that enter the region from the east (Lowers, 1960). These storms are most likely to occur during May and June.

The permit area is bisected by the Sage Creek Divide, which separates the Platte River Basin to the south from the Cheyenne River Basin to the north. The elevation along this drainage divided is about 5700 feet mean sea level.

The permit area comprises portions of Sage Creek, which is a tributary of the North Platte River (Figure D-6.7). Most channel slopes average between 40 and 90 feet per mile, but slopes of smaller tributary streams are greater than 100 feet per mile.

The average annual runoff from this part of Wyoming is approximately 0.3 to 0.5 inch, or between approximately 0.022 and 0.037 cubic foot per second per square mile (U.S. Soil Conservation Service, 1975; Hodson et al., 1973). Data is available for the Sage Creek watershed (North Platte River). The U.S. Geological Survey (USGS) operated a crest-stage gage on a tributary of Frank Draw (#1 on Figure D-6.7) from 1965 through 1973. Another USGS crest-stage gage was installed on a direct tributary of Sage Creek (#2 on Figure D-6.7) in 1965. Data from these gages indicate that the larger discharges from these streams were probably the result of runoff from convective storms (Table D-6.38). On the basis of a comparison of those peak discharges from the two tributaries that occurred on the same day from a common storm, there appears to be no correlation between the size of the drainage areas and the amounts discharged. However, it should be noted that the Frank Draw tributary is long and narrow, while much of the Sage Creek tributary is broad, with substantial Quaternary deposits across its bottomlands (Figure D-6.8).

Table D-6.38 shows that measurable flows from small watersheds in the permit area may not occur for several consecutive years. For larger watersheds, an average of one to two runoff events can be expected each year during the summer months (U.S. Soil Conservation Service, 1975). Only one event has resulted in providing enough flow for a water quality sample from Sage Creek. In 1998, after an abnormal snow event, enough water was present in Sage Creek resulting from the snow melt to allow a water sample to be collected.

Groundwater was pumped from the Bill Smith Mineshaft from 1974 to 1993. After this water was treated in a settling pond, it was discharged into a tributary of Sage Creek at a rate of about 4 cubic feet per second. The discharge from the mineshaft began in January 1974 and resulted in the movement of the flow front infiltrating the characteristically sandy stream bed 14 miles downstream. Discharge from the settling pond was discontinued in February 1993. Since that time, the tributary to Sage Creek has been dry except for an occasional runoff from natural precipitation.

Flood Prediction

A regional approach was used to conduct a flood analysis for the permit area. A multiple regression method was used to predict floods for the 2 and 100 year recurrence intervals (U.S. Soil Conservation Service, 1965). The results of this analysis are shown in Table D-6.38. Figure D-

6.10 illustrates the effectiveness of prediction for the 12 stations. Unit peak discharge for each station (numbered at the top of the figure) is shown for 2, 25, 50, and 100 year recurrence intervals and for the probable maximum flood. The 6 hour precipitation is noted in parentheses behind each curve label.

Table D-6.38 CREST STAGE PARTIAL-RECORD STATIONS: FRANK DRAW AND SAGE CREEK TRIBUTARIES

Station	Date of Peak Flow	Gage Height (ft)	Peak Discharge (cfs)[a]	Unit Peak Discharge (cfsm)[b]
Frank Draw Tributary				
No. 06648720[c]	06/24/65	2.90	142	180
	08/19/66	4.21	342	433
	06/23/67	2.46	96	122
	07/15/68	1.95	53	67
	06/11/69	0.70	4.9	6.2
	06/12/70	1.12	14	18
	05/30/71	3.80	270	342
	05/09/72	0.44	2.0	2.5
	07/30/73	3.07	163	206
	---------	STATION	DISCONTINUED	-----------
Sage Creek Tributary				
No. 06648780[d]	07/25/65	2.00	229	166
	08/19/66	0.72	33	24
	06/15/67	0.47	14	10
	1968	[e]	[e]	--
	1969	[e]	[e]	--
	06/12/70	0.35	7.8	5.6
	05/05/71	1.20	89	64
	08/02/72	0.92	51	37
	07/22/73	0.99	59	43
	1974	[f]	[f]	--
	1975	[f]	[f]	--
	1976	[f]	[f]	--

[a] cfs = cubic feet per second

[b] cfsm = cubic feet per second per square mile

[c] Location: SW1/4 NW1/4, Sec. 1, T35N, R74W, 60 upstream from culvert on Ross Road, about 16 miles northwest of Orpha, Wyoming. Drainage Area, 0.79 square mile.

[d] Location: NE1/4 NW1/4, Sec. 18, T35N, R73W, 600 feet upstream from culvert on Ross Road, about 14 miles northwest of Orpha, Wyoming. Drainage area, 1.38 miles.

[e] Peak stage did not reach bottom of gage

[f] No evidence of flow

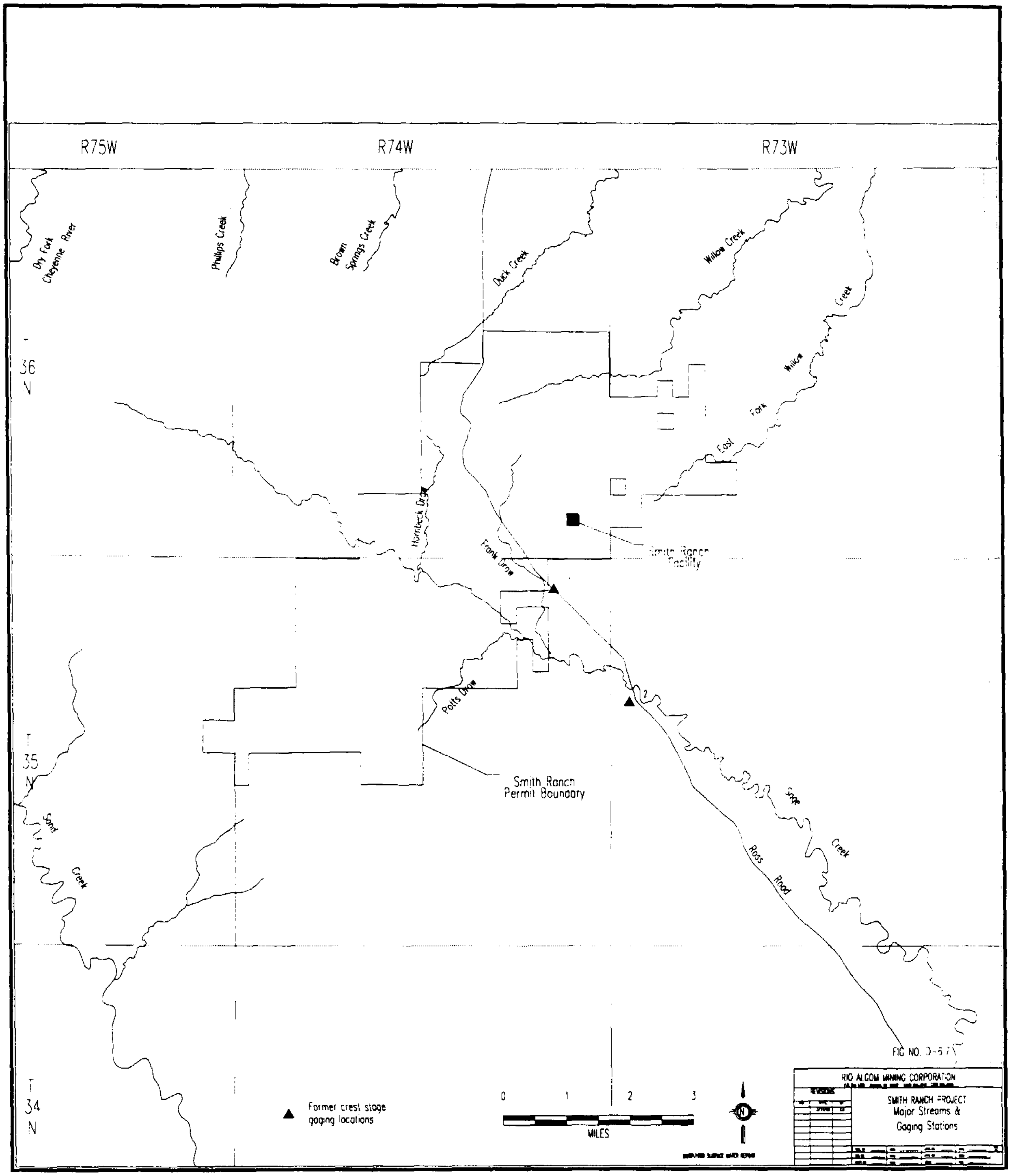

Figure D6-7 Major Streams and Gauging Stations

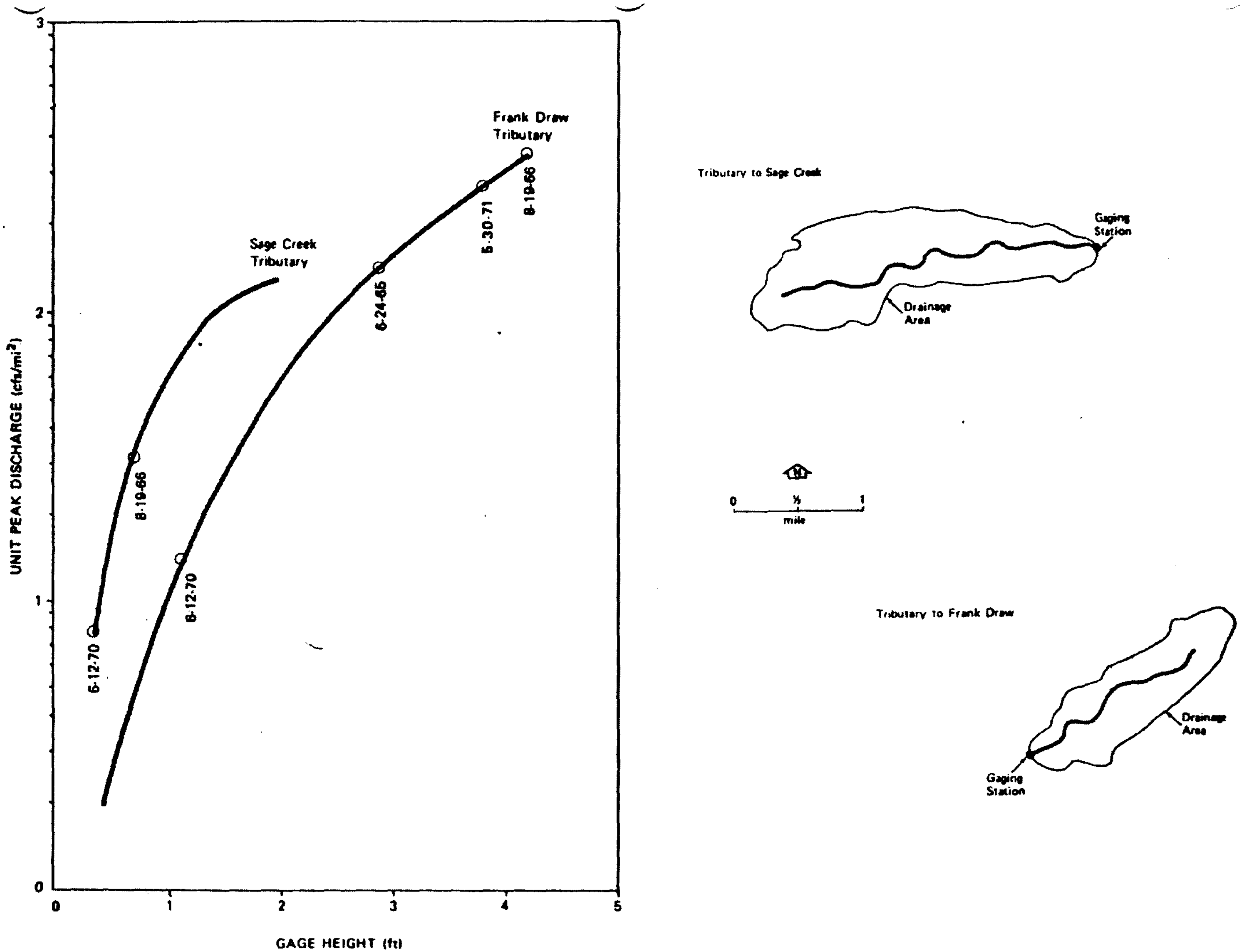

Figure D6-8 Discharge Rate of Two Sage Creek Tributaries

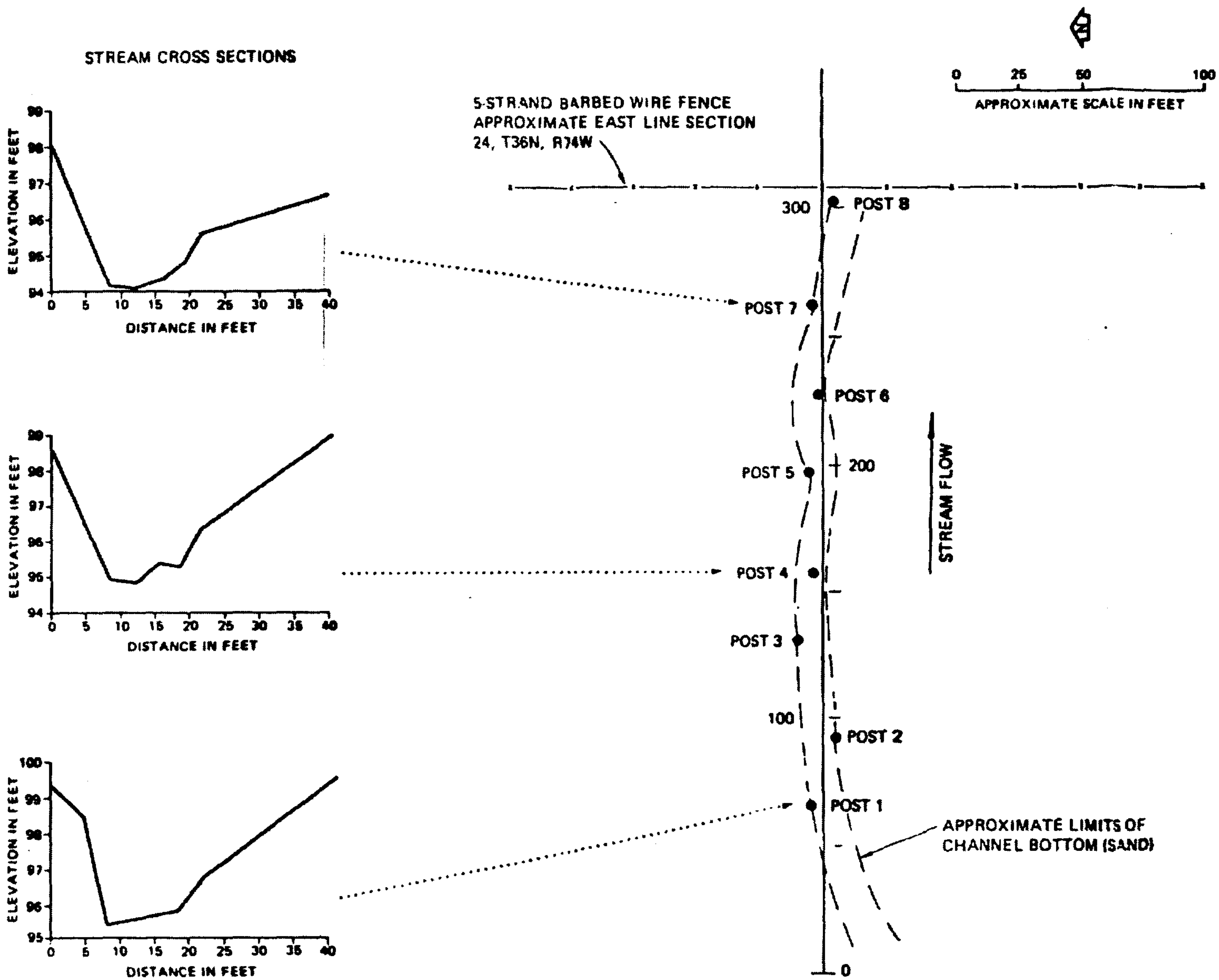

Figure D6-9 Cross Sections and Locations of Crest-Stage Gages

Table D-6.39. SPECIFIC DRAINAGE BASIN CHARACTERISTICS **

Station Number	Drainage Basin	Recurrence Interval (years)	6-Hour Precipitation (inches)	Drainage Area (sq mi)	Basin Slope (ft/mi)	Maximum Relief (feet)	Channel Slope (ft/mi)	Peak Discharge (cfs)	Unit Peak Discharge (cfsm)
2	Unnamed tributary	2	1.1					45	57
	to Frank Draw at	25	2.3					240	300
	former USGS	50	2.6	0.69	393	331	130	330	420
	gaging station	100	3.0					420	530
	No. 066437290	PMP *	19.0					3,900	4,900
4	Unnamed tributary	2	1.1					80	58
	to Sage Creek at	25	2.3					380	280
	USGS gaging	50	2.6	1.38	380	310	95	510	370
	station No.	100	3.0					660	480
	06648780 in Sec.	PMP	19.0					5,200	3,800
	18, T35N, R73W								
5	Hornbeck Draw at	2	1.1					190	65
	Sage Creek in	25	2.3					900	310
	Sec. 4, T35, R74W	50	2.6	2.9	502	365	92	1,200	410
		100	3.0					1,600	550
		PMP	19.0					11,000	3,800
8	Frank Draw at	2	1.1					240	36
	Sage Creek in	25	2.3					1,250	190
	Sec. 11, T35N,	50	2.6	6.6	447	475	72	1,700	260
	R74W	100	3.0					2,250	340
		PMP	19.0					19,800	3,000
12	Sage Creek at	2	1.1					430	6
	lease boundary in	25	2.3					3,500	50
	Sec. 27, T35N,	50	2.6	66.7	-	923	29	5,100	80
	R73W	100	3.0					7,000	101
		PMP	19.0					18,000	1,200

** By USGS Method – Open File Report 77-727

* PMP = probable maximum precipitation

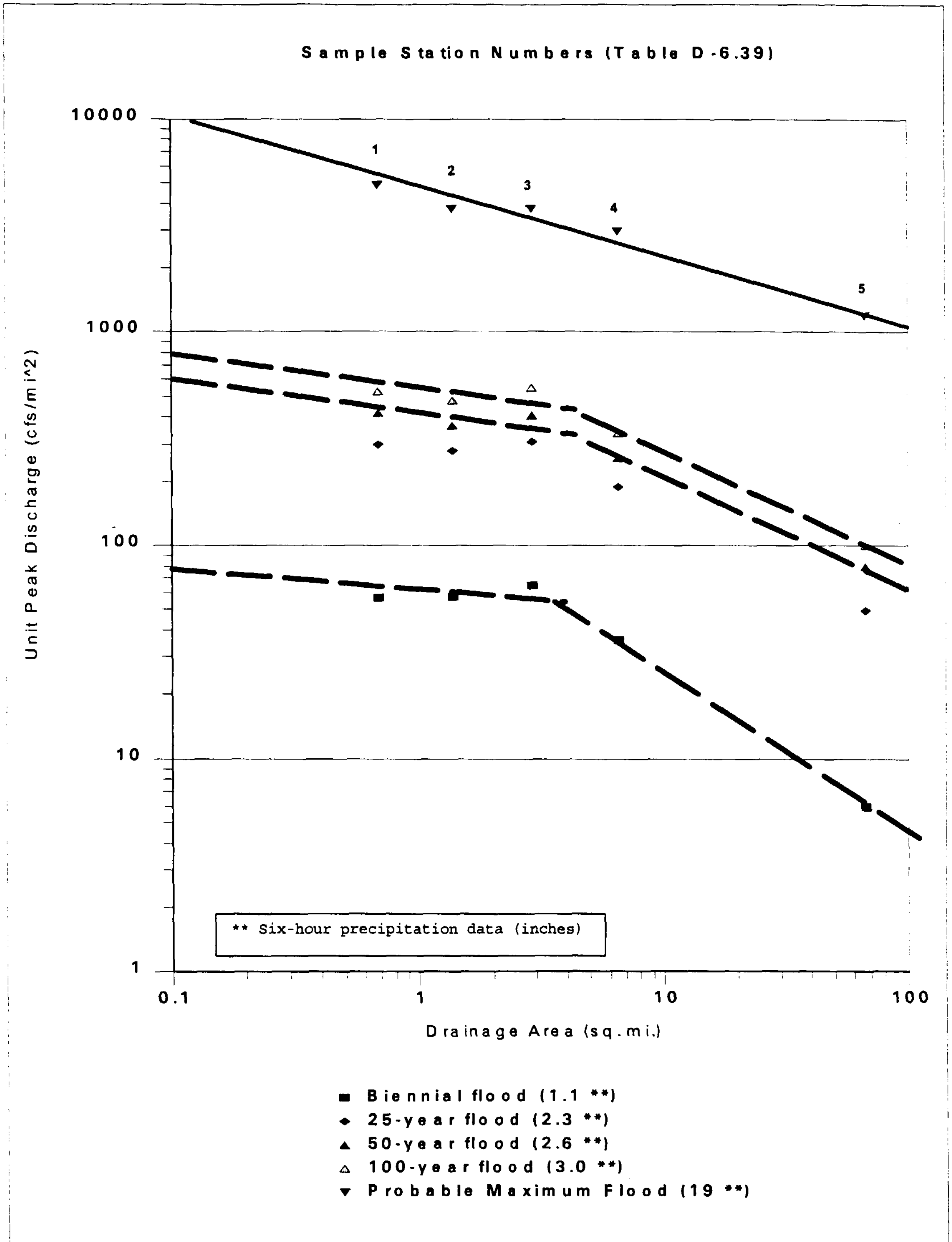

Figure D-6.10 Relationship of Peak Discharge to Drainage Area

FLOOD PREDICTION EQUATIONS

In general, the form of regression equation for predicting the N-year flood for drainage areas of less than 10 square miles is as follows: *

$$Q_n = CA^a S_B^b R_M^c S_C^d$$

where: Q_N is the peak flood discharge for recurrence interval N, in feet per second

A is the drainage area, in square miles

S_B is the basin slope, in feet per mile

R_M is the maximum basin relief, in feet

S_c is the channel slope, in feet per mile

C, a, b, c, and d are regression constants

Equation[a]	Correlation Coefficient	Standard Error of Estimate (%)
$Q_2 = 34.1A^{1.134} S_B^{1.216} R_M^{-1.609} S_C^{0.539}$	0.88	40.4
$Q_5 = 30.8A^{1.105} S_B^{1.135} R_M^{-1.412} S_C^{0.588}$	0.91	33.3
$Q_{10} = 33.0A^{1.094} S_B^{1.080} R_M^{-1.308} S_C^{0.603}$	0.92	31.8
$Q_{25} = 37.7A^{1.086} S_B^{1.012} R_M^{-1.192} S_C^{0.613}$	0.92	32.6
$Q_{50} = 43.9A^{1.084} S_B^{0.962} R_M^{-1.118} S_C^{0.616}$	0.91	34.5
$Q_{100} = 50.2A^{1.082} S_B^{0.914} R_M^{-1.047} S_C^{0.615}$	0.90	37.4

* G.S. Craig, Jr., U.S. Geological Survey, Cheyenne, Wyoming; personal communication, 1976.

[a] Based on data from approximately 22 watersheds in Wyoming.

For drainage areas larger than 10 square miles, the regression equation for predicting N-year floods in the portion of Wyoming that includes the permit area is as follows:*

$$Q_N = CA^b$$

where: Q_N is the peak flood discharge for recurrence interval N, in cubic feet per second

A is the drainage area, in square miles

C and b are regression coefficients

Equation	Correlation Coefficient[a]
$Q_2 = 93.8A^{0.36}$	0.73
$Q_5 = 252A^{0.36}$	--
$Q_{10} = 425A^{0.37}$	0.83
$Q_{25} = 742A^{0.37}$	0.81
$Q_{50} = 1070A^{0.37}$	0.79
$Q_{100} = 1480A^{0.37}$	0.76

* H.W. Lowham, U.S. Geological Survey, Cheyenne, Wyoming; personal communication, 1976

[a] Average standard errors of estimate range from 60 to over 80 percent

WATER QUALITY

Results of water quality surveys are shown in Tables D-6.40 through D-6.41. The locations of the sampling stations are shown in Figure D-6.11. For convenience, the data are presented as major constituents, minor constituents, trace elements, and radioactive trace elements.

Since the data are for a mixture of surface water and groundwater samples, there appears to be no generally recognizable areal pattern. However, collection of the data into groups according to relative depth of source provides relative correlation of water quality characteristics from various sources. This approach was taken as the basis for the discussion that follows.

Major Constituents

Table D-6.40 shows the results of analyses of major constituents and includes the major cations and anions as well as pH and specific conductance.

At all surface water quality sampling points calcium is the dominant cation and bicarbonate is the dominant anion in most of the same stations. In two of the creek sampling points sulfate is the dominant anion. In all cases, chloride concentration is extremely low.

The drainage from the de-watering discharge at the Bill Smith Mine is presented as sequential downstream sample locations D-0 through D-5 in Table D-6.40. Creek 403 is just downstream from this discharge and shows a very close correlation to the water from this source.

Wells of shallow to intermediate depth (0 to 200 feet) penetrate a zone that is generally above the projection of the Badger coal seam. There is remarkable similarity of water quality in these shallow wells south of

Willow Creek. In all cases, calcium and bicarbonate are the dominant cation and anion respectively, and the fractions of the other ions are very similar.

Table D-6.40 MAJOR CONSTITUENTS, WATER QUALITY ANALYSES

Wyoming Well Number	Kerr-McGee Source Numeration	pH (units)	Spec. Cond. (μmhos/cm)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	HCO_3 (mg/l)	SO_4 (mg/l)	Cl (mg/l)
Surface Stations									
35-74-18ba	CR-403	7.8	850	78	38	36	190	280	9
Shallow Wells	**(0-200 ft deep)**								
34-74-1ad	WW-105	7.5	430	51	16	6	230	44	<5
36-74-26ba	WW-109	7.6	690	84	26	12	300	110	16
Deep Wells	**(>200 ft. deep)**								
35-74-12ac	WW-101	-	-	97	16	37	193	220	8
35-74-12ac	WW-102	-	-	91	13	27	264	115	10
36-74-25cc	TW-1	7.5	790	83	28	29	220	210	<5
36-74-25dd	TW-2	7.2	770	81	25	30	230	180	<5
36-74-27cd	WW-110	7.5	-	75	23	4	280	44	<4
36-74-36ab	WW-103	7.3	440	46	15	13	200	63	<5
Mine Discharge [a]									
36-74-36ba	D-0	6.9	770	77	25	28	220	220	<5
36-74-35db	D-4	7.2	690	75	24	27	160	200	<5
35-74-2d	D-5	7.3	710	67	25	28	180	200	<5

[a] **Mine Water is no longer being discharged**

Table D-6.41 MINOR CONSTITUENTS, WATER QUALITY ANALYSES

Wyoming Well Number	Kerr-McGee Source Numeration	Fe (mg/l)	Mn (mg/l)	TSS (mg/l)	PO_4 as P (mg/l)	NO_3 as N (mg/l)	F^- (mg/l)	B (mg/l)
Surface Stations								
35-74-18ba	CR-403	0.3	0.049	3	0.06	-	0.58	0.35
Shallow Wells	**(0-200 ft deep)**							
34-74-1ad	WW-105	0.48	0.002	-	0.06	2.00	0.30	0.08
36-74-26ba	WW-109	1.70	0.015	-	<0.02	<0.01	0.22	0.20
Deep Wells	**(>200 ft. deep)**							
35-74-12ac	WW-101	1.60[a]	0.02	26	0.01	0.02	0.31	0.29
35-74-12ac	WW-102	0.05	0.11	2	0.02	0.02	0.35	0.13
36-74-25cc	TW-1	1.00	0.054	<1	<0.04	<0.01	0.40	0.30
36-74-25dd	TW-2	0.98	0.051	<1	-	<0.01	1.20	0.35
36-74-27cd	WW-110	0.48	0.070	-	0.02	<0.01	0.56	-
36-74-36ab	WW-103	0.25	0.002	-	-	-	0.40	0.15
Mine Discharge[b]								
36-74-36ba4	Pond #3	<0.02	-	5	<0.01	0.70	0.23	<0.01
36-74-36ba	D-0	1.00	0.047	39	0.18	<0.01	0.40	0.30
36-74-35db	D-4	0.42	0.039	28	<0.04	<0.01	0.48	0.40
35-74-2d	D-5	0.25	0.036	13	<0.04	<0.01	0.50	0.25

[a] Galvanized pipe used for casing was corroded.
[b] Mine water no longer discharged

Table D-6.42 TRACE ELEMENTS, WATER QUALITY ANALYSES

Wyoming Well Number	Kerr-McGee Source Numeration	Al (mg/l)	As (mg/l)	Cr (mg/l)	Cu (mg/l)	Sr (mg/l)	V (mg/l)	Zn (mg/l)
Surface Stations								
35-74-18ba	CR-403	0.032	0.001	0.001	0.001	1.10	<0.001	0.010
Shallow Wells	**(0-200 ft deep)**							
34-74-1ad	WW-105	<0.001	<0.001	<0.001	<0.001	0.30	<0.001	0.280
36-74-26ba	WW-109	-	<0.001	0.004	0.005	0.45	<0.015	0.480
Deep Wells	**(>200 ft. deep)**							
35-74-12ac	WW-101	-	-	<0.010	0.020	0.29	<0.050	2.000[a]
35-74-12ac	WW-102	-	-	<0.010	0.010	0.38	<0.050	0.030
36-74-25cc	TW-1	0.001	<0.001	<0.001	0.002	1.10	<0.001	0.003
36-74-25dd	TW-2	0.002	0.001	0.001	0.003	1.10	<0.001	0.003
36-74-27cd	WW-110	-	<0.001	<0.001	0.010	0.18	0.180	0.170
36-74-36ab	WW-103	<0.001	0.002	<0.001	0.065	0.45	<0.001	0.220
Mine Discharge[b]								
36-74-36ba4	Pond #3	-	<0.01	-	-	-	<0.05	-
36-74-36ba	D-0	0.400	<0.001	0.002	<0.001	0.98	0.004	0.010
36-74-35db	D-4	0.160	<0.001	0.001	0.001	0.99	0.002	0.010
35-74-2d	D-5	0.037	<0.001	0.005	0.002	0.96	0.006	0.010

[a] Galvanized pipe used for casing was corroded
[b] Mine water no longer discharged

Table D-6.43 RADIOACTIVE TRACE ELEMENTS, WATER QUALITY ANALYSES

Wyoming Well Number	Kerr-McGee Source Numeration	Uranium (mg/l)	Radium-226 (pCi/l)	pa [a]	Gross Alpha (pCi/l)	Gross Beta (pCi/l)
Surface Stations						
35-74-18ba	CR-403	0.031[c]	1.37	2.71	44	<18
Shallow Wells	(0-200 ft deep)					
34-74-1ad	WW-105	0.030	0.643	3.44	34	23
36-74-26ba	WW-109	0.089[a]	0.400	5.00	84	51
Deep Wells	(>200 ft. deep)					
35-74-12ac	WW-101	0.014	-	-	-	-
35-74-12ac	WW-102	0.029	0.600	3.47	-	-
36-74-25cc	TW-1	0.016	28.71	+0.99	100	<18
36-74-25dd	TW-2	0.014	22.52	+0.88	70	<18
36-74-27cd	WW-110	0.086	1.30	3.79	-	-
36-74-36ab	WW-103	0.028[a]	0.99	2.94	50	18
Mine Discharge[b]						
36-74-36ba4	Pond #3	0.014	1.92	1.58	-	-
36-74-36ba	D-0 [d]	0.027	1.92	2.24	62	<18
36-74-35db	D-4	0.034	5.86	1.37	59	<18
35-74-2d	D-5	0.037	1.78	2.63	53	<18

[a] pa = -ln (Ra/U)
[c] Water samples in which thorium-230 was detected at levels approximately twice the analytical error
[b] Mine water no longer discharged
[d] Sampling sites D-0, D-4, and D-5 are downstream from Pond #3

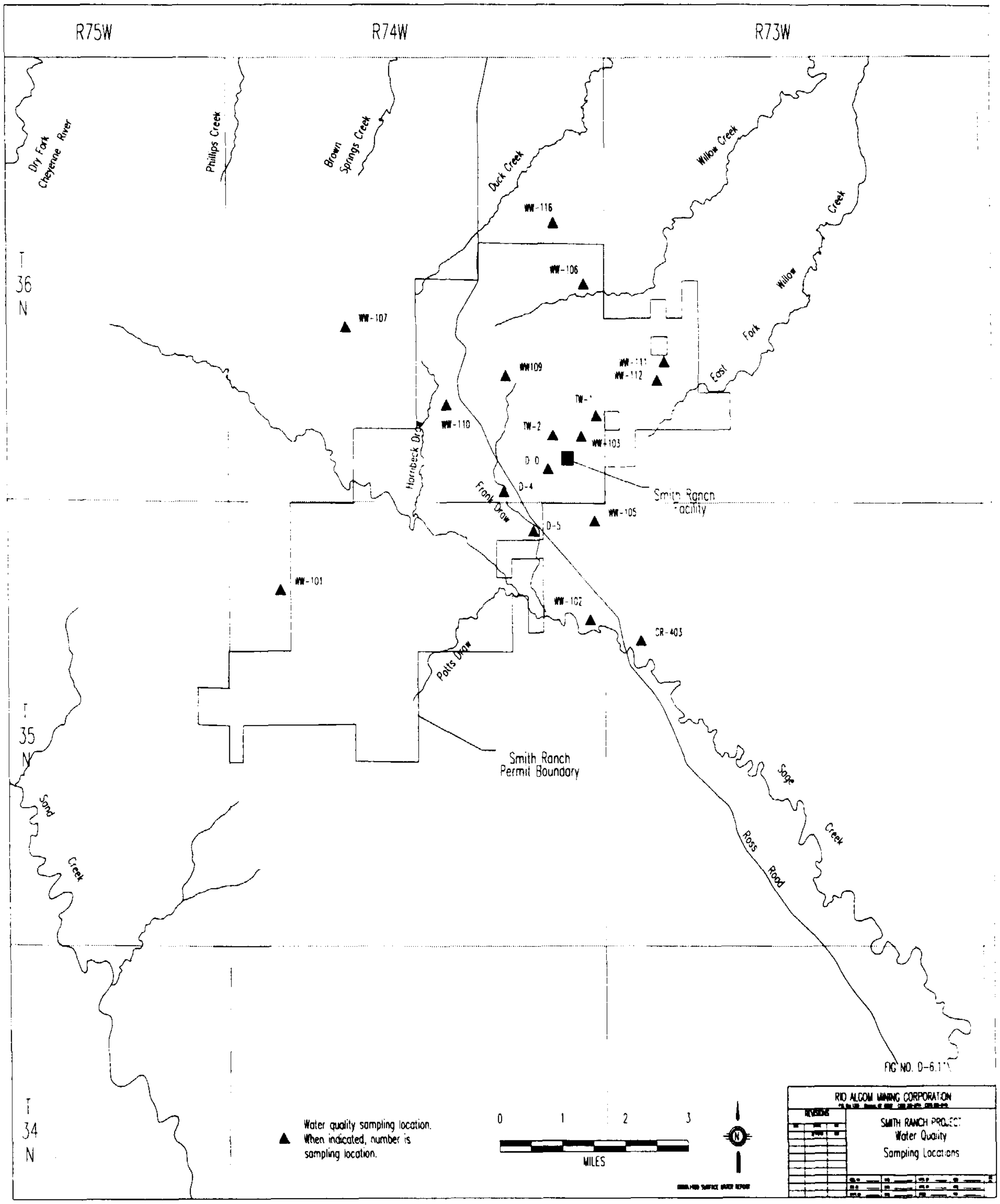

Figure D-6.11 Water Quality Sampling Locations

The same is true for the series of deep wells of 34-74-2dd, WW-102, TW-2, and TW-1. There is an increase in magnesium and sulfate concentration down-dip from the outcrop of the School coal seam that may be attributed to the much higher solubility of magnesium sulfate than that of calcium or magnesium carbonate.

Minor Constituents

Table D-6.41 shows the analyses for minor constituents. The results for iron and manganese show high variability, which is probably due to the variations in redox potential of the samples. The content of nutrients is fairly low.

Analyses for potassium, hardness, alkalinity, temperature, nitrite, cyanide, chlorine, oil and grease, ammonia, organic nitrogen, and fecal coliforms were performed at some stations. The results were generally insignificant (at or below detection levels) and for convenience were omitted from the table.

Trace Elements

Table D-6.42 shows the results of trace element analyses. Of the 23 trace elements analyzed, only those sources shown contained detectable or significant amounts. The following elements were analyzed for but were not detected at any of the stations at the limits given (all are in mg/l):

Antimony	0.01 mg/l
Beryllium	0.001
Cadmium	0.002
Cobalt	0.02
Iodide	0.1
Lead	0.001
Lithium	0.001
Mercury	0.001
Molybdenum	0.001

Nickel	0.02
Selenium	0.001
Silver	0.001
Tin	0.05
Titanium	0.2

In addition, there were insignificant traces of barium and bromide 0.05 ppm and 0.71 ppm, respectively).

Radioactive Trace Elements

Between January 1974 and July 1976, analyses for radium-226 and total uranium were made on the water samples from the permit area. Miscellaneous water samples taken at the Bill Smith Mine also included spot-checks for thorium-230, gross alpha, and gross beta. As in the chemical and trace element analyses, some of the water sources in the permit area were sampled again for radioactivity in September 1976. At that time the analyses were expanded to include thorium-230, thorium-232, strontium-90, gross alpha, and gross beta. Table D-6.43 shows the results of the analyses from all sample periods.

Thorium analyses were generally indeterminate, with thorium-232 at or below detection limits in all samples and thorium-230 at or marginally above detection limits. For those samples whose thorium-230 content, as analyzed, was at least twice the probable error in detection, there appeared to be little or no correlation to either uranium or radium content of the water. The highest values, however, came from wells in the Wasatch Formation. In none of the samples was there any potential for suggesting equilibrium between the thorium and radium or uranium. In general, the thorium levels reported were on the order of three to four magnitudes lower than that of the radium activity.

Three samples of water were analyzed for strontium-90 content (LFE). Spring 201 showed less than 0.5 picocurie per liter (pCi/l), pit I showed 2.3 pCi/l, and well WW-112 showed 1.6 pCi/l. With a probable data error reported of 0.5 pCi/l, there is little significant difference in the latter two values and serious question regarding detection in the spring water. In 1977, samples taken at station D-5, the discharge pond at the Bill Smith Mine, and wells TW-1 and TW-2 were analyzed for strontium-90. All values were below the detectable level (0.8 pCi/l).

Because the thorium and strontium-90 data were generally insignificant, they were omitted from the tabulation characterizing the radioactive content of the water (Table D-6.43). Total uranium, radium-226, natural logarithm of the radium/uranium activity ratio, and gross alpha and beta are listed in the table. Generally, the data shown are those of the most recent sampling period (September 1976) because of its more complete nature. For water sources previously sampled that were not re sampled at that time, the data available for them are noted.

Radium analyses included both soluble and insoluble components. The data tabulated are the summations of both. The insoluble radium was 5 percent, or higher, of the total in most of the surface sources reported but in only four of the subsurface sources, WW-107, WW-115, WW-116, and FW-302. It may be noted that all of these locations correspond to the Wasatch Formation, or in the northern area, where the Wasatch and Fort Union appear to be poorly differentiated and for which the waters appear common. For those sources re-sampled in September 1976, all the waters except WW-115 showed a marked decrease in insoluble radium, which suggests an influence of renewed physical activity (and pumping) in the mine area, a difference in field sampling technique (including preservation), or both.

Perhaps the most interesting and useful result of the radioactive analyses is the trend of the radium-to-uranium* ratio, shown as the negative natural logarithm and represented in Table D-6.11 as pA. It may be seen that waters derived from sources near the surface or above the coal seam traces are almost uniformly strongly negative, indicating that uranium is moving into the water out of equilibrium with radium. This is to be expected in this upper zone of the sediments where oxygen is relatively plentiful. In the deep wells, where waters are derived from formations underlying the coal seams, the pA's of the samples are near zero or definitely positive, indicating that radium is moving into or with the waters relatively independent of the uranium, a characteristic to be expected in a reducing environment. For a given horizon there is some gradation in the pA's with relative position between the outcrop and the center of the basin along the general hydrologic gradient.

In general, there appears to be no material change with time in the uranium content of water samples from the permit area. However, pumping appears to have significantly increased the radium content in the groundwater near the Bill Smith Mine de-watering wells.

*Based on the assumption of nominal uranium-234 content in the dissolved uranium

The relative quantities of uranium and radium in the groundwater appear to have a relationship that varies in geologic space. This variability may be explained by reviewing the geohydrologic source of the water. Examination of the available data indicates that the groundwater with a positive pA is derived from depths below the oxidizing zone for the groundwater (e.g., TW-1). Consequently, the observed geographic transition in groundwater radium and uranium content is due to a combination of topographic elevation, regional groundwater levels, and the relative availability of oxygen or carbonaceous matter (and sulfide) in the sediments through which the water has passed.

In reduced form uranium is very insoluble, even in the moderately alkaline bicarbonate solutions that dominate the region. Consequently, it is available for solution in groundwater primarily in those zones that are oxidizing (largely limited to the Wasatch Formation). The presence of "insoluble" radium in some of the water samples can be largely attributed to alterations taking place at the ground surface or in the sampling containers. These alterations would include loss of CO 2 with reduction of the bicarbonate buffering capability, oxidation of the dissolved iron to the insoluble ferric form with which radium is known to co-precipitate, and possibly as the result of the reduction of effective anion balance between bicarbonate and sulfate.

The relatively high concentration of uranium in the waters of the oxidizing zone of the Wasatch Formation is maintained even where the groundwater passes through considerable quantities of sand having a significant, if limited, capacity for adsorbing cations. The oxidized uranium is probably held in solution by the formation of anionic bicarbonate complexes (e.g., $[\ UO_2(HCO_3)_3\ ]^-$), which are not readily adsorbed by sand, when the water is dominated by smaller, more mobile anions such as bicarbonate or sulfate.

Hydrology

Attachment 'A'

Bill Smith Mine Site Pump Test

Pump testing was conducted at the Bill Smith Mine site in 1974 by Harshbarger and Associates and a copy of Harshbarger's report is attached. The locations of the test wells used in the Harshbarger study are shown on Figure 1 in the report. The primary purpose of pump tests conducted at well sites TW-1 and TW-2 was to obtain quantitative hydrologic data necessary for designing a mine dewatering and water level monitoring network. The tests were conducted during separate periods of time at TW-1 and TW-2 using a pumping well, five shallow observation wells, and five deep observation wells. All observation well sites shown in Figure 1 include one shallow and one deep observation well. The depths, completion intervals, and distances of the observation wells from the pump well are given on page 10 of the attached report.

The shallow observation wells penetrated approximately 500 feet of the unconfined Wasatch formation. The pumping wells and deeper observation wells penetrated the confined Fort Union aquifer. Near the Bill Smith Mine the aquitard between the shallow and the deeper observation wells ranges from 40 to 75 feet thick, but it is less than 5 feet thick near well site TW-2.

From the data it was estimated that the average transmissivity of the confined aquifer ranged from about 8000 gpd/ft in the vicinity of wells OWD-3 and OWD-5 to 5000 gpd/ft at wells OWD-1 and OWD-2. The storage coefficient ranged from 0.00015 to 0.00035.

No noticeable changes in the water levels in the shallow observations wells were noted, even though pumping lowered the water levels in the aquifer beneath the aquitard below the top of the confined aquifer in areas adjacent to wells TW-1 and TW-2.

REPORT

R-W301-75-2

November 10, 1975

ANALYSIS OF CONSTANT YIELD TESTS OF WELLS TW-2 AND TW-1 BILL SMITH MINE, CONVERSE COUNTY, WYOMING

Prepared For

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ANALYSIS OF CONSTANT YIELD TESTS OF WELLS TW-2 AND TW-1
BILL SMITH MINE, CONVERSE COUNTY, WYOMING

CONCLUSIONS

The following conclusions and recommendations are given based on the data obtained from the performance of pumping tests of wells TW-1 and TW-2. Kerr McGee Nuclear Corporation provided essential information for the analysis, including the borehole geophysical logs and isopachous maps of the "P" shale and "O" sand lithologic units.

1. The average transmissivity of the artesian aquifer system between wells OWD-3 and OWD-5 is about 7,500 gpd/ft (gallons per day per foot width of aquifer at 1:1 hydraulic gradient); the average storage coefficient is about 0.0003.

2. Transmissivity in the vicinity of well TW-1 is about 5,500 gpd/ft and in the well OWD-2 vicinity it is less than 5,000 gpd/ft; the storage coefficient is about 0.0004. The lower value of transmissivity as compared to that near TW-2 is attributed to finer-grained material in the aquifer near well TW-1 and a lesser thickness of the "O" and "M" sands.

3. Pumping of wells TW-1 and TW-2 created a cone of pressure relief to more than 10,000 feet during the 6 and 10-day pumping periods. The simultaneous pumping of the two wells for a prolonged period of time would create a cone of pressure relief to extend about 3 to 4 miles from the wells.

4. The hydrostatic head in the water-table aquifer overlying the "P" shale is higher in elevation than the head in the underlying "O" and "M" sands; consequently, there is a hydraulic gradient downward through the "P" shale. Pumping of wells TW-1 and TW-2 did not cause noticeable changes in the water level in observation wells tapping the water-table aquifer; therefore, there was no apparent increase in the rate of water movement through the "P" shale during the pumping periods.

5. Pumping of wells TW-1 and TW-2 induced water-table conditions to occur in the immediate vicinity of each well as the hydrostatic head was lowered below the top of the "O" sand.

6. Additional wells will be required for dewatering operations to accommodate the proposed mining operations.

7. Additional observation wells in both the water-table and artesian aquifer systems are essential to monitor the effect pumping in the artesian system will have on both systems.

RECOMMENDATIONS

1. Wells TW-1 and TW-2 should be equipped with 300 gpm (gallons per minute) and 400 gpm pumps, respectively and should be capable to produce this discharge rate from a depth of 800 feet. The pumps should be operated continuously. If necessary to maintain continous pumping, throttle the discharge and/or install a water-return line from the discharge pipe to the well to maintain the pumping water level above the pump intake.

2. Install additional dewatering wells into the artesian aquifer, "O" and "M" sands, along the proposed mine drifts. The wells should be spaced at about 2,000-foot intervals and should pump continuously for at least one year before the drift advances to the well vicinity (Figure 14).

3. Conduct a 10-day constant discharge test at each new dewatering well. Each constant discharge test should be preceded by a step-discharge test with a pump that can be throttled to obtain three separate rates--the minimum difference between rates should be 50 gpm. Install two observation wells tapping the artesian system; one well at 100 feet and the other at 700 feet from the pumped well.

4. Install paired observation wells during 1976 in those areas where mining is proposed for the next 10 years. One of the paired wells should tap the water-table aquifer and the other should tap the artesian aquifer. Install several observation wells where the "P" shale is less than 10 feet thick.

5. Measure water levels in all pumped wells and observation wells on a routine schedule. The water level in wells being pumped should be measured at least twice a week. Observation wells within 1 mile of active mining or construction should be monitored monthly; wells within several hundred feet of the mining or construction operations should be monitored weekly. Two paired well sites within 1 mile of active mining should be equipped with continuous water-level sensing recorders. All observation wells should be monitored monthly for the first 2 years after the wells are completed. Thereafter, wells more than 1 mile from active mining operations should be monitored every 3 months.

6. Construct hydrographs of the water levels obtained from all observation wells; the time scale should have monthly subdivisions for each year. The depth-to-water scale should be such that 0.10-foot difference in reading can be clearly distinguished.

7. Metering devices should be installed on all pumped wells and all water-discharge lines from mine workings. The devices should indicate the rate of discharge, the time period of tho discharge, and the total discharge per day.

ANALYSIS OF CONSTANT YIELD TESTS OF WELLS TW-2 AND TW-1 BILL SMITH MINE, CONVERSE COUNTY, WYOMING

INTRODUCTION

In April 1974, Harshbarger and Associates were requested to provide a preliminary opinion on the occurrence of groundwater in the Bill Smith mine area and potential water problems that might be encountered during the construction of proposed mine workings. Data available at that time comprised: Water level and pumpage records from the Bill Smith mine shaft, a dewatering well, and monitor wells; borehole geophysical information; geologic cross-sections; reports and maps compiled by the U.S. Geological Survey and Wyoming State Engineer's office; and information obtained by J.W. Harshbarger during a cursory field examination of the Bill Smith mine area. Analyses of these data led to the division of the rock units into major units based on their hydrogeologic significance: 1) Approximately 500 feet of alternating sandstone and shale in which groundwater occurs under unconfined water-table conditions and comprises a water-table aquifer system; 2) approximately 60 feet of shale referred to as the "P" shale that functions as an aquitard between the water-table aquifer system and an artesian aquifer system in underlying rocks; and 3) the "O" and "M" sands below the "P" shale which constitute an artesian aquifer system. The "O" sand is approximately 300 feet thick and consists of five distinct sand zones, the thickest is about 80 feet, and interbedded shales. The "O" sand is separated from the "M" sand by the "N" shale, which is approximately 30 feet thick. The "M" sand is about 50 feet thick and is underlain by a 20-foot thick shale referred to as the "L" shale.

The bottom of the Bill Smith mine shaft is proposed to extend to the base of the "L" shale; therefore, two types of potential water problems associated with the groundwater system were envisioned: 1) Flooding of the mine workings by inflow of groundwater, and 2) collapse of the mine workings due to existing hydrostatic pressure in the artesian aquifer system. It was concluded that the existing water-level and pumpage data were inadequate to define the hydraulic characteristics of the "O" and "M" sands, the relationship between the piezometric level in the confined zone and the water table elevation in the unconfined zone, and the degree of hydraulic connection between the confined "O" and "M" sand and the overlying unconfined water-table. Determination of the hydraulic characteristics of the artesian aquifer system and the degree of interconnection between the unconfined and confined aquifer systems would provide data to design a well field that would reduce the pressure in the artesian system sufficiently to accommodate mining operations and allay hazardous conditions from excessive inflow of groundwater.

In order to obtain adequate data to define the unknown characteristics and relationships, Harshbarger and Associates proposed the construction of two large diameter wells in the confined groundwater system and a network of observation wells in the unconfined and confined groundwater systems. It was proposed that the two large diameter wells be pumped, each at different times, at a constant rate for a period of at least 10 days and water levels observed in the pumped well and observation wells during and after the pumping period.

Locations selected for the two large diameter wells are: well TW-2 in the SW$\frac{1}{4}$SW$\frac{1}{4}$ section 25, T. 36 N., R. 74 W., and well TW-1 in the SE$\frac{1}{4}$SE$\frac{1}{4}$ section 25 (Figure 1). Well TW-2 was completed in June 1975 and well TW-1 in September 1975. The first pumping test was conducted on well TW-2 during July 21-31, 1975 and a second pumping test was conducted on well TW-1 during September 29 through October 4, 1975. The data collected from these two tests provide the basis for the analysis of the aquifer parameters and well field design given in this report.

Grateful appreciation is extended to Mr. Darrell Robinson, Chief Geologist, Kerr McGee Nuclear Corporation and his staff for their excellent collection of data during the tests and valuable discussion of the subsurface geological conditions.

TEST WELL FACILITIES

WELLS TO BE PUMPED

Well TW-2 was scheduled for completion at a depth of 940 feet; however, problems with a "lost" bit in the hole resulted in completing the well at a shallower depth. Interpretation of a geophysical log indicated the location of the "O" sand between the depths of 580 and 835 feet except for shale between 687 and 706 feet and the "M" sand between the depths of 899 and 932 feet. During the enlargement of the borehole a drill bit was dropped and efforts to recover the "lost" bit were not successful and the borehole was completed at the 922-foot level. Johnson shaped wire well screen sections, 16 inches in diameter, were installed in intervals 903-916 feet in the "M" sand and 708-832 feet and 585-679 feet in the "O" sand. Blank 16-inch diameter casing was installed elsewhere in the casing string and a gravel pack was placed around the screened intervals.

Well TW-1 was drilled and cased to a depth of 1,006 feet. Johnson shaped wire well screen sections, 16 inches in diameter, were installed in intervals 978-998 feet in the "M" sand and 800-903 feet and 675-758 feet in the "O" sand. Blank 16-inch diameter casing was installed elsewhere in the casing string. A gravel pack was placed around the screened intervals. Blank casing and a cement seal around the blank casing above the "O" sand prevent direct entry of water from the unconfined aquifer system.

A 1½-inch diameter pipe was suspended inside the casing of wells TW-2 and TW-1 through which depth-to-water measurements were obtained. The bottom of these pipes was set below the level of the pump intake.

A Reda 9-stage submersible pump powered by a 300 hp (horsepower) electric motor and capable of discharging about 700 gpm (gallons per minute) from a depth of 800 feet was used to pump wells TW-2 and TW-1 during the tests. The pump intake was set at about the 796-foot level in well TW-2 and at about the 900-foot level in well TW-1.

A 1,000-foot discharge line was connected to the pump column above the land surface. A discharge control valve was placed in the line at the well and the water discharged was measured by a Parshall flume at the outlet of the discharge line. A continuous water-stage recorder activated by a float recoıded the stage of the water in the flume and totalized the amount of water discharged.

OBSERVATION WELLS

Observation wells were constructed in the vicinity of wells TW-2 and TW-1. The observation wells were installed in pairs; one well of a pair taps the water-table aquifer system and the other well taps the artesian aquifer system. Well number identifiers designate the aquifer system tapped. The letters OWS refer to the water-table aquifer system; OWD refer to the artesian aquifer system.

Observation wells in the water-table aquifer system were constructed as open hole to the "P" shale. The casing string consists of $1\frac{1}{2}$-inch diameter blank pipe from land surface to the upper water-bearing sand, and $1\frac{1}{2}$-inch diameter slotted pipe from that level to the bottom of the hole. A cement seal was placed around the upper several feet of casing to secure the pipe in place and prevent surface water from entering the well bore.

Observation wells tapping the artesian aquifer system have 6-inch I.D. casing set from land surface to about the base of the "P" shale and cemented in place. The casing string consists of 1½-inch diameter blank pipe from land surface to the top of the "O" sand and slotted pipe through the "O" sand. The casing string in observation wells OWD-1 and OWD-4 have slotted pipe extending through the "O" and "M" sands.

The following tabulation gives additional construction data about the observation wells.

OBSERVATION WELL	ALTITUDE TOP OF CASING (Feet)	WELL DEPTH (Feet)	PERFORATED INTERVAL (Feet)	DISTANCE FROM WELL TW-2 (Feet)	DISTANCE FROM WELL TW-1 (Feet)
OWS-1	5585.5	567	147-399; 462-504; 546-567	3,920	154
OWD-1	5586.1	987	651-903; 945-987	3,920	154
OWS-2	5593.8	584	101-584	4,800	1,040
OWD-2	5593.9	900	667-900	4,800	1,040
OWS-3	5562.5	570	108-570	1,920	1,840
OWD-3	5563.1	887	614-887	1,920	1,840
OWS-4	5546.6	536	94-536	110	3,800
OWD-4	5546.7	943	586-943	110	3,800
OWS-5	5534.8	512	113-512	1,015	4,600
OWD-5	5534.7	897	574-897	1,015	4,600

WATER-LEVEL MEASURING DEVICE

Electrical tape sounders were used to measure the depth to water in wells. An electrical tape sounder consists of a two-conductor insulated cable, an electrode attached to the lower end of the cable, a battery to supply power, an ammeter to show when contact is made with the water surface, and a reel to hold the cable. The cable is graduated in 5-foot intervals by numbered metal markers. Readings of depth to water were made to the nearest hundredth of a foot by measuring with a 5-foot scale divided into feet, tenths, and hundredths.

WELL TW-2 PUMP TEST

PRE-PUMPING PERIOD

Pumping of well TW-2 was not started until the water levels in all wells indicated a predictable trend. The pump which had been operating continuously in the vent hole near the Bill Smith mine shaft was stopped and removed for repairs on July 3, 1975; on July 12 the pump was replaced and started pumping again. This shut-down and subsequent restarting of pumping from the vent hole caused pressure disturbances in the confined aquifer system; consequently, the start of the constant yield test in well TW-2 was delayed until the effects of the disturbance had stabilized in the observation wells. Depth-to-water measurements were made once or twice a day in all observation wells and two monitor wells near the mine shaft in the period from July 12 to July 20. On July 20 it was concluded that the water levels in the observation wells were following predictable fluctuation trends and that the constant yield test of well TW-2 could be started the next day.

CONSTANT YIELD PUMPING PERIOD

The pump in well TW-2 was turned on at 0820 hours on July 21, 1975 and the discharge valve was adjusted to a constant discharge rate of about 550 gpm. The discharge control valve was adjusted when necessary during the first several hours of pumping to maintain the discharge rate at approximately 550 gpm. Pumping was continuous for 10 days except for a 5 minute power failure between 1726 and 1731 hours on July 21 and a 1 hour 50 minute power failure between 0500 and 0650 hours on July 29. A study of the recorder chart, which indicated the water stage at the Parshall flume, revealed that the average rate of discharge during the 10-day period was about 560 gpm.

Depth-to-water measurements were made in the pumped well and in the observation wells in accordance with Appendix in the report, "Groundwater Conditions and Water Control for Proposed Workings at the Bill Smith Mine near Glenrock, Wyoming". The measuring device at well OWS-1 malfunctioned on the second day of the pumping phase, and no additional water-level data were obtained from that well. No measurements were made in OWS-2 during the pumping and post-pumping periods.

POST-PUMPING PERIOD

The pump was turned off at 0800 hours on July 31. Depth to water was measured in the pumped well and observation wells, except the wells in the shallow system, at the same time intervals used during the pumping period. There had been no measurable effect on the water levels in wells tapping the shallow aquifer system; therefore,the time intervals between measurements in those wells were greater than those used during the pumping period. Measurement of the water levels were continued for 10 days after pumping ceased in well TW-2.

ANALYSIS OF TEST DATA

Significant magnitudes of drawdown occurred in all observation wells tapping the artesian system. The static water level, the amount of drawdown, the residual drawdown (difference between static water level and the water level 10 days after pumping stopped), and the distance from well TW-2 to the observation well are given in the following tabulation.

WELL	DISTANCE FROM WELL TW-2 (Feet)	STATIC WATER LEVEL (Feet)	MAXIMUM DRAWDOWN (Feet)	RESIDUAL DRAWDOWN 10 DAYS AFTER PUMPING STOPPED (Feet)
TW-2	0	487.42	270.62	4.0
OWD-4	110	487.05	64.29	4.0
OWD-5	1,015	455.10	38.23	5.3
OWD-3	1,920	520.40	23.50	4.4
OWD-1	3,920	537.03	15.90	5.4
OWD-2	4,800	538.61	10.04	2.3

The maximum drawdown was greatest near the pumped well and was less at greater distances from the pumped well, as shown in the above tabulation.

Water-level data obtained during the pumping and post-pumping periods were analyzed by the Theis non-equilibrium equation and the modified non-equilibrium graphical procedures to obtain information about the hydraulic properties of the artesian aquifer in the test site area. Water levels in wells tapping the artesian system were affected to some degree by changes in barometric pressure. Barometric effects have not been corrected in the water level data obtained; however, corrections probably would not have changed the data pattern sufficiently to cause significant errors in computing coefficients of transmissivity and storage. Some errors were made in making depth-to-water measurements, and the more obvious ones were eliminated from calculation procedures. Computational values of transmissivity and storage from the data analysis are given in Table 1.

TABLE 1.-- SUMMARY OF HYDRAULIC PROPERTIES OF THE "O" AND "M" SANDSTONES, PUMP TEST OF WELL TW-2, JULY 21 - AUGUST 9, 1975

	SEMI-LOGARITHMIC				LOGARITHMIC			
	DRAWDOWN		RECOVERY		DRAWDOWN		RECOVERY	
ELL	TRANSMISSIVITY 1/	STORAGE 2/	TRANSMISSIVITY	STORAGE	TRANSMISSIVITY	STORAGE	TRANSMISSIVITY	STORAG
'D-1	8,100	0.00019	7,400	0.00022	6,970	0.00026	6,300	0.0003
'D-2	3/	3/	3/	3/	8,330	.00032	8,440	.0003
D-3	8,450	.00032	7,040	.00037	7,050	.00042	8,670	.0004
D-4	8,450	.00010	6,570	.0020 4/	2,850 4/	.0006 4/	6,980	.0017
D-5	8,000	.00020	7,400	.00026	8,000	.00034	6,400	.0003
W-2	3/	3/	6,300	3/	3/	3/	3/	3/

1/ Gallons per day per foot width of aquifer at 1:1 hydraulic gradient

2/ Dimensionless; ratio of volume of water released per unit decline in head per unit volume

3/ Cannot be interpreted by procedure

4/ Coefficients not considered to be valid

HARSHBARGER and ASSOCIATES
1975 Tucson, Arizona

The transmissivity and storage values given in Table 1, within the various categories, are in good agreement. Transmissivity values range from 6,300 to 8,450 gpd/ft (gallons per day per foot). It is considered that a reasonable average value would be 7,500 gpd/ft. Storage coefficient values range from 0.00010 to 0.00046 and average 0.00030. Computation based on distance-drawdown graph (Figure 7) indicates the transmissivity and storage values are about 7,700 gpd/ft and 0.0022 respectively.

Figure 2 is a hydrograph of water levels in wells OWS-1, OWS-2, OWS-3, OWS-4, and OWS-5 tapping the water table aquifer system. Pumping of well TW-2 caused no apparent change in water level in those wells, and, therefore, it could be concluded that no appreciable increase in movement of water occurred from the water table aquifer to the artesian aquifer through the "P" shale aquitard. The hydrostatic head in the water table aquifer is higher than the head in the artesian aquifer; consequently, there is a hydraulic gradient downward from the water table aquifer to the artesian aquifer system. The vertical permeability of the "P" shale is low and the downward movement of water is very slow; thus, the amount of water moving through the "P" shale is small per unit area, particularly in areas where the shale is thick.

An isopach map of the "P" shale shows the approximate thickness of the shale at the sites of the observation wells to be: OWS-1, 45 feet; OWS-2, 45 feet; OWS-3, 40 feet; OWS-4, 75 feet; and OWS-5, 75 feet. However, the same map reveals areas within 600 feet of well TW-2 where the "P" shale is less than 5 feet thick. These areas are small and probably could be classed as "windows" in the shale if the shale is missing entirely. The drawdown curve of the pumped well does not exhibit a shape that would indicate leaky aquifer conditions. It is concluded that there was little or no increase in the downward movement of water through the "P" shale during the pumping period. The increase in the amount of water that might move downward through the "P" shale during a prolonged period of pumping cannot be calculated from the available data.

Figure 3 is a semi-logarithmic graph of water-level drawdown and recovery versus time after pumping started (drawdown curve) and time after pumping stopped (recovery curve) for well TW-2. Some of the irregularities in the drawdown curve were caused by changes in pumping rate when the discharge control valve was adjusted; two stoppages of pumping by power failures also caused additional irregularities in the curve.

A change from artesian to water-table conditions probably occurred in the vicinity of well TW-2 during the pumping period and should have caused a decrease in the downward slope of the drawdown curve. However, if that effect occurred, it cannot be identified on the drawdown curve with certainty. The water level in well TW-2 was drawn down to about the 757-foot level below measuring point or about 755 feet below land surface. At that level, the water in the well probably was more than 100 feet below the hydrostatic head in the aquifer at the aquifer-well interface. Data are insufficient to determine the exact position of the head in the aquifer at the aquifer-well interface. The head in the aquifer at the aquifer-well interface would drop below the top of the "O" sand, which is at a depth of about 580 feet below land surface, when the change from artesian to water table conditions occurs. A tentative interpretation is that the head at the aquifer-well interface dropped below the top of the "O" sand at well TW-2 and might have declined several feet below that level. Additional information on this question is given later in a discussion of Figure 7.

Water-level recovery data were used to compute transmissivity only; storage was not computed because the effective radius of the pumped well was not determinable.

Figure 4 is a semi-logarithmic graph of water-level drawdown versus time after pumping started for observation wells OWD-1, OWD-2, OWD-3, OWD-4, and OWD-5. If the aquifer were ideal (homogeneous, isotropic, infinite areal extent, and instantaneous release of water from storage) and the pumping rate remained constant, the latter part of the drawdown curves for observation wells tapping that aquifer would become parallel; thus, the rate of water level decline in all wells would reach a common value. Less than ideal aquifer conditions and a short pumping period would result in drawdown curves not attaining an absolute parallel pattern. The curve for well OWD-4 (well is 110 feet from well TW-2) contains several changes in slope, some being attributed to adjustments in pumping rate and others to local geological conditions near well TW-2. Well OWD-4 is close to the pumped well and the water level in well OWD-4 reacts more readily to local conditions around the pumped well than the water levels do in the more remote observation wells. Drilling mud probably is entrained in the aquifer near well TW-2 because of the long time the well was under construction. Some of the mud could be partially blocking some sand intervals, thereby causing anomalous head differences in the aquifer adjacent to the well which decrease in effect as distance from the pumped well increase. The effects of change from artesian to water-table conditions at the pumped well would extend to well OWD-4 several hours before such effect would reach the more distant observation wells. If the pumping period had been several tens of days, the drawdown curves in the observation wells would have attained a more nearly parallel pattern.

It is not possible to positively identify an inflection on the drawdown curve of well OWD-4, or any of the other observation wells, and be sure that the inflection is a response to the change from artesian to water-table conditions near well TW-2. It is believed that the effect would reach well OWD-4 in the first several hundred minutes after pumping started and extend to well OWD-5 probably no later than several thousand minutes after pumping started, but it cannot be identified from the curves on Figure 4.

Values for transmissivity and storage were computed using drawdown data for wells OWD-1, OWD-3, OWD-4, and OWD-5. Values were not computed from drawdown data for the other observation wells as the pumping period was insufficient to meet the conditions of the computational procedure.

Figure 5 is a semi-logarithmic graph of water-level recovery versus time after pumping stopped for wells OWD-1, OWD-2, OWD-3, OWD-4, and OWD-5. The recovery curves, particularly that for well OWD-4, exhibit less irregularities than their companion curves in Figure 4. Irregularities caused by changes in pumping rate did not affect the recovery data; the water levels respond to a uniform rate of recharge to the cone of depression created during the pumping period. The effect of a change from water table to artesian condition at well TW-2 apparently reached well OWD-4 prior to 200 minutes after pumping stopped. The reason for the anomaly in the recovery curve of well OWD-4 between the elapsed recovery time of 1,000 and 1,800 minutes is not readily apparent. It might have been caused by the dislocation of a metal marker on the cable of the water-level measuring device.

Figure 6 is a logarithmic graph of water-level drawdown and recovery after pumping started (drawdown curve) or stopped (recovery curve) for wells OWD-1, OWD-3, OWD-4, and OWD-5.

The curves for well OWD-2 were not included because of their close proximity to the curves of OWD-1. Theoretically, the drawdown and recovery curves of an observation well would be in close agreement on the logarithmic graph if the aquifer conditions were ideal. The separation between these two curves for well OWD-4 indicates the effect of local conditions that were mentioned in the discussion of Figures 4 and 5.

Figure 7 is a semi-logarithmic graph of drawdown versus distance for selected times during the pumping period. Lines connecting data points for a common time were extended to the 1-foot distance which is assumed to be the approximate effective radius of well TW-2. The drawdown at 1-foot is interpreted as being the drawdown of head in the aquifer at the aquifer-well interface. The drawdown at the aquifer-well interface was compared with the drawdown in the pumped well. The drawdown at the aquifer-well interface and in the well at the three periods of time selected are: 1,000 minutes, 131 feet and 213 feet; 5,000 minutes, 146 feet and 243 feet; and 10,000 minutes, 151 feet and 259 feet. The efficiency of well TW-2 when pumping about 560 gpm was calculated by dividing the drawdown at the aquifer-well interface by the drawdown in the well; the result was multiplied by 100 to express the efficiency in percent. The efficiency of well TW-2 is about 60 percent at a pumping rate of about 560 gpm.

Pumping of TW-2 for 10 days caused some decline in water levels in two monitor wells near the Bill Smith mine shaft which reduced the rate of water yield from the shaft and the vent hole. The water level in monitor well M-2 declined about 10.5 feet during the 10-day pumping period. Measurements were not made each day in monitor well M-1; consequently, the records do not show the amount of change in water level in that well. Some of the decline is attributed to pumping from the shaft and the vent hole; however, most is attributed to pumping of well TW-2. The combined rate of discharge from the shaft and the vent hole decreased about 110 gpm during the pumping period of well TW-2.

WELL TW-1 PUMP TEST

PRE-PUMPING PERIOD

A step-discharge test was attempted in well TW-1 prior to the start of the constant discharge test. The object of the step test was to determine the head loss in the aquifer and the head loss through the gravel pack and screen and obtain information about the specific capacity of the well. The well was to have been pumped at three different rates of discharge, each rate being maintained constant for 2 hours. The test was unsuccessful because of difficulty in operating the pump at rates considerably less than the full discharge rating of the pump. When the pumping rate was 600 gpm, the water level declined to the pump intake; and by partially closing the discharge control valve to achieve smaller rates of pumping endangered the seals of the pump. As a last effort in the step-test, the control valve was set to a discharge rate of about 460 gpm. A study of the drawdown data at that pumping rate indicated that the constant discharge test should be operated at that rate.

The disturbance of hydraulic head in the aquifer caused by the step-test pumping required that the start of the constant discharge test be delayed until the effect of that disturbance was negligible. The recovery of the water levels were monitored daily, and it was concluded that the constant discharge test could begin on September 29, 1975.

CONSTANT YIELD PUMPING PERIOD

The pump in well TW-1 was started at 0800 hours on September 29, 1975. It was decided not to change the setting of the discharge control valve during the pumping period in hopes of avoiding some of the irregularities in the drawdown curves such as seen in the drawdown curve of well TW-2. The test was to continue for 10 days, unless the water level in the pumped well declined below the 880-foot level. A semi-logarithmic graph of drawdown versus time of pumping was kept current and projections of the drawdown were revised as the test progressed. Projections indicated that the drawdown would reach the 880-foot level either during the evening of October 5 or the early morning hours of October 6. It was decided to stop pumping at 0800 hours on October 5 to assure that personnel would be available to obtain water-level recovery measurements. No power failures occurred during the 6-day pumping period. The average rate of discharge was about 425 gpm.

Water-level measurements were made in all observation wells except OWS-4 and OWS-5. Measurements were not made in those two wells because data from the test of well TW-2 showed no evidence of water movement from the water-table to the artesian aquifer in the vicinity of the two wells. If no water moved between the two aquifer systems in that area when a large head difference was created near wells OWS-4 and OWS-5, it was considered unlikely that the two wells would show water movement when a much smaller head difference was created by pumping well TW-1.

The water level in the observation wells was measured with the frequency-distance relation used in the constant discharge test of well TW-2.

POST-PUMPING PERIOD

Pumping of well TW-1 was stopped at 0800 hours on October 5, 1975. Recovery water level measurements were made in the pumped well and in observation wells OWS-1, OWD-1, OWS-2, and OWD-2. Measurements were not made in the other observation wells because the measuring in the recovery period was to last no more than 2 days. The greater distance to the other observation wells would have yielded no better information than was obtained in them during the pumping period. Recovery water level measurements were made in the pumped well and nearby observation wells primarily to study the head changes in the aquifer when irregularities that might be caused by a slowly changing pumping rate were eliminated. The discharge rate decreased from about 460 gpm to about 400 gpm during the pumping period.

ANALYSIS OF TEST DATA

Drawdowns occurred in all observation wells tapping the artesian aquifer system when well TW-1 was pumped at a near-constant discharge rate for 6 days. The static water level, the amount of drawdown, the residual drawdown (difference between static level and the water level 30 hours after pumping stopped), and the distance from well TW-1 to the observation wells are given in the following tabulation.

WELL	DISTANCE FROM WELL TW-1 (Feet)	STATIC WATER LEVEL (Feet)	MAXIMUM DRAWDOWN (Feet)	RESIDUAL DRAWDOWN 30 HOURS AFTER PUMPING STOPPED (Feet)
TW-1	0	569.48	305.12	15.90
OWD-1	154	547.12	54.41	15.50
OWD-2	1,040	543.29	39.74	16.49
OWD-3	1,840	525.06	16.64	---
OWD-4	3,800	491.49	6.28	---
OWD-5	4,600	459.00	5.36	---

Water-level data obtained during the pumping and recovery periods were analyzed by the Theis non-equilibrium equation and the modified non-equilibrium graphic procedures to obtain information about the hydraulic properties of the artesian aquifer in the test site area. As during the test of well TW-2, barometric effects on the water level in wells were not considered in analyzing the data; those effects probably would not have changed the data pattern sufficiently to cause significant changes in the computation of transmissivity and storage. Computational values of transmissivity and storage from the data analysis are given in Table 2.

The transmissivity values given in Table 2 range from 2,670 gpd/ft (gallons per day per foot) to 9,550 gpd/ft. The lower values are for well TW-1 and observation wells east of TW-1; the higher values are for observation wells west of TW-1 in the vicinity of well TW-2. The lower transmissivity probably is related to a greater percentage of fine-grained material in the artesian aquifer near and east of well TW-1 and/or a probable decrease in thickness of the aquifer by an increase eastward in the number and thickness of shale beds.

Figure 8 is a hydrograph of water levels in wells OWS-1, OWS-2, and OWS-3 tapping the water-table aquifer system. The hydrostatic head in the water-table aquifer system is higher than that of the artesian system in the test site area; consequently the hydraulic gradient is from the water-table to the artesian system. The vertical permeability of the "P" shale (the aquitard between the two systems) is very low and the amount of water transmitted downward through that shale is small per unit area. The greatest movement per unit area will be where the shale is thin or possibly absent. Pumping of well TW-1 caused no apparent change in water level in the wells in the water-table aquifer at the test site; therefore, it is concluded that pumping of well TW-1 did not increase the rate of drainage of water from the water-table to the artesian aquifer system. It is probable that over a long period of pumping the effects of recharge from the water-table system to the artesian system might become evident.

TABLE 2.--SUMMARY OF HYDRAULIC PROPERTIES OF THE "O" AND "M" SANDSTONES, PUMP TEST OF WELL TW-1, SEPTEMBER 29 - OCTOBER 6, 1975

	SEMI-LOGARITHMIC				LOGARITHMIC			
	DRAWDOWN		RECOVERY		DRAWDOWN		RECOVERY	
	TRANSMISSIVITY 1/	STORAGE 2/	TRANSMISSIVITY	STORAGE	TRANSMISSIVITY	STORAGE	TRANSMISSIVITY	STORAG
1	3,870	0.00036	6,600	0.00057	3,040	0.00047	6,580	0.0005
2	4,680	.00011	4,680	.00011	3,250	.00051	3,750	.0002
3	3/	3/	3/	3/	7,270	.00018	-	-
4	3/	3/	3/	3/	9,550	.00036	-	-
5	3/	3/	3/	3/	8,860	.00031	-	-
1	2,670	3/	4,010	3/	3/	3/	3/	3/

1/ Gallons per day per foot width of aquifer at 1:1 hydraulic gradient

2/ Dimensionless; ratio of volume of water released per unit decline in head per unit volume

3/ Cannot be interpreted by procedure

HARSHBARGER and ASSOCIATES
1975 Tucson, Arizona

Figure 9 is a semi-logarithmic graph of water-level drawdown and recovery versus time after pumping started (drawdown curve) and stopped (recovery curve) for well TW-1. The initial discharge rate of about 460 gpm gradually decreased during the pumping period and was about 400 gpm at the end of the pumping period. Allowing the discharge rate to decrease gradually rather than adjusting the discharge control valve to try and maintain a constant rate of discharge, eliminated the abrupted shifts in the drawdown curve such as occurred in the test of TW-2. The reduction in the downward trend of the curve in the time interval 240-800 minutes is in response to the change from artesian to water-table conditions in the aquifer near the well. The steepening of the downward trend in drawdown after 800 minutes of pumping is probably related to the well characteristics rather than conditions of the aquifer. An increase in the drawdown slope in the nearby observation well (OWD-1) would have occurred if this factor were related to the aquifer.

The water level in the pumped well declined more rapidly than the hydrostatic head in the aquifer at the aquifer-well interface. The drawdown curve for well TW-1 shows that the drawdown in the well was approximately 230 feet when a change from artesian to water table conditions began. Studies of the drawdown in the observation wells with respect to distance from the pumped well indicate that the hydrostatic head at the aquifer-well interface may have declined as much as 130 feet at the end of the pumping period as compared to the drawdown of 305 feet in well TW-1.

Transmissivity was computed from the recovery data for well TW-1. Storage was not computed because the effective radius of the well was not determinable.

Figure 10 is a semi-logarithmic graph of water-level drawdown versus time after pumping started for wells OWD-1, OWD-2, OWD-3, OWD-4, and OWD-5. The non-parallel nature of the curves, one to the other, indicates a difference in the hydraulic properties of the aquifer within the test site. The curves for wells OWD-1 and OWD-2 have some similarity in shape; whereas, the curves for wells OWD-3, OWD-4, and OWD-5 have a similarity in shape. Computations of transmissivity given in Table 2 show higher values for the wells near TW-2 and lower values for wells near TW-1.

The change in slope of the drawdown curve for well OWD-1 after 200-300 minutes of pumping is in response to the change from artesian to water table conditions near well TW-1. A change in slope of the drawdown curve for well OWD-2 also is apparent, but the time of the change cannot be determined precisely for well OWD-1. Changes in slope in the drawdown curves for the other three observation wells are not apparent.

The slope of the drawdown curve for well OWD-1 after the effect of the change from artesian to water table occurs remains constant and does not shift to an increase in slope as did the drawdown curve of the pumped well. This lack of change in slope is interpreted as indicating that the increase in rate of drawdown in well TW-1 is related to the hydraulic characteristic of the pumped well and not to the aquifer.

Values for transmissivity and storage were not computed from drawdown data for wells OWD-3, OWD-4, and OWD-5 using the modified non-equilibrium graphic procedures because the time of pumping was not long enough to cause sufficient drawdown in those wells to create conditions prescribed for the procedures.

Figure 11 is a semi-logarithmic graph of water level recovery for wells OWD-1 and OWD-2. These are the only observation wells tapping the artesian aquifer system from which recovery data were collected. The change from water table to artesian conditions in the aquifer near well TW-1 is not apparent in either of these curves. The greater part of the curves reflect artesian conditions in the aquifer.

Figure 12 is a logarithmic graph of water level drawdown and recovery versus time after pumping started (drawdown curves) or stopped (recovery curves) for wells OWD-1 and OWD-2; drawdown curves also are shown for wells OWD-3, OWD-4, and OWD-5. No recovery data were obtained for the latter three wells. The difference in shape between the drawdown and recovery curves for well OWD-1 and also those for OWD-2 reflect the change from artesian to water table and back to artesian conditions as well as the non-homogeneity of the aquifer.

Figure 13 is a semi-logarithmic graph of water level drawdown in the observation wells versus distance from well TW-1 for selected periods of time. Lines drawn along data plots for each common time were extended to the 1-foot distance, which is assumed to be the aquifer-well interface. The intersection of the lines at the 1-foot distance approximates the drawdown of the hydrostatic head at the aquifer-well interface. The 300-minute and 1,000-minute lines are parallel; however, there is doubt that part of the line for 1,000 minutes should be parallel at distances less than 100 feet from the pumped well. The change from artesian to water table conditions at the pumped well altered the rate of drawdown near the pumped well. The 8,600-minute line slopes toward the other lines and shows the effect of the change in conditions in the aquifer. Data plots of 1,000 minutes and 8,600 minutes for well OWD-2 are displaced from the lines as a result of the artesian to water table change. If the change from artesian to water table conditions occurred near the pumped well after about 240 minutes of pumping, as discussed previously, then the effect of the change began radiating outward from the pumped well at that time. As a consequence, the rate of lowering of the hydrostatic head in the aquifer would decrease at the pumped well.

The transmissivity and storage computed from the slope of the 300 and 1,000-minute lines, are 6,000 gpd/ft and 0.00084, respectively; the transmissivity computed for the 8,600-minute line is 6,300 gpd/ft. It is believed a transmissivity of about 5,500 gpd/ft would be representative for the artesian aquifer in the well TW-1 locality.

SUMMARY

The performance of pumping tests on wells TW-1 and TW-2 accommodated with five paired observation wells (Figure 1) provides definitive data on the artesian aquifer system beneath the "P" shale aquitard. The analysis of each pump test indicates that the asymptotic portion of the depression cone of the potentiometric surface extended at least two miles at the end of the pumping period (Figures 7 and 13). This extent and a computed coefficient of storage of about 3×10^{-4} clearly demonstrate the existence of artesian hydraulic conditions in the "O" and "M" sands. The areal extent of the depression cone is not known beyond the outlying observation wells OWD-2 and OWD-5. However, study of the isopachous maps of the "P" shale aquitard indicates continuity over an area of about 3 square miles. In the vicinity of the observation wells, the aquitard ranges from 40 to 75 feet thick; but at two locations, about 600 feet from well TW-2, the "P" shale is less than 5 feet thick. The water level in an observation well in the water table aquifer above such a thin shale section might have been affected by pumping of well TW-2; however, these are small areas and may not have significant influence on the gross system.

The water level data obtained from the observation wells which penetrated only the shallow water table aquifer above the "P" shale did not show any influence of pumping from wells TW-1 and TW-2 (Figures 2 and 8). Although the vertical permeability of the "P" shale is not known, the non-influence of pumping response on the water table aquifer indicates a relatively low vertical coefficient of permeability. The magnitude of potential leakage via the "P" shale is dependent upon the thickness, vertical permeability, the hydraulic head differential between the water table aquifer and the

potentiometric surface of the "O" sand aquifer system. A tentative estimate was made as to the length of time of vertical leakage via the "P" shale, based on the following assumed values: Vertical hydraulic head differential of 500 feet; vertical coefficient of permeability ranging from 0.01 to 0.001 gallons per day per square foot; thickness of the "P" shale of 20, 50, and 100 feet; and a porosity of 40 percent. The range of travel times, based on the assumed parameters, is given in the following tabulation:

PARAMETERS USED TO ESTIMATE TRAVEL TIME OF GROUNDWATER FLOW FROM WATER-TABLE AQUIFER TO THE "O" SAND AQUIFER, BILL SMITH MINE AREA

Hydraulic Conductivity (Gallons/day/ft^2)	Aquitard Thickness (Feet)	Estimated Flow Rate (Feet/year)	Time Required For Groundwater To Move Via The "P" Shale (Years)
0.01	20	30	0.65
0.01	50	12	4+
0.01	100	6	16+
0.001	20	3	6.5
0.001	50	1.2	42
0.001	100	0.6	167

These estimates indicate that significant leakage via the "P" shale could occur during mining operations in areas where the shale is less than 20 feet thick, having a hydraulic conductivity of 0.01 gpd/ft^2 or greater.

The coefficient of transmissivity determined from the well TW-2 test ranges from 6,300 to 8,450 gpd/ft and from 2,670 to 9,550 gpd/ft for well TW-1 test (Tables 1 and 2). A study of these T values indicates that the average T for the western part of the test area (Figure 1) is about 7,500 gpd/ft and about 5,500 gpd/ft in the eastern part of the test area. A major factor related to the variability of T values is the total thickness of the "O" and "M" sands and the grain-size distribution within the sand units. The intercalation frequency of the lenticular shale units within the "O" sand might also account for erratic drawdown characteristics. A review of the isopachous map of the "O" sandstone indicates it is slightly more than 300 feet thick in the western area and about 250 feet in the eastern area. Examination of several borehole geophysical logs indicates there is perhaps a greater percentage of fine-grained material in the "O" sand in the eastern part of the area. The variability of the lithologic fabric in the Bill Smith area has a significant effect on the variability of transmissivity. However, the average T values are considered to be adequate to project the response that would be expected to occur from long-term continuous pumping.

The principal objective of the two pumping tests was to assess whether or not it would be tenable to create a depression cone in the potentiometric surface to accommodate proposed mining operations. A preliminary projection analysis has been attempted using the average T and S values obtained from the two pump tests with continuous pumping of 400 gpm at well TW-2 and 300 gpm at well TW-1. Two additional hypothetical wells were also assumed to be in operation as follows; one at about 1,000 feet west of OWD-5 and the other at about 1,200 feet north of OWD-2. The assumed pumping rates for the two additional wells are 400 and 300 gpm, respectively. Projected drawdown was computed at all well locations and the projected drawdown cone after about one year of continuous pumping is shown on Figure 14. The depression cone has an elongate "U" configuration, roughly parallel to the alignment of the pumping wells. It indicates that the hydraulic head of the "O" sand aquifer would be beneath the base of the "P" shale aquitard with continuous pumpage from the four wells in about one year. At about that time, non-artesian hydraulic conditions would prevail in the "O" sand aquifer system and the yield from the wells would probably be appreciably less. As mine drifts proceed forward into the depressurized area, most of the water could be withdrawn via the mine drainage sump-pump system; and pumping via the wells could be terminated.

The principal utility of the dewater wells would be to depressurize the artesian hydraulic head in the area ahead of the mine operations. These advance dewater wells should be pumped continuously to intercept the groundwater inflow along the margin of the depression cone. When the water level in the "O" sand aquifer is under non-artesian conditions, the drainage of water from storage in the sand could be accommodated by the mine drift drainage via the water sump constructed near each shaft.

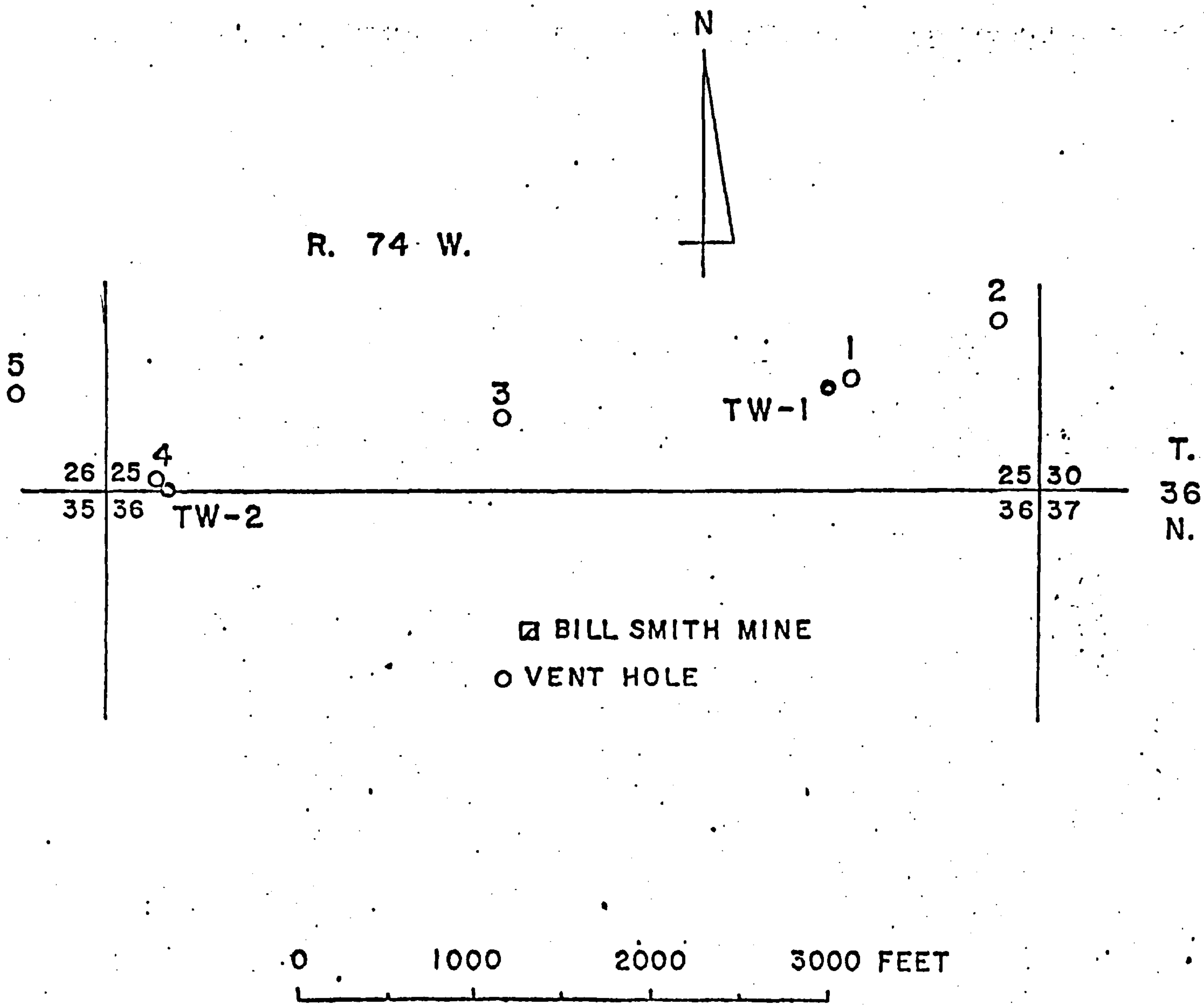


FIGURE I --MAP OF BILL SMITH MINE AREA AND TEST WELL LOCATIONS

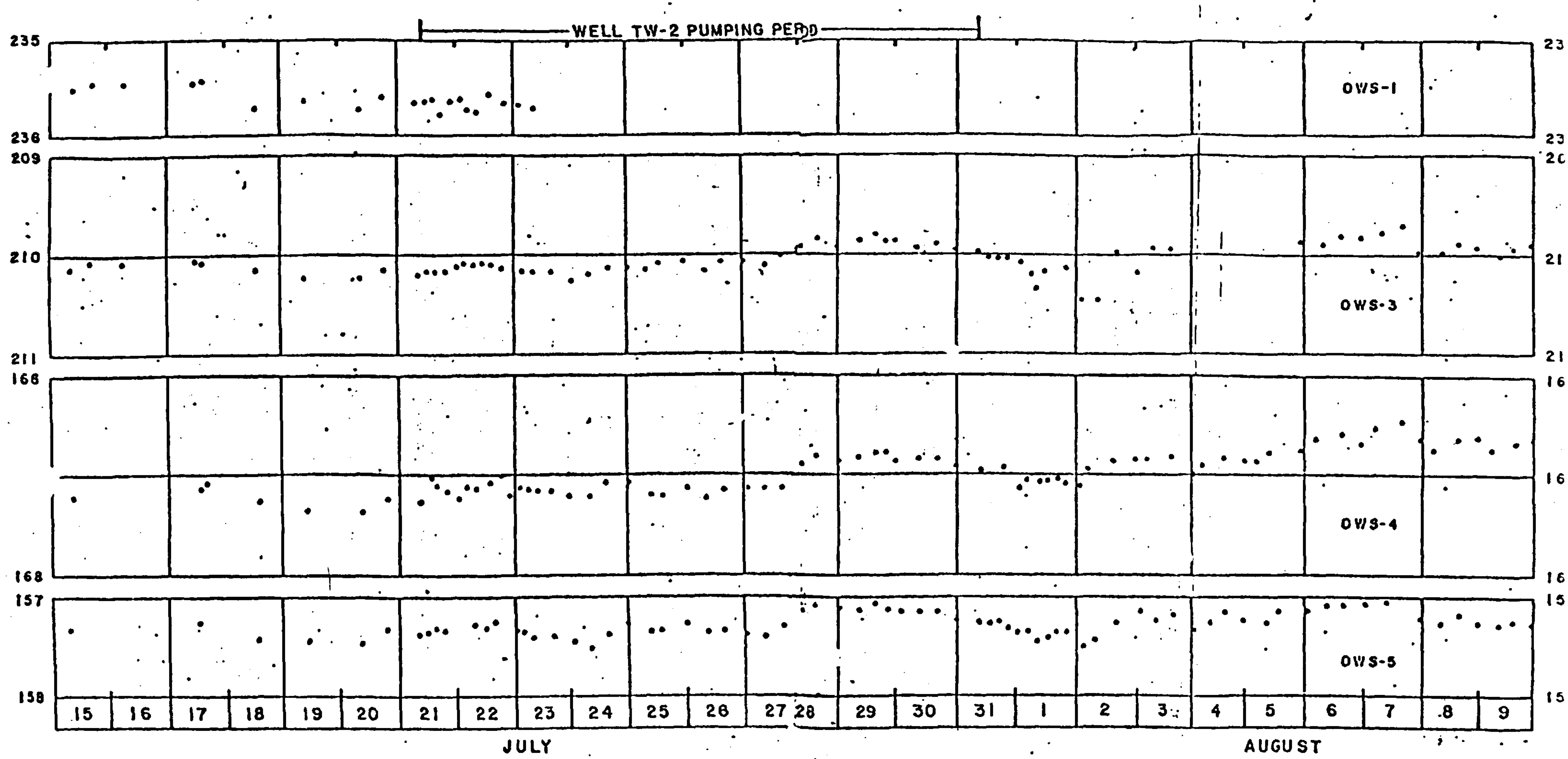


FIGURE 2 -- HYDROGRAPHS WATER LEVEL IN OBSERVATION ELLS IN WATER TABLE AQUIFER, JULY 15 - AUGUST 9, 1975

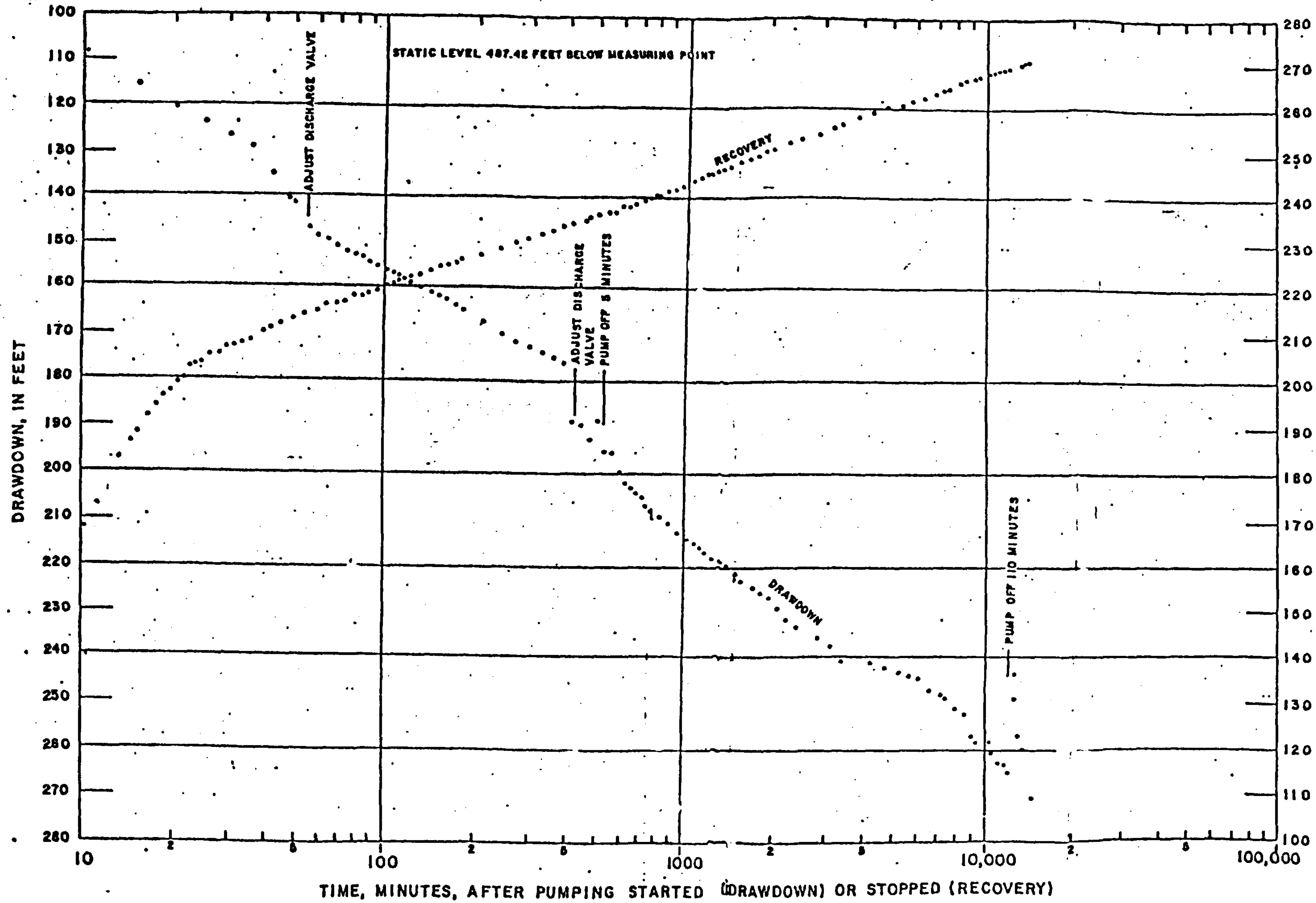


FIGURE 3 — SEMI-LOGARITHMIC GRAPH OF DRAWDOWN AND RECOVERY IN WELL TW-2

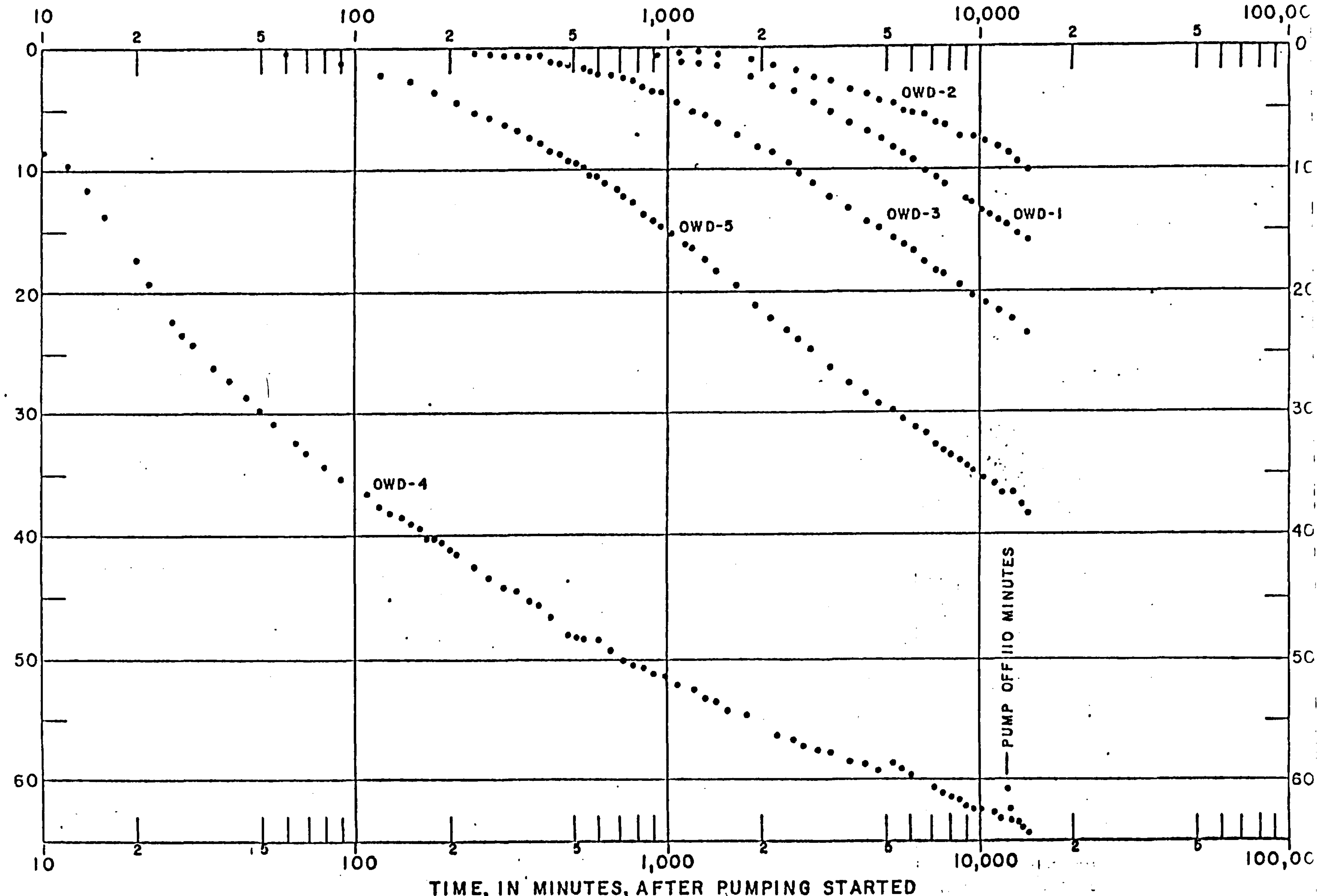


FIGURE 4--SEMI-LOGARITHMIC GRAPH OF DRAWDOWN IN WELLS OWD-1, OWD-2, OWD-3, OWD-4

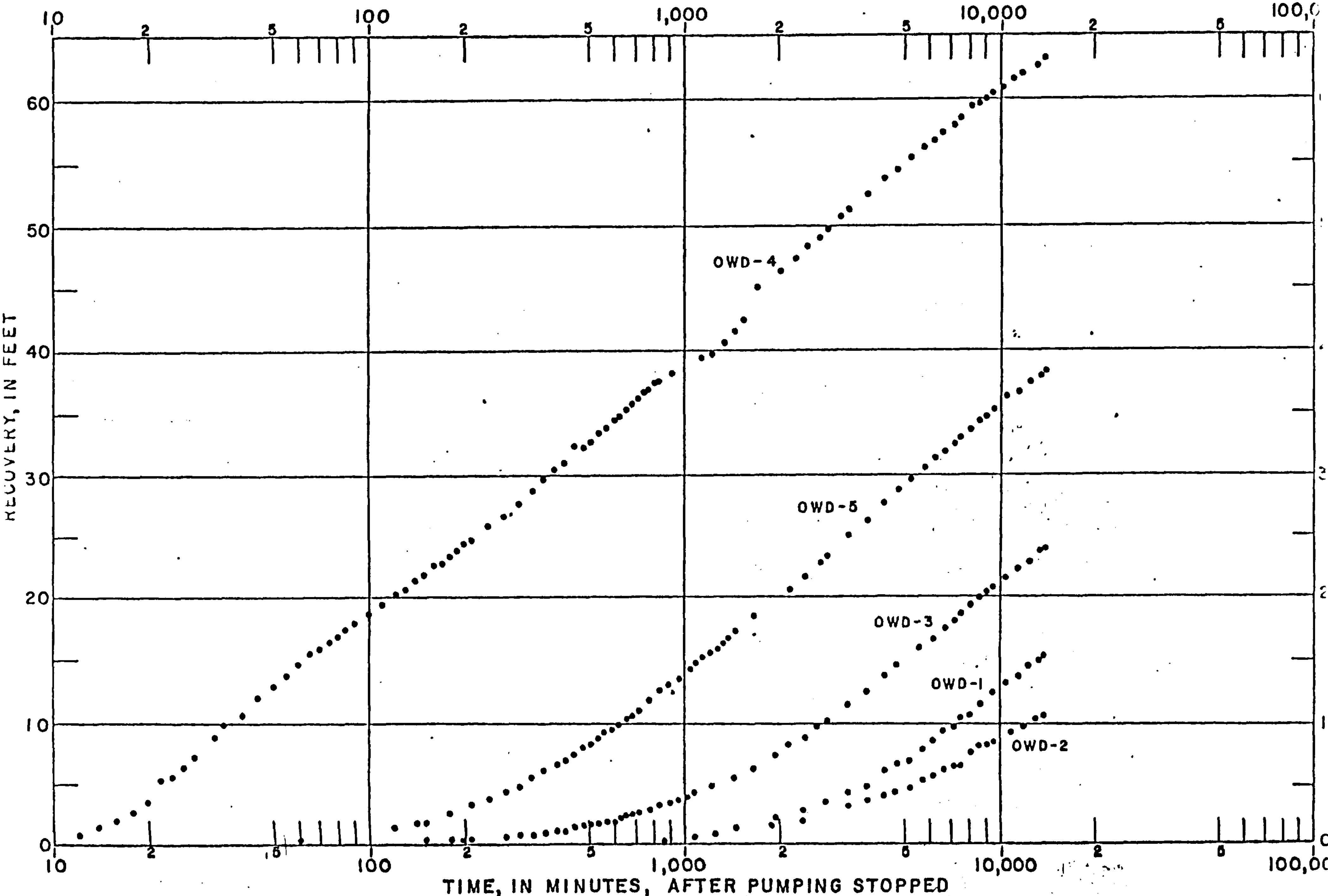


FIGURE 5 --SEMI-LOGARITHMIC GRAPH OF RECOVERY IN WELLS OWD-1, OWD-2, OWD-3, OWD-4

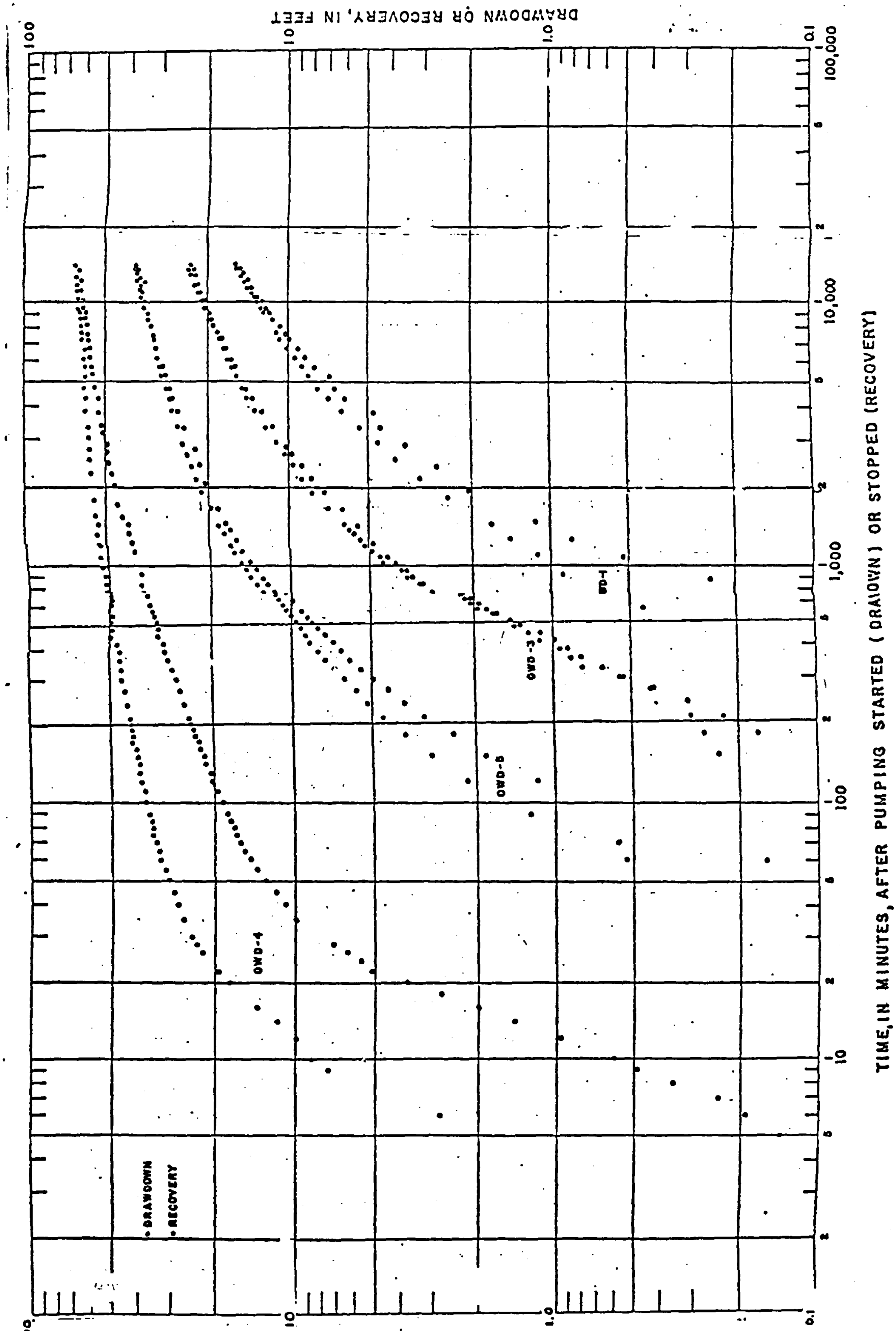


FIGURE 6 --LOGARITHMIC GRAPH OF DRAWDOWN AND RECOVERY IN WELLS OWD-1, OWD-3, OWD-4, AND OWD-5; WELL TW-2 TEST

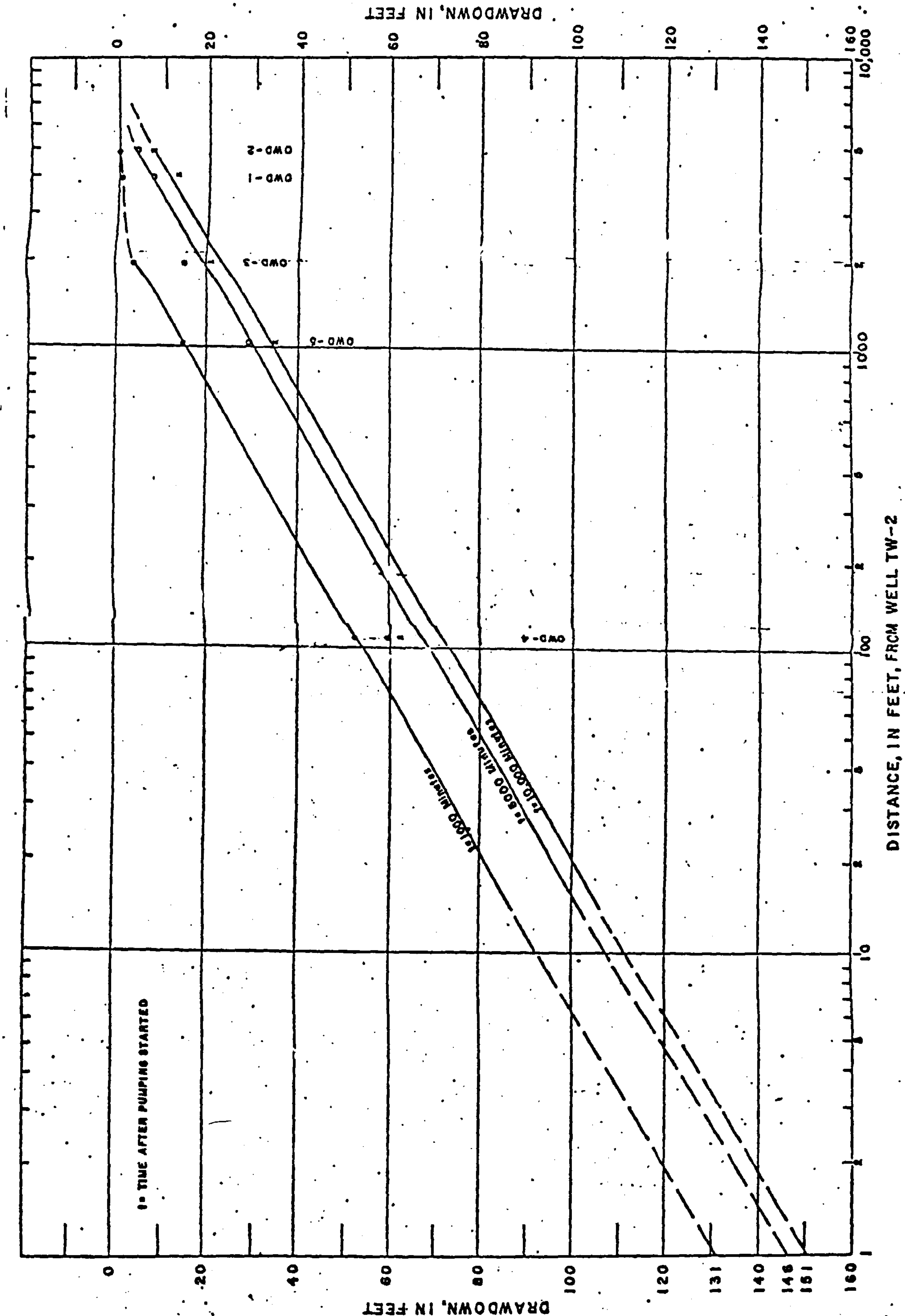


FIGURE 7 --DISTANCE-DRAWDOWN GRAPH FOR WELLS IN BILL SMITH MINE AREA; WELL TW-2 TEST

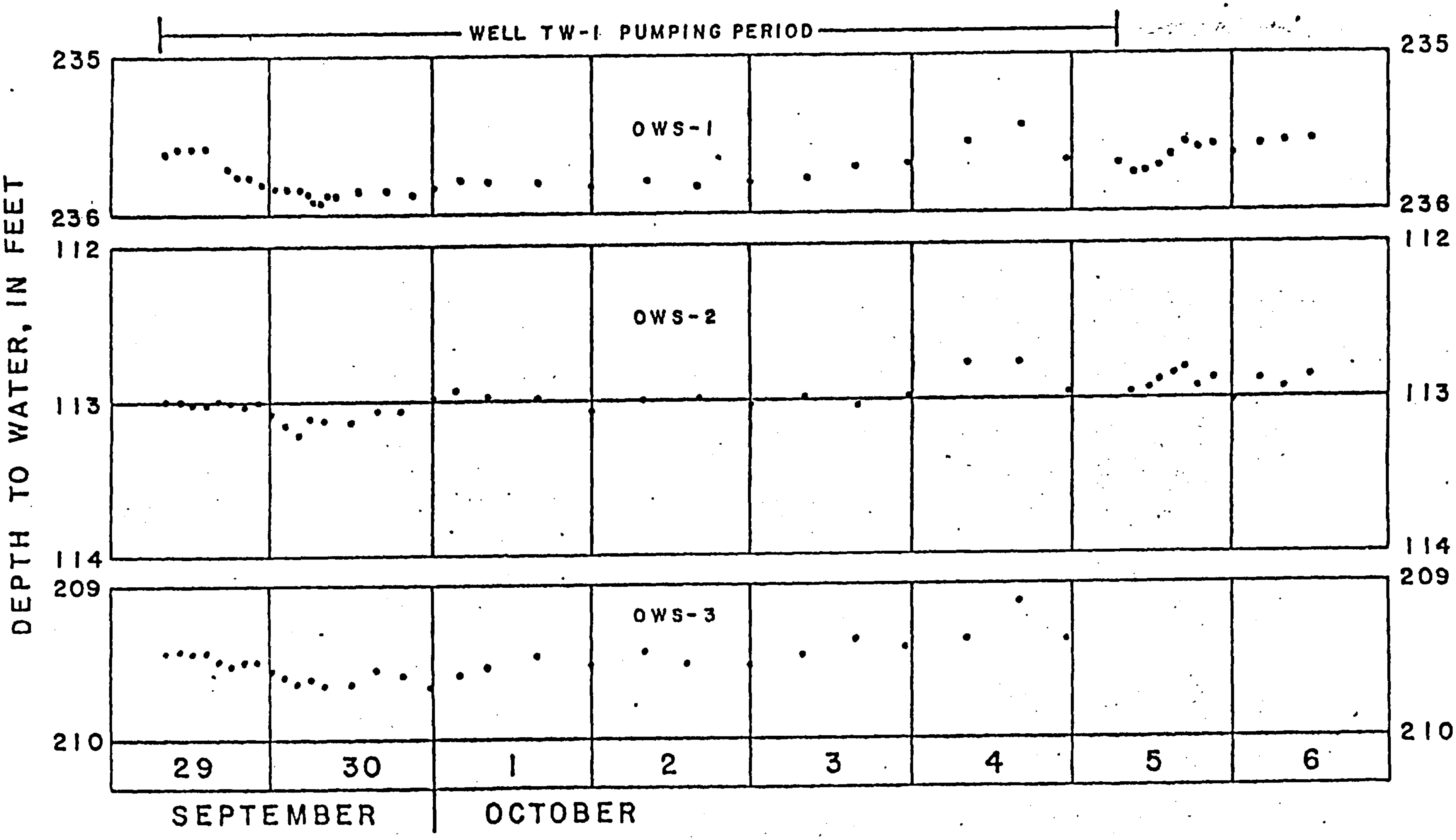


FIGURE 8 --HYDROGRAPHS WATER LEVEL IN OBSERVATION WELLS IN WATER TABLE AQUIFER, SEPTEMBER 29 - OCTOBER 6, 1975

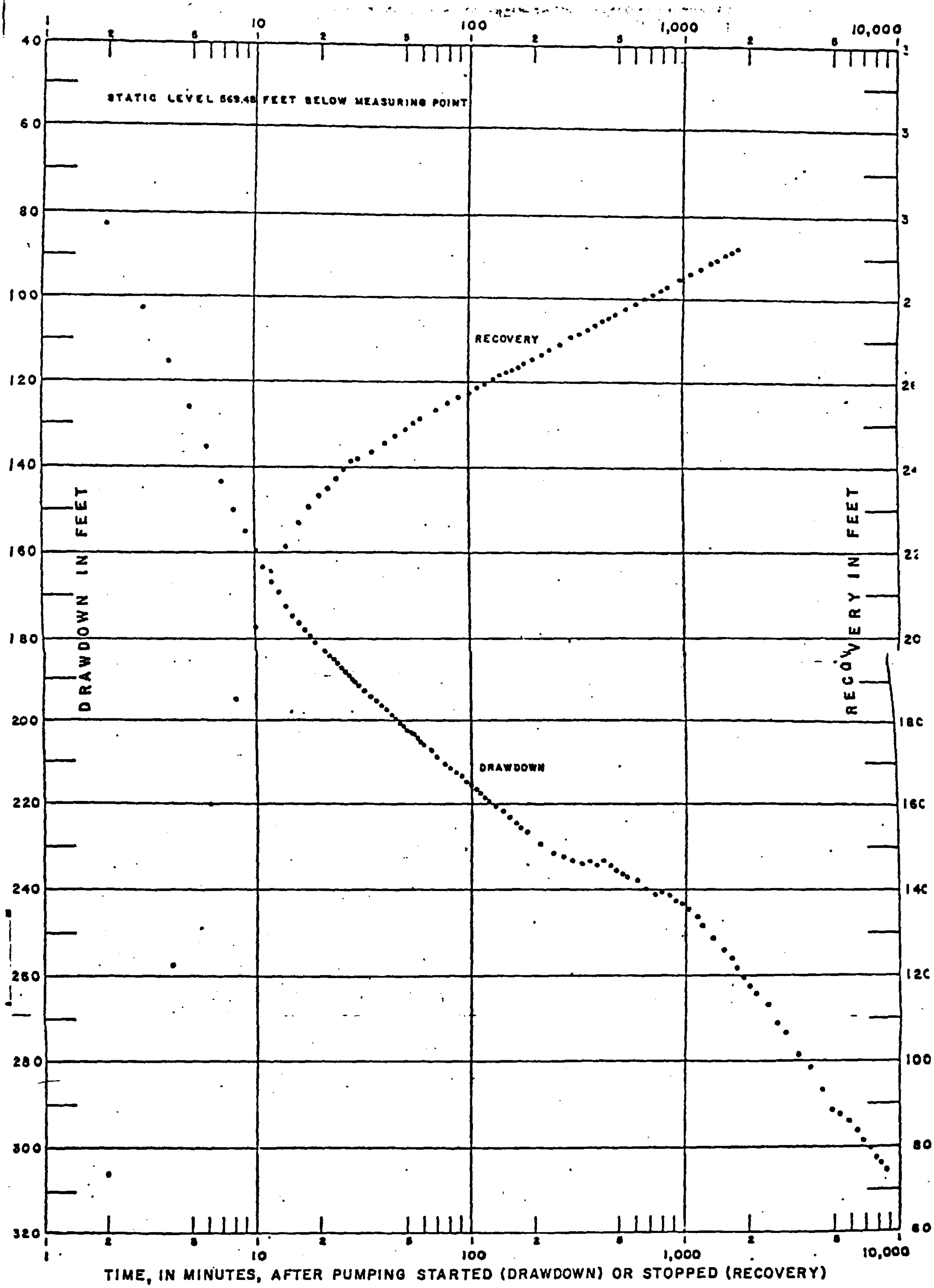


FIGURE 9 --SEMI-LOGARITHMIC GRAPH OF DRAWDOWN AND RECOVERY IN WELL TW-1

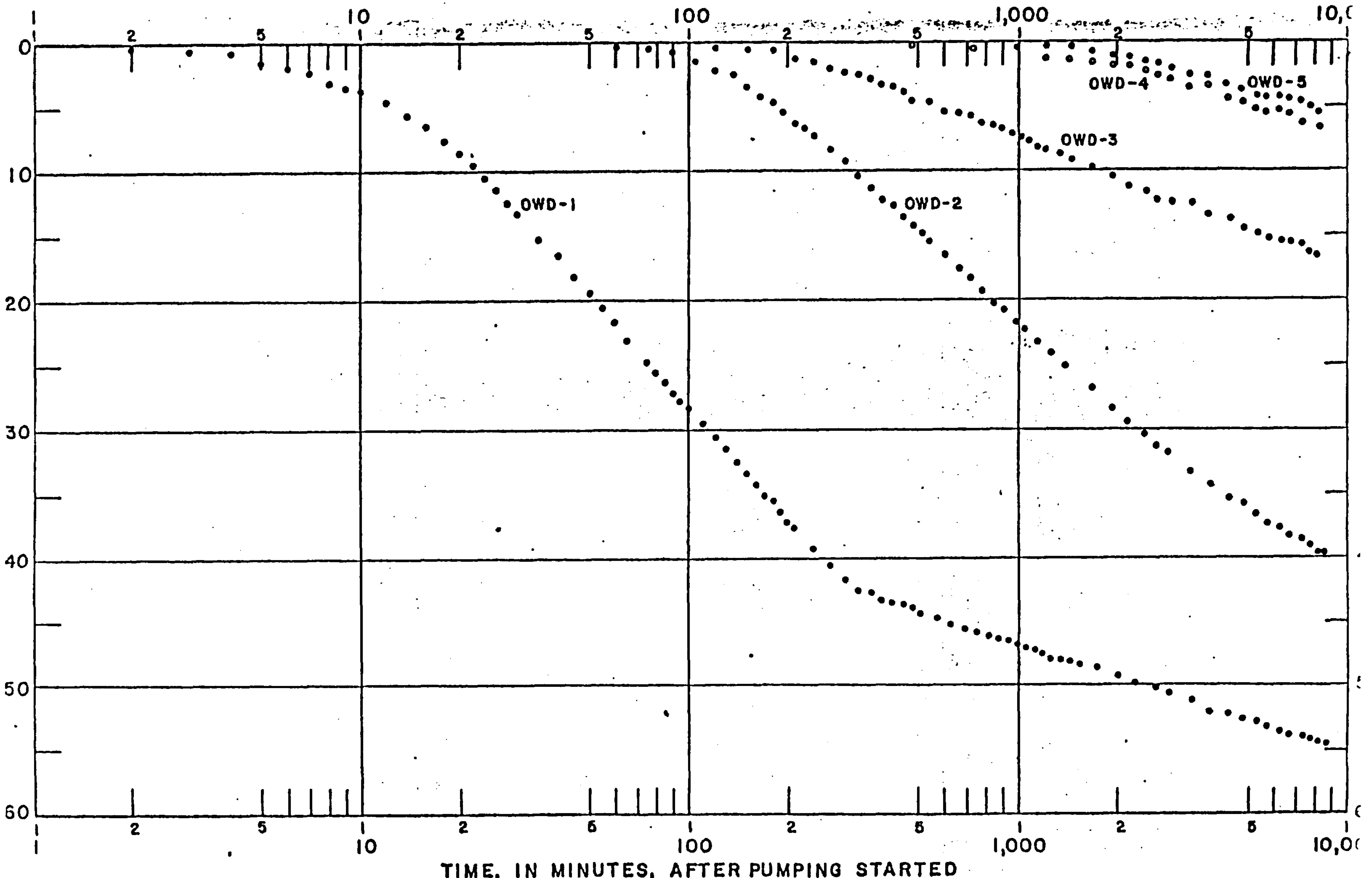


FIGURE 10--SEMI-LOGARITHMIC GRAPH OF DRAWDOWN IN WELLS OWD-1, OWD-2, OWD-3, OWD-4 AND OWD-5, WELL TH-1 TEST

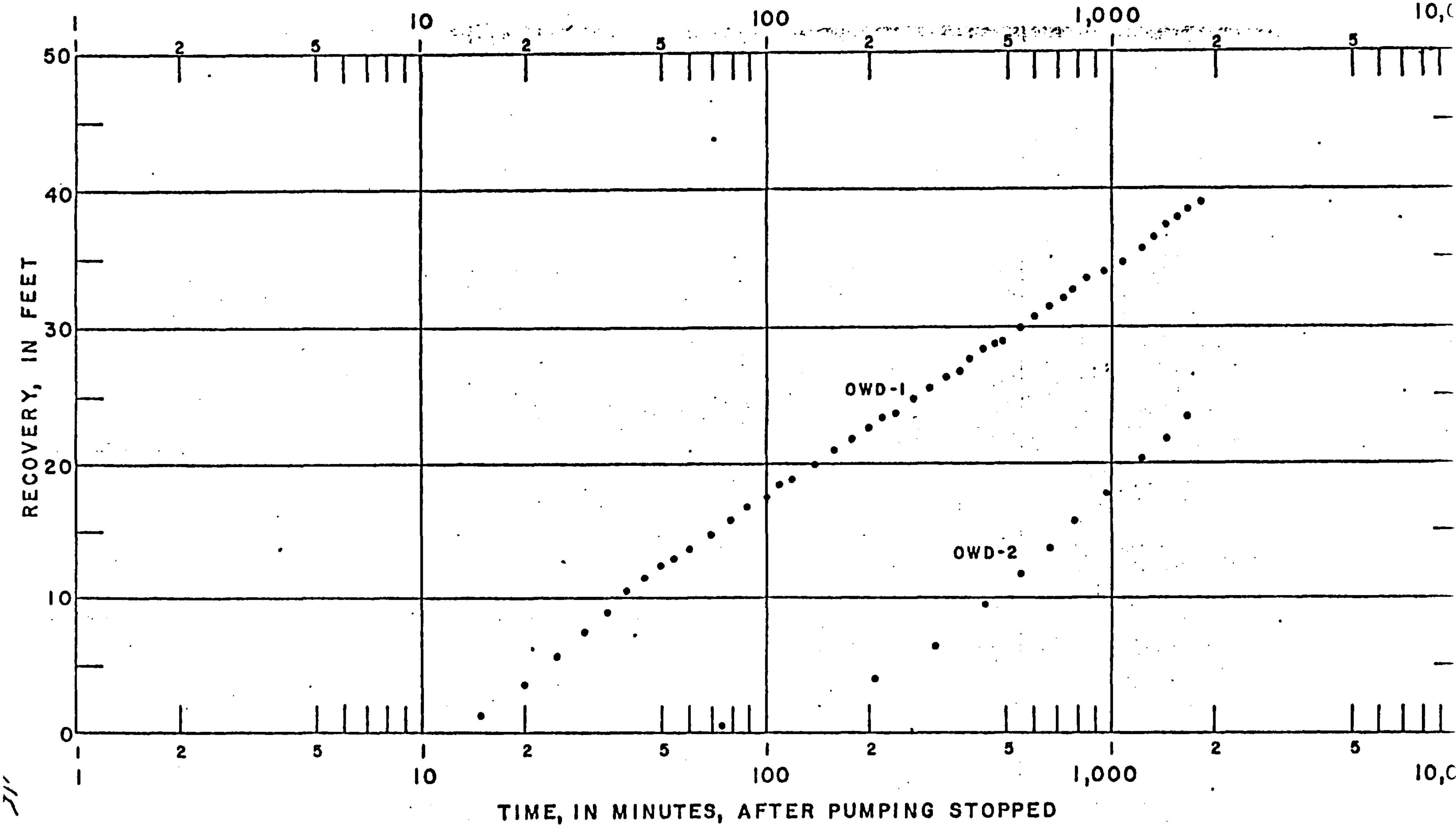


FIGURE 11--SEMI-LOGARITHMIC GRAPH OF RECOVERY IN WELLS OWD-1 AND OWD-2; WELL TW-1 TEST

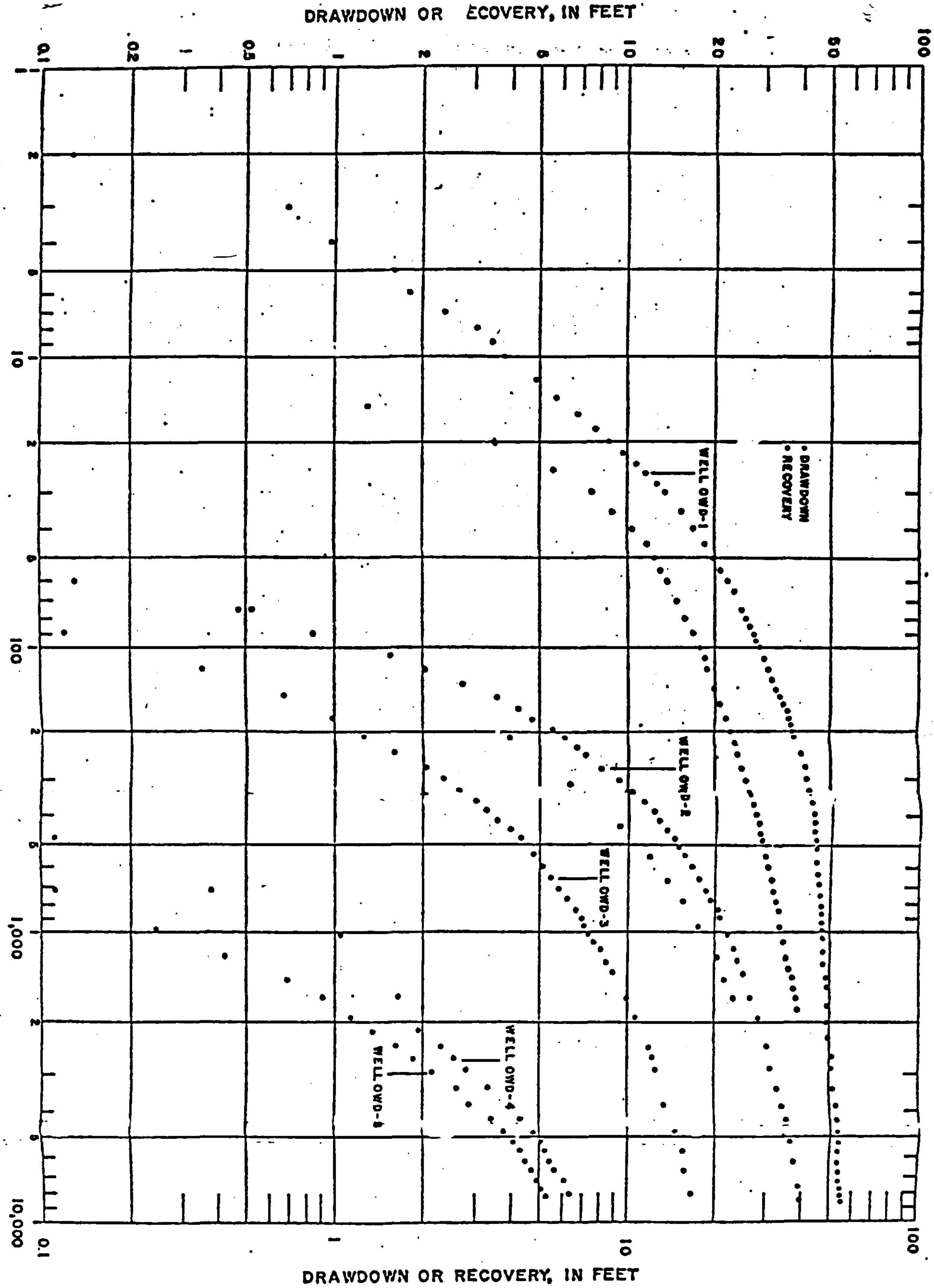


FIGURE 12--LOGARITHMIC GRAPH OF DRAWDOWN AND RECOVERY IN WELLS OWD-1, OWD-2, OWD-3, OWD-4, AND OWD-5; WELL TW-1 TEST

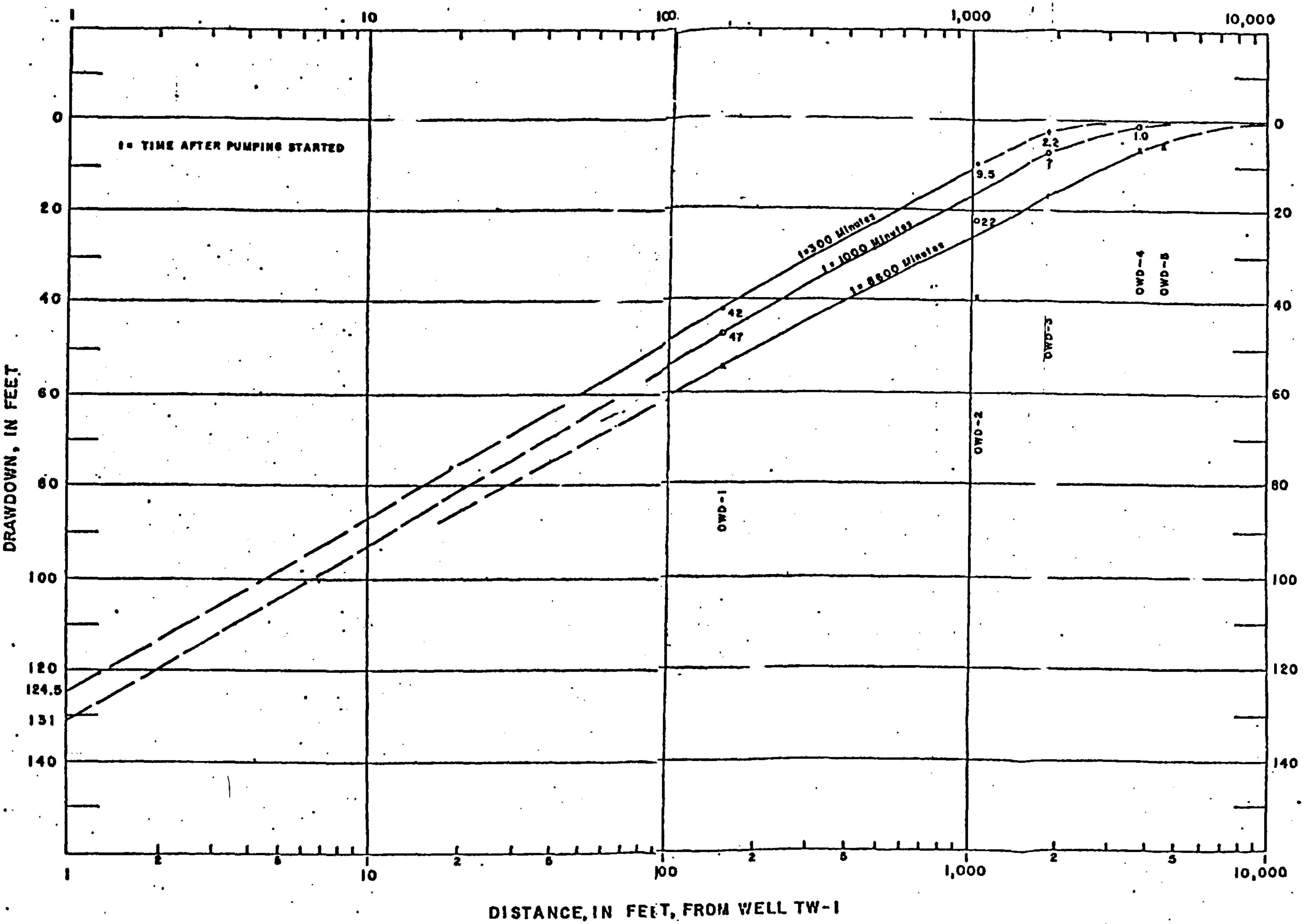


FIGURE 13--DISTANCE-DRAWDOWN GRAPH FOR WELLS IN BILL SMITH MINE AREA; WELL TW-1 TEST

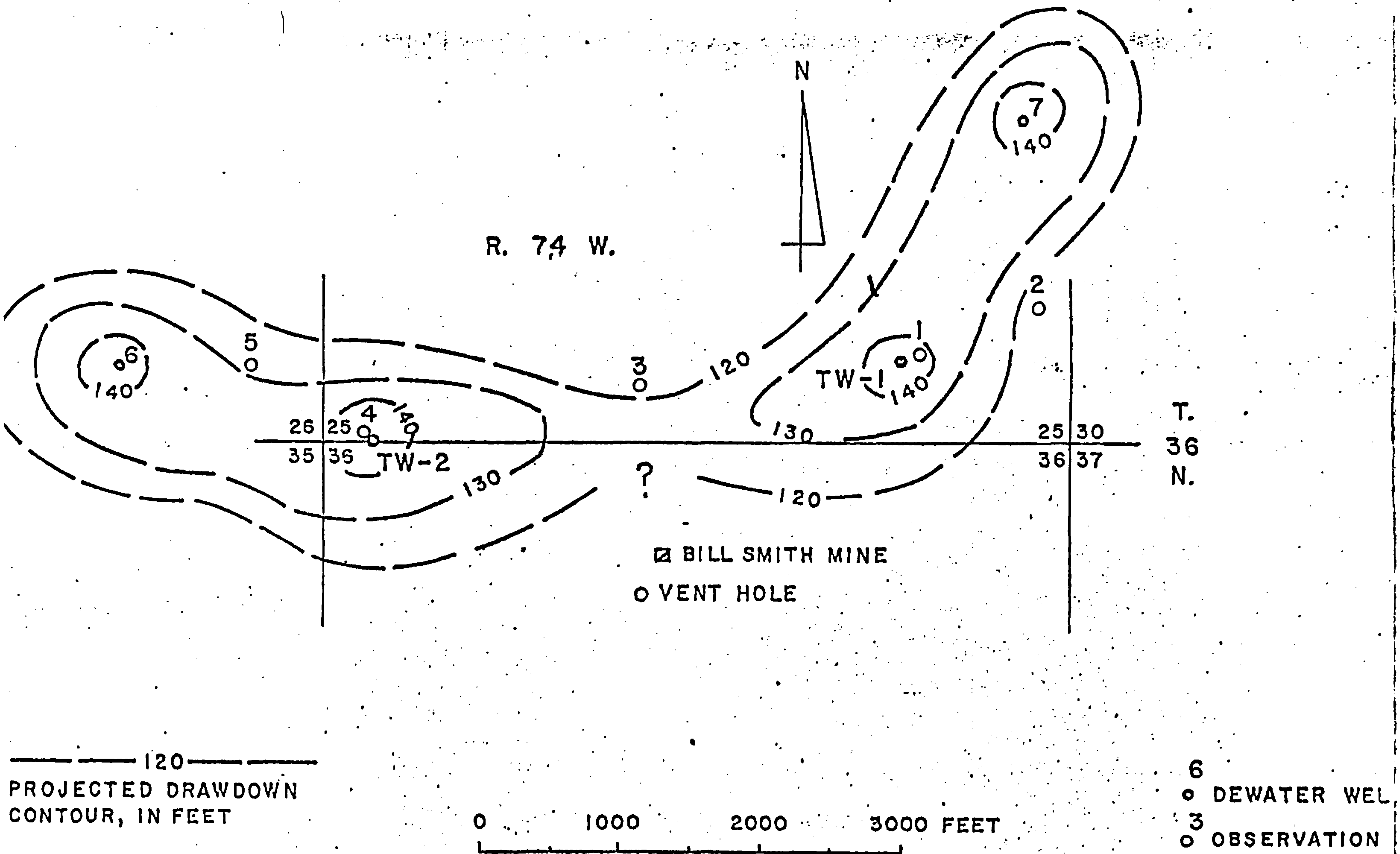


FIGURE 14 --MAP OF BILL SMITH MINE AREA AND DEWATER WELL LOCATIONS

Hydrology

Attachment 'B'

Q-Sand Pilot Pump Test

The pump test for the Q-Sand ISL pilot was conducted in April 1981 to demonstrate the site was suitable for a solution mining research and development test site. The average Q-Sand transmissivity at the test site was 950 gpd/ft with a permeability and storage coefficient of 32 gpd/ft^2 and $6x10^{-5}$, respectively. NRC's Environmental Impact Appraisal (EIA) concluded the vertical permeability of the overlying and underlying shale was in the range of $6x10^{-8}$ cm/sec to $6x10^{-6}$ cm/sec. The Q-Sand pilot leaching began in October 1981 and aquifer restoration was complete in May 1985. No vertical or lateral excursion occurred during the life of the project. Those sections of NRC's EIA discussing the Q-Sand pump test are attached.

UNITED STATES NUCLEAR REGULATORY COMMISSION

ENVIRONMENTAL IMPACT APPRAISAL

BY THE

DIVISION OF WASTE MANAGEMENT

IN CONSIDERATION OF THE ISSUANCE OF

SOURCE MATERIAL LICENSE NO. SUA-1387 FOR THE

KERR-McGEE NUCLEAR CORPORATION

SOUTH POWDER RIVER BASIN "Q" SAND SOLUTION MINING PROJECT

DOCKET NO. 40-8768

Dated: June 1981

Groundwater units in the vicinity of the proposed test site consist of 0-30 feet of alluvium and several hundred feet of lenticular sandstones of Wasatch and Fort Union Age (see Table 2.2.01). The lenticular sandstones of the Wasatch Formation form the upper "W" aquifer at the site. It is a low-yielding aquifer that is geologically confined but not confined under pressure. The water level in the "W" aquifer at the site is approximately 190 feet below the land surface. Most water wells penetrate the Wasatch ("S" aquifer) and Fort Union Formations ("Q" and "O" aquifers). In the vicinity of the test area, such wells generally yield from 5 to 20 gallons per minute (gpm), but some wells yield in excess of 100 gpm. In general, the groundwater in the basal Wasatch ("S" aquifer) and Fort Union Formations ("Q" and "O" aquifers) is under artesian pressure and groundwater flow in each of the aquifers appears to move to the north-northeast from the proposed test area (Figure 2.2.07).

All known wells in the license area and adjacent lands are owned and operated by Kerr-McGee and are properly constructed. An inventory of the wells with the well designation, completion aquifer, surface elevation, well depth, and the water level and yield at time of completion is included in Tables 2.2.02 and 2.2.02(a). Wells which do not have a yield value were completed as observation wells and were not pumped. The approximate well locations relative to the license area are also shown in Figure 2.2.06. The only well that is being used on-site is well WW103 which is completed in the "W" sand and is pumped at around 10 gpm. The mine shaft which penetrates the lower "O" aquifer is being dewatered at a rate of around 1700 gpm.

A long-term aquifer pumping test was conducted so that evaluations could be made of the hydrogeological characteristics of the "Q" sand and of the isolation provided by the overlying and underlying shales in the test area. The pumped well and three monitor wells were completed and monitored in the "Q" sand. Two additional monitor wells were also monitored in the overlying (S-sand zone) and underlying (O-sand zone) aquifers to check for vertical communication. The locations of the wells used in the pumping test (QP-3 was pumped and wells QI-2, QI-7, QI-11, QMS-1, and QMO-1 monitored as observation wells) are shown in Figure 2.2.07. The well completion data are provided in Tables 2.2.02 and 2.2.02(a) and the pump test data, data plots, and barometric pressure readings taken for the aquifer pump test are included in Appendix B.

The aquifer pumping test was conducted on well QP-3 for a period of nearly three days 4305 minutes (from 9:38 a.m. on April 10, 1981 to 9:23 a.m. on April 13, 1981), at a steady discharge rate of 16.7 gpm.

The results of the analyses of the "Q" sand observation well drawdown and recovery data are listed in Table 2.2.03, and log-log drawdown and recovery data plots with match points indicated are included in Appendix B, Figures B-1 and B-2. These data indicate that the "Q" ore zone aquifer is a confined leaky aquifer, with an average value of transmissivity of approximately 950 gpd/ft, a permeability of around 32 gpd/ft^2 (.002 cm/sec), and a storage coefficient of around 6×10^{-5}.

TABLE 2.2.01 DESCRIPTION OF HYDROGEOLOGIC UNITS IN THE VICINITY OF THE PROPOSED SITE

Geologic Age	Hydro-geologic Unit	Approximate Thickness (feet)	Lithologic Character-istics	Hydrologic Character-istics
Eocene	Wasatch Formation	0-500	Fine- to coarse-grained lenticular arkosic sand-stone, and interbedded claystone and siltstone	Groundwater production generally good, but lenticular nature restricts aquifer use locally; yields of as much as 140 gpm have been produced
Paleocene	Fort Union Formation	3000	Fine- to coarse-grained, lenticular sandstone, and interbedded carbon-aceous shale and coal	Groundwater production good beneath site; yields of 550 gpm have been produced over prolonged periods
Cretaceous	Lance Formation	3000	Fine- to medium-grained sandstone, and inter-bedded sand, shale, and claystone	Groundwater production largely unknown in vicnity of site; probably would not yield over 20 gpm
Cretaceous	Fox Hills	500-700	Fine- to medium-grained sandstone, and inter-bedded thin sandy shale	Groundwater production largely unknown in vicinity of site; probably would not yield over 100 gpm

Sources: Hodson et al., 1973; Hodson, 1971; Harshbarger and Associates, 1974.

TABLE 2.2.02

INVENTORY OF WELLS ON THE LICENSE AREA AND ADJACENT LANDS

KERR-McGEE "Q" SAND PROJECT
CONVERSE COUNTY, WYOMING

Figure 2.2.06 Location No.	Kerr-McGee[1] Well Number	Wyoming Well Permit Number	Aquifer	Elevation of Land Surface (Feet Above MSL)	Depth of Well (Feet)	Elevation of Water Level (Feet Above MSL)	Date of Level Measurement (Month/Year)	Yield (GPM)
1	TW-2	29,277	Fort Union	5541.9	946	5054.5	7/76	560
2	OWS-4	--	Wasatch	5546.6	546	5375.6	7/76	--
3	OWD-4	--	Fort Union	5546.7	943	5107.0	7/76	--
4	OWS-3	--	Wasatch	5562.5	570	5350.6	7/76	--
5	OWD-3	--	Fort Union	5563.1	897	5057.8	7/76	--
6	TW-1	28,276	Fort Union	5599.5	1006	5030.0	7/76	425
7	OWS-1	--	Wasatch	5585.5	567	5349.7	7/76	--
8	OWD-1	--	Fort Union	5586.1	987	5060.7	7/76	--
9	OWS-2	--	Wasatch	5593.8	584	5482.0	7/76	--
10	OWD-2	--	Fort Union	5593.9	900	5070.9	7/76	--
11 (2)	WW103	2,574	Wasatch	5540	474	5280	9/69	140
12 (3)	Mine Shaft	15,500	Fort Union	5519	949	5250	11/74	850
13	OWD-6	--	Fort Union	5568	868	4955	12/79	--
14	QI-1	--	Fort Union	5555	509	5171	12/79	--
15	QP-1	--	Fort Union	5545	497	5169.5	12/79	15
16	QI-2	--	Fort Union	5541	497	5166.5	12/79	18
17	QM-1	--	Fort Union	5551	505	5174	12/79	--
18	QMD-1	--	Fort Union	5543	612	4962	12/79	--
19	QMS-1	--	Wasatch	5554	421	5239.5	12/79	--
20	I-300	--	Fort Union	5574	812	-0-	11/79	--
21	I-500	--	Fort Union	557	774	-0-	11/79	--

[1]All known wells in the license area and adjacent lands are owned an operated by Kerr-McGee.

[2]Well WW103 is the only well that Kerr-McGee is currently operating for water supply, at a rate of approximately 10 gpm from the W aquifer.

[3]The mine shaft is being pumped at around 1700 gpm, from the 0 aquifer.

TABLE 2.2.02(a)

ISL WELLS
KERR-McGEE Q SAND PROJECT
CONVERSE COUNTRY, WYOMING

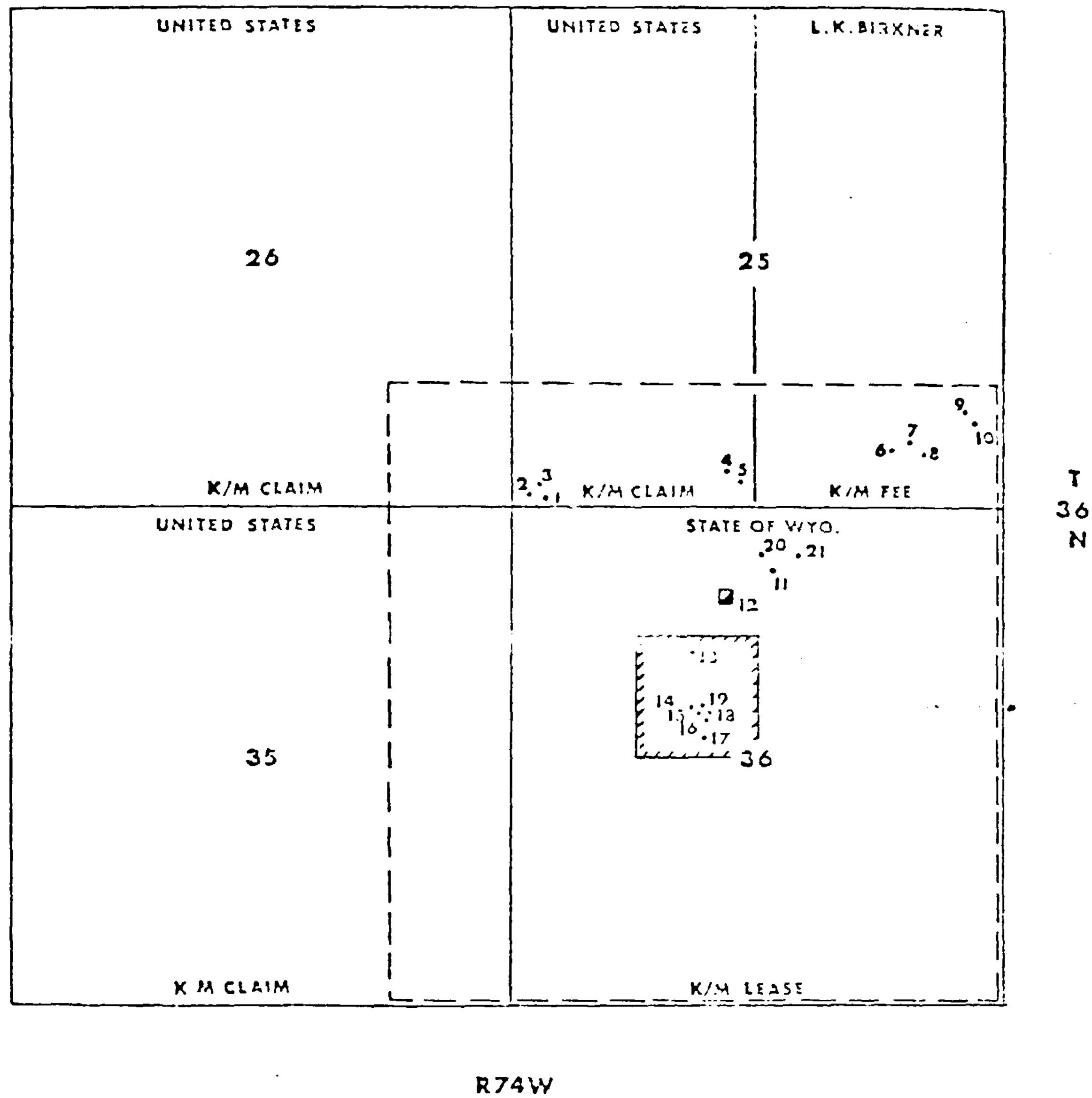
Kerr-McGee Well Number	Elevation at Top of casing (feet above MSL)	Depth of well (feet)	Depth from Casing Top 9/11/80	MSL Elevation	Completion Interval (T.D.-up)
QP-1*	5549.65	497	375.80	5173.85	497'-475'
QP-2	5544.06	495	369.40	5174.66	495'-470'
QP-3	5557.24	512	383.97	5173.27	512'-480'
QP-4	5559.96	515	386.83	5173.13	515'-490'
QP-5	5552.11	517	378.88	5173.23	517'-465'
QI-1*	5556.17	509	382.86	5173.31	509'-492'
QI-2	5546.38	496	372.45	5173.93	496'-475'
QI-4	5548.68	513	375.22	5173.46	513'-475'
QI-5	5560.62	513	387.55	5173.07	513'-490'
QI-6	5565.42	520	392.35	5173.07	520'-495'
QI-7	5567.82	522	394.88	5172.94	522'-495'
QI-8	5553.52	503	379.59	5173.94	503'-480'
QI-9	5552.04	505	378.66	5173.38	505'-480'
QI-10	5543.38	514	369.80	5173.58	514'-465'
QI-11	5554.35	525	381.28	5173.07	525'-475'
QMW-1**	5558.71	350	188.48	5370.23	350'-170'
QMS-1**	5553.63	421	315.35	5238.28	421'-393'
QMO-1**	5545.47	612	579.34	4966.13	612'-558'
QM-1	5550.53	505	375.75	5174.78	505'-475'
QM-2	5535.80	505	361.35	5174.45	505'-460'
QM-3	5528.17	505	354.65	5173.52	505'-455
QM-4	5550.72	539	378.10	5172.62	539'-475
QM-5	5582.73	537	410.9	5171.83	537'-513
QM-6	5562.61	520	390.16	5172.45	520'-495
QM-7	5562.15	514	388.81	5173.34	514'-438
QM-8	5556.75	508	380.08	5176.67	508'-494

*6" I.D. steel casing, all other holes cased with 4.33 I.D. fiberglass
**Monitor well completed in another aquifer unit. Wells QMS-1 and QMW-1 are completed in the Wasatch formation. All other wells are completed in the Fort Union formation.

FIGURE 2.2.06

APPROXIMATE WELL LOCATIONS
LICENSE AREA AND ADJACENT LANDS

KERR-McGEE 'Q' SAND PROJECT
CONVERSE COUNTY WYOMING



LICENSE AREA

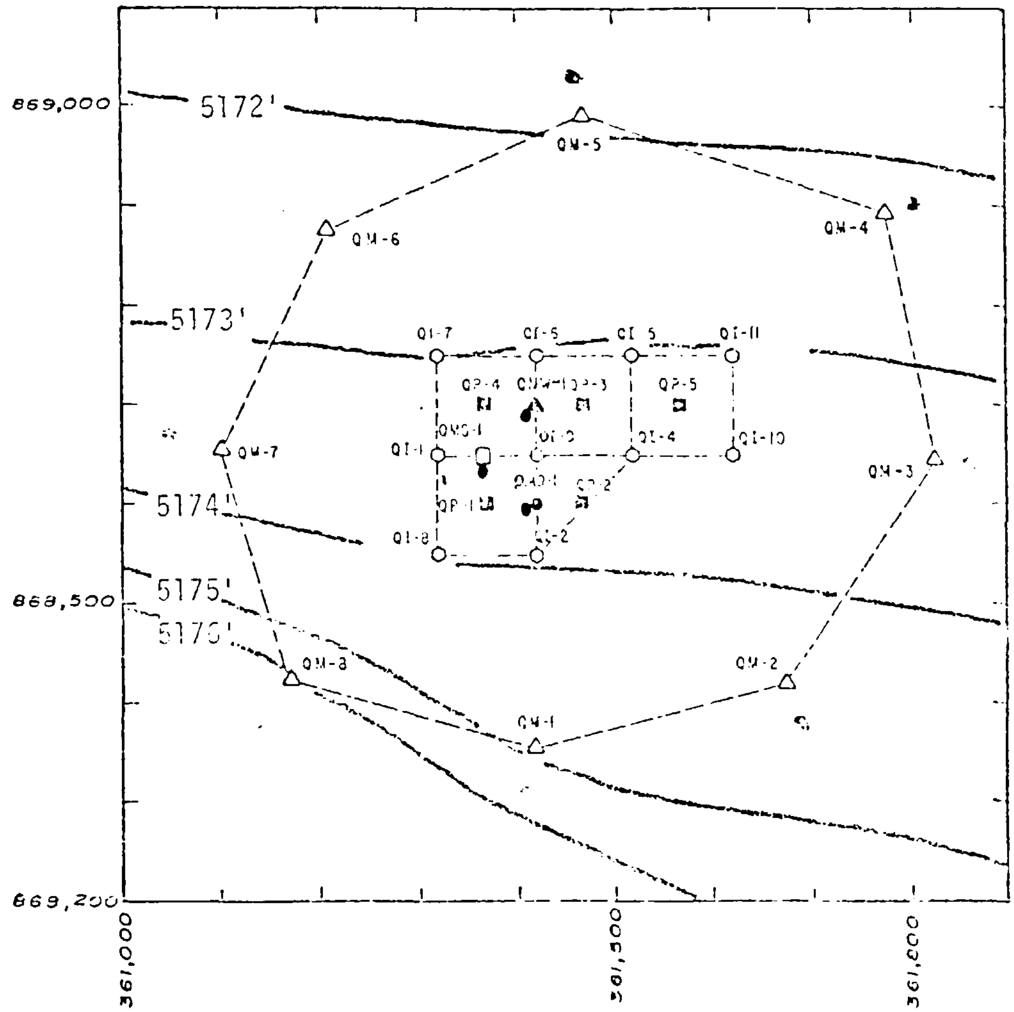
LIMITS OF ADJACENT LANDS

BILL SMITH MINE SHAFT

APPROXIMATE WELL LOCATION (See Table 2.2.02 for well data)

STATE — SURFACE OWNER
PROPERTY LIMITS
K/M — MINERAL OWNER OR LESSEE

Figure 2.2.07 IN SITU R&D PROJECT WELL PATTERN
"Q" SAND DEPOSIT
SECTION 36-T36N, R74W
CONVERSE COUNTY, WYOMING



LEGEND

- Production Well QP
- Injection Well QI

Monitor Wells:

- "Q" Ore Zone (QM-1 → 8)
- "W" Shallow Zone (QMW-1)
- "S" Shallow Zone (QMS-1)
- "O" Deep Zone (QMD-1)

— 5172 — WATER LEVEL ELEVATION ABOVE MSL
(Q Ore Zone Aquifer, 1980)

SCALE 1" = 200'

TABLE 2.2.03

"Q" SAND AQUIFER PROPERTIES
Q-SAND PILOT PROJECT

Well Number	Q-Sand Transmissivity (T, gpd/ft) Drawdown	Recovery	Q-Sand Thickness (m, feet)	Permeability (P=Tav/m, gpd/ft²)	Q-Sand Storativity (dimensionless)	r /b	p'/m' [gpd/ft²/ft]	m' ft	p' gpd/ ft²	ft/ yr	cm/ sec
QI-2	770	1472	21		7×10^{-5}, 6.6×10^{-5}	0.3, 0	.0026	40	.1	5.7	5.6x1[illegible]
QI-7	798	722	27		7×10^{-5}, 4.3×10^{-5}	0.3, 0.3	.0029, .0026	40	.12, .10	5.8, 5	5.6x1[illegible] 5x10[illegible]
QI-11	912	1007	50		8×10^{-5}, 4.5×10^{-5}	0.3, 0.3	.003, .0036	40	.13, .15	6, 7.3	6x10[illegible] 7x10[illegible]
Representative Values		950	30	32	6×10^{-5}		.003	40	.01	6	6x10[illegible]

(1)Based on the thickness of the "R" Shale from Cross Sections (Figures 2.2.04 and 2.2.05).

Early drawdown and recovery data from the "Q" sand observation wells were matched to the Hantush leaky type curves ($^{r}/B=0.3$) while later data indicated the presence of a low flow boundary. Analysis of the early data, which were analyzed assuming no water released from storage in the aquitard, indicates that the vertical permeability of the overlying "R" shale may be around 6 ft/yr ($6x10^{-6}$ cm/sec). Although water probably was released from storage in the aquitard, the results of the pump test analysis completed are believed to be representative of the hydrogeologic properties of the Q-aquifer and the "R" confining unit. Analysis of the later data indicate the presence of at least one barrier or low flow boundary, located approximately 350, 400, and 430 feet away from observation wells QI-2, QI-7, and QI-11, respectively. Thinning of the "Q" sand aquifer to the south and west of the well field could account for the barrier boundary that was observed (see Figures 2.2.04 and 2.2.05 and Appendix B, Figures B-1 and B-2).

Water levels in the overlying and underlying S and O sand aquifers were monitored in wells QMS-1 and QMO-1, respectively. Water levels in these observation wells did not fluctuate during pumping from the "Q" ore zone aquifer, demonstrating that there is confinement of the ore zone from the surrounding aquifer units. Water level data from these wells are plotted in Figure B-3 of Appendix B.

Analyses of the aquifer pump test data indicate that the vertical permeability of the "R" confining shale unit (assuming that water flowed down through the "R" shale and not up through the "P" shale based on vertical hydraulic gradients) is around 6 ft/yr ($6x10^{-6}$ cm/sec). Laboratory permeability tests conducted by Kerr-McGee on plugs taken from cored sections of the R and P shales indicate permeabilities of less than $5x10^{-4}$ ft/yr ($4.7x10^{-10}$ cm/sec).

The NRC staff believes that the vertical permeability of the R and P shales is not as low as $5x10^{-4}$ ft/yr ($4.7x10^{-10}$ cm/sec), based on: (1) the analyses of the aquifer pump test data, (2) values for permeability cited in the literature ($5x10^{-4}$ ft/yr to 5 ft/yr for shale, Walton, 1970), and (3) the fact that most laboratory permeability tests generally indicate permeabilities that are much lower than in the field.

Realizing that some of the recharge that was observed during the early part of the aquifer pump test could have come from waters released from storage in the aquitard, and not waters "leaking" down from the S aquifer through the R shale, then a vertical permeability of 6 ft/yr may be conservative (slightly high). However, taking into account all of the information presented, the NRC staff believes that the vertical permeability of the R and P shales is low and ranges from around .06 ft/yr ($6x10^{-8}$ cm/sec) to 6 ft/yr ($6x10^{-6}$ cm/sec).

Based on the hydrogeologic information obtained at the site, confinement of the "Q" sand aquifer appears to be adequate.

The potentiometric water level elevations of the W,S,Q, and O sand aquifers are each distinct at the site and measure approximately 5370 feet, 5240 feet, 5168-5174 feet and 4955-4962 feet above mean sea level, respectively. Although water levels in the O aquifer have been affected by underground mine dewatering, it appears that the natural vertical hydraulic potential decreases with depth.

APPENDIX B

AQUIFER PUMP TEST DATA AND DATA PLOTS

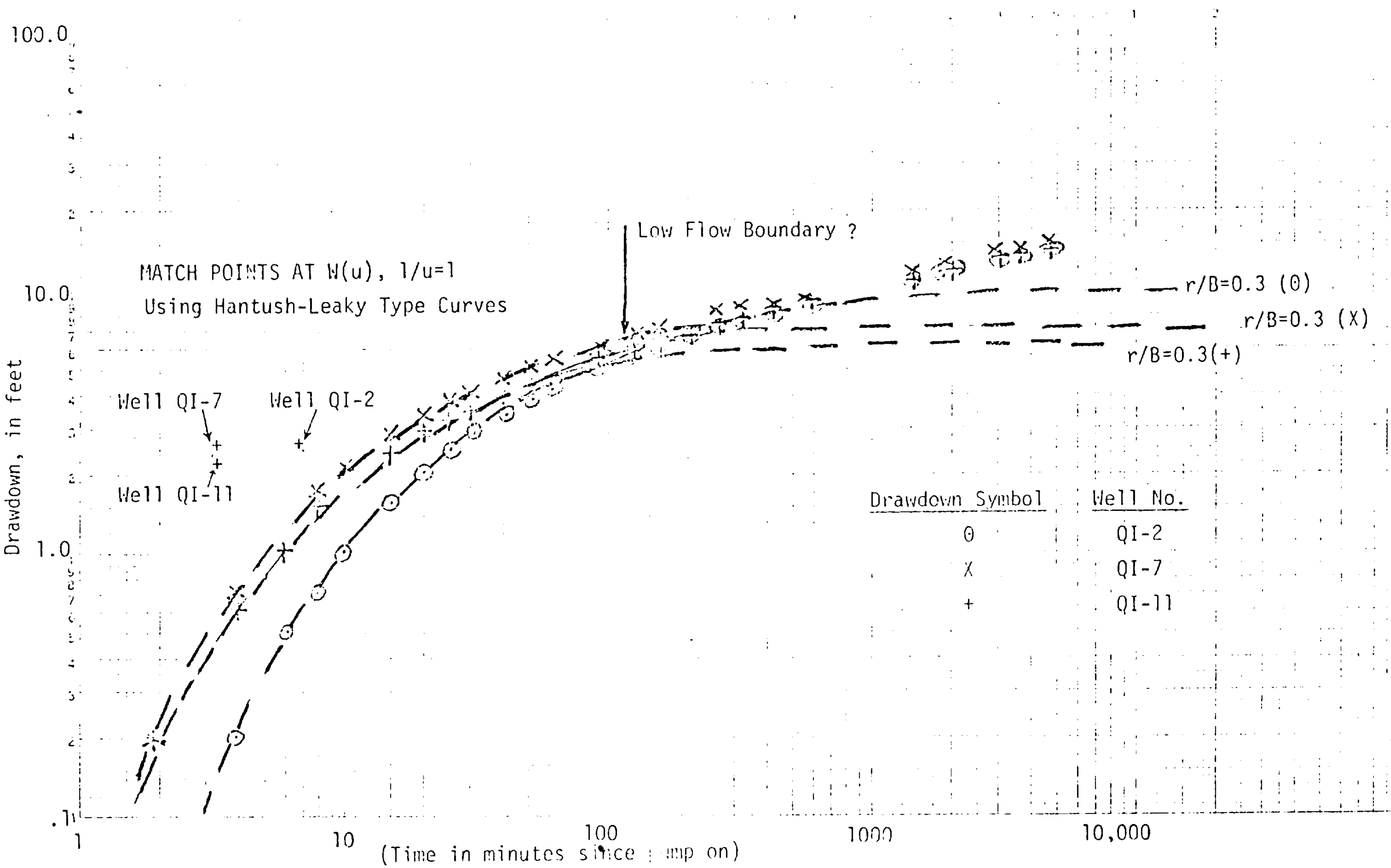


FIGURE B-1 LOG-LOG DRAWDOWN DATA PLOTS FOR Q-. AND OBSERVATION WELLS QI-2, QI-7, QI-11

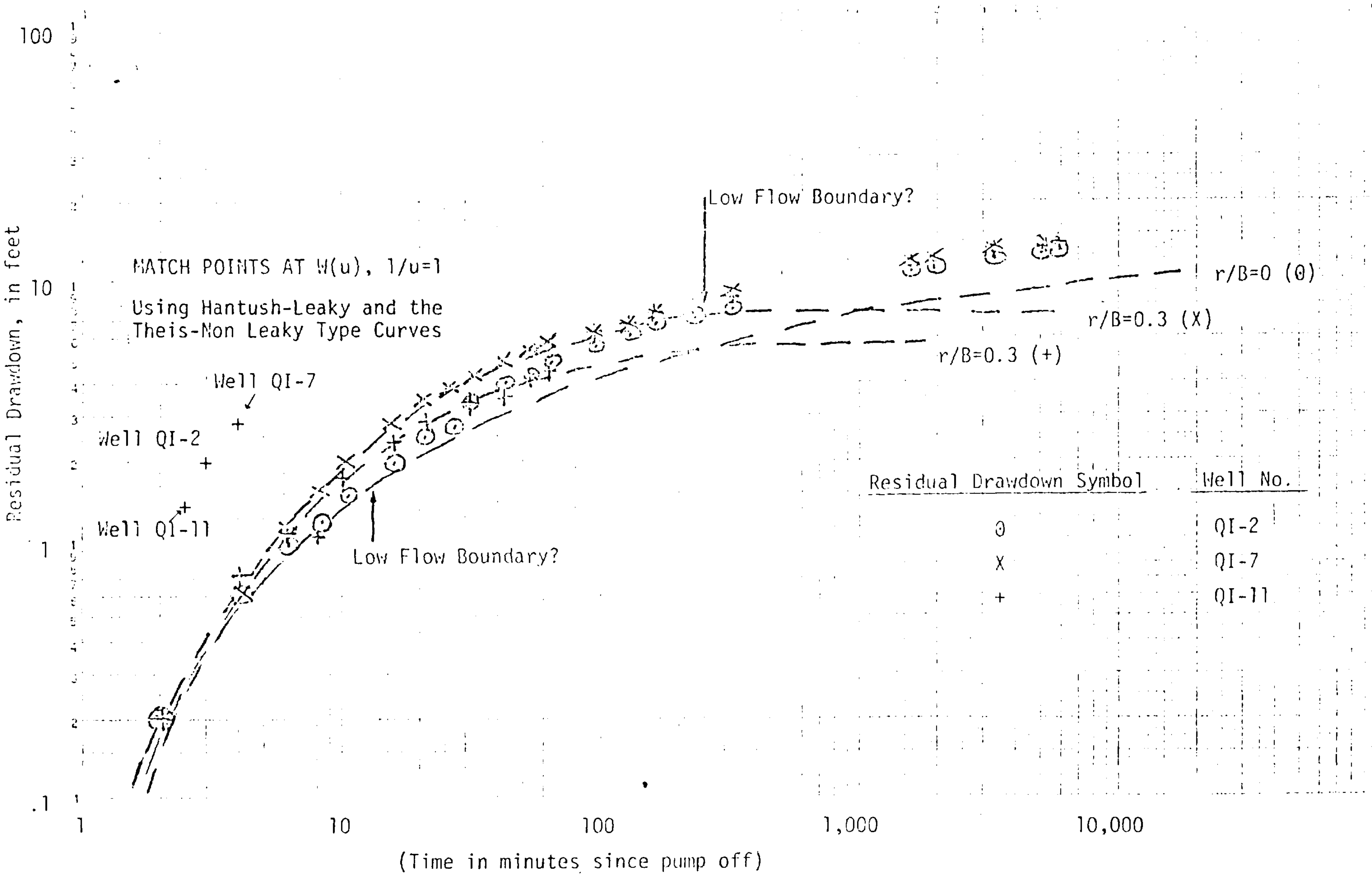


FIGURE B-2 LOG-LOG RECOVERY DRAWDOWN DATA PLOTS FOR Q-SAND OBSERVATION WELLS QI-2, QI-7, QI-11

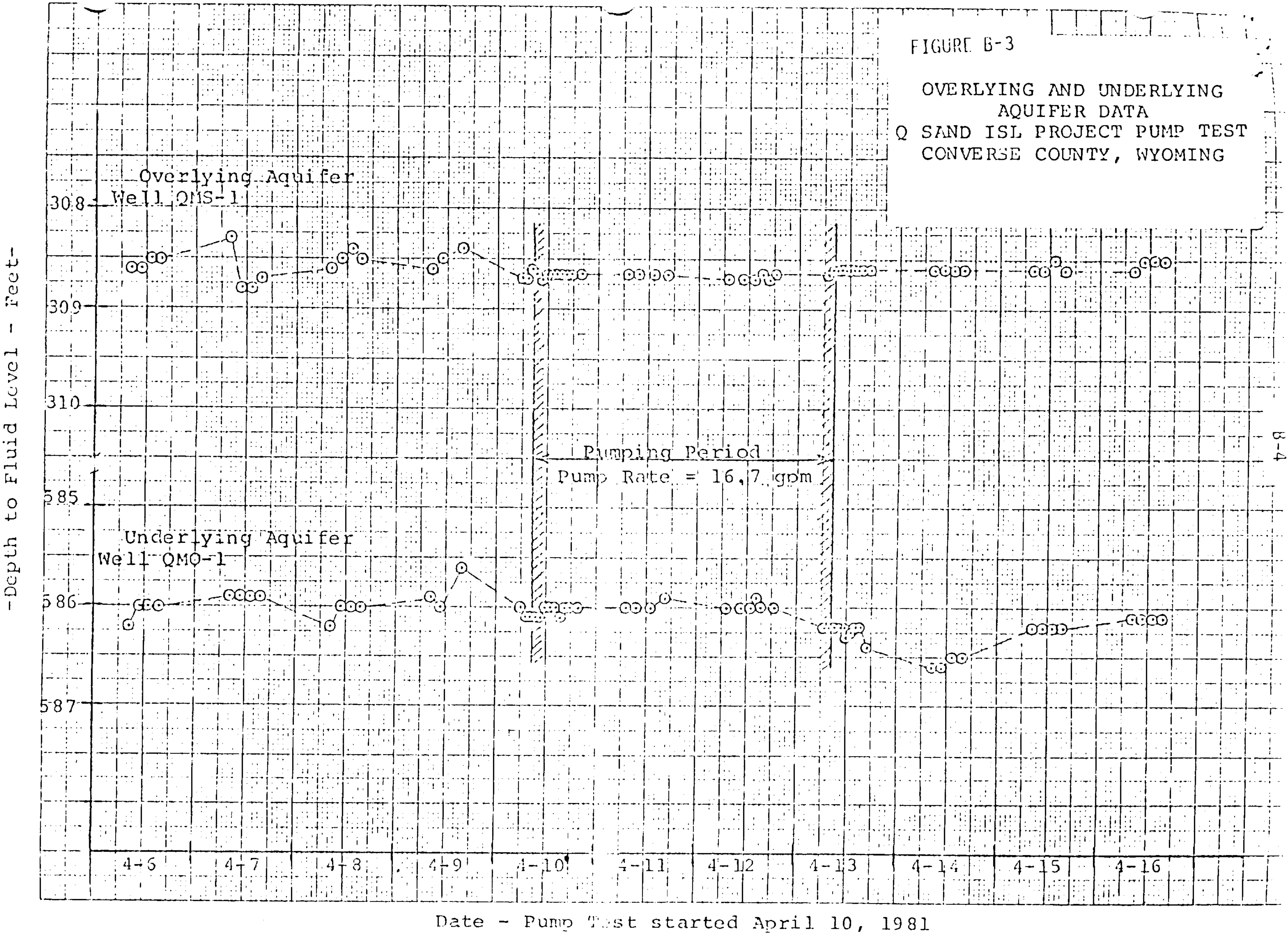


FIGURE B-3
OVERLYING AND UNDERLYING AQUIFER DATA
Q SAND ISL PROJECT PUMP TEST
CONVERSE COUNTY, WYOMING
Overlying Aquifer
Well QMS-1
308
309
310
Pumping Period
Pump Rate = 16.7 gpm
585
Underlying Aquifer
Well QMO-1
586
587
-Depth to Fluid Level - Feet-
4-6
4-7
4-8
4-9
4-10
4-11
4-12
4-13
4-14
4-15
4-16
Date - Pump Test started April 10, 1981

TABLE B-1

OVERLYING AND UNDERLYING AQUIFER DATA
Q SAND ISL PROJECT PUMPT TEST
CONVERSE COUNTY, WYOMING

Date/Time	Depth to Fluid Level - Feet: Overlying Aquifer Well QMS-1	Depth to Fluid Level - Feet: Underlying Aquifer Well QMO-1	Q Sand Aquifer Well QI-2
4-6-81			
1000	308.6	586.2	
1200	308.6	586.0	376.0
1400	308.5	586.0	375.5
1600	308.5	586.0	375.6
4-7-81			
1000	308.3	585.9	375.5
1200	308.8	585.9	373.3
1400	308.8	585.9	375.5
1600	308.7	585.9	375.4
4-8-81			
1000	308.6	586.2	375.5
1200	308.5	586.0	375.5
1400	308.4	586.0	375.5
1600	308.5	586.0	375.5
4-9-81			
1000	308.6	585.9	375.5
1200	308.5	586.0	375.4
1600	308.4	585.6	375.4
4-10-81			
818	308.7	586.0	-
836	308.7	586.1	-
914	308.6	586.1	375.7
955[1]	308.65	586.1	377.2[2]
1033	308.7	586.1	379.6
1103	308.7	586.0	380.5
1134	308.65	586.0	380.0
1206	308.65	586.0	381.5
1300	308.65	586.0	382.1
1354	308.65	586.0	382.6
1450	308.65	586.1	382.9
1540	308.65	586.0	383.3
1625	308.65	586.0	383.5
1845	308.65	586.0	384.0
4-11-81			
745	308.65	586.0	386.1
1030	308.65	586.0	386.2
1330	308.65	586.0	386.7
1620	308.65	585.9	386.9

[1]Pump startad on 4-10-81 at 9:38 am
[2]Level data during test interpolated

TABLE B-1 Cont'd.

Date/Time	Depth to Fluid Level - Feet: Overlying Aquifer Well QMS-1	Depth to Fluid Level - Feet: Underlying Aquifer Well QMO-1	Q Sand Aquifer Well QI-2
4-12-81			
830	308.7	586.0	388.1
1050	308.7	586.0	388.2
1300	308.7	586.0	388.4
1400	308.65	585.9	388.4
1525	308.7	586.0	388.5
1830	308.65	586.0	388.6
4-13-81			
810	308.65	586.2	389.3
915	308.6	586.2	389.3
940[3]	308.6	586.2	387.4[3]
958	308.6	586.2	386.1
1015	308.6	586.2	385.3
1040	308.6	586.2	384.6
1120	308.6	586.2	383.6
1200	308.6	586.3	383.1
1255	308.6	586.25	382.4
1320	308.6	586.2	382.2
1420	308.6	586.2	382.0
1620	308.6	586.4	381.4
4-14-81			
1000	308.6	586.6	379.4
1200	308.6	586.6	379.2
1400	308.6	586.5	379.2
1600	308.6	586.5	379.0
4-15-81			
1000	308.6	586.2	378.2
1200	308.6	586.2	378.1
1400	308.5	586.2	378.1
1600	308.6	586.2	378.1
4-16-81			
1000	308.6	586.1	377.6
1200	308.5	586.1	377.6
1400	308.5	586.1	377.5
1600	308.5	586.1	377.5

[3] Pump shutdown on 4-13-91 at 9:23 am

TABLE B-2

Q SAND AQUIFER DRAWDOWN DATA
Q SAND ISL PROJECT PUMP TEST
CONVERSE COUNTY, WYOMING

Time From Start of Pump Minutes	Pumped Well QP-3	Drawdown, In Monitor Wells, In Feet: Monitor Well QI-2	Monitor Well QI-7	Monitor Well QI-11
2	13.0	-	0.2	0.2
4	13.8	0.2	0.7	0.6
6	13.9	0.5	1.2	1.0
8	14.6	0.7	1.7	1.5
10	15.1	1.0	2.1	1.9
15	15.6	1.5	2.8	2.3
20	15.8	2.0	3.3	2.8
25	16.3	2.4	3.7	3.1
30	16.6	2.8	4.0	3.3
40	16.9	3.3	4.5	3.7
50	17.6	3.7	4.8	4.0
60	17.8	4.1	5.2	4.4
90	18.5	4.9	5.8	5.0
120	19.0	5.4	6.4	5.5
150	19.5	5.9	6.[illegible]	6.0
200	20.0	6.4	7.3	6.5
250	-	6.9	7.8	7.1
300	20.7	7.2	8.2	7.4
360	21.0	7.6	8.4	7.7
400	21.3	7.7	8.5	7.9
550	22.0	8.3	9.3	8.6
1330	24.1	10.4	11.4	10.5
1490	24.4	10.5	11.7	10.9
1670	24.8	11.0	12.0	11.1
1840	25.1	11.2	12.3	11.4
2810	26.3	12.4	13.6	12.7
2960	26.5	12.5	13.7	12.9
3090	26.6	12.7	13.8	13.0
3240	26.6	12.8	13.9	13.1
3430	26.8	12.9	14.0	13.3
4180	27.5	13.6	14.8	14.0
4300	27.6	13.6	14.9	14.0
4305		-Pump Shut Off-		

TABLE B-3

Q SAND AQUIFER RECOVERY DATA
Q SAND ISL PROJECT PUMP TEST
CONVERSE COUNTY, WYOMING

Time From Start of Pump Minutes	Time Since Pumping Stopped Minutes	Residual Drawdown in Monitor Wells - Feet			
		Pumped Well QP-3	Monitor Well QI-2	Monitor Well QI-7	Monitor Well QI-11
4307	2	16.1	0=13.8	14.7	13.8
4309	4	14.8	13.2	14.3	13.3
4311	6	14.0	12.9	13.8	13.0
4313	8	13.5	12.7	13.4	13.0
4315	10	13.1	12.4	13.0	12.3
4320	15	12.3	11.9	12.2	11.8
4325	20	11.8	11.4	11.7	11.3
4330	25	11.4	11.2	11.2	11.3
4335	30	11.0	10.7	10.9	10.9
4345	40	10.4	10.1	10.3	10.7
4355	50	10.0	9.7	9.9	10.1
4365	60	9.7	9.3	9.5	9.8
4395	90	8.9	8.6	8.9	8.0
4425	120	8.4	7.9	8.3	7.7
4455	150	7.8	7.3	8.0	7.2
4520	215	7.4	6.9	7.3	6.8
4540	235	6.7	6.5	6.8	6.8
4600	295	6.4	6.5	6.4	6.1
4720	415	5.9	5.7	6.0	5.3
5780	1475	4.0	3.7	3.9	3.3
5900	1595	3.7	3.5	3.7	3.0
6020	1715	3.5	3.5	3.5	2.9
6140	1835	3.5	3.3	3.5	2.9
7220	2915	2.7	2.5	2.7	2.1
7340	3035	2.6	2.4	2.6	2.0
7460	3155	2.5	2.4	2.6	1.8
7580	3275	2.5	2.4	2.5	1.8
8660	4355	2.0	1.9	2.0	1.4
8780	4475	2.0	1.9	2.0	1.3
8900	4595	1.9	1.8	1.9	1.3
9020	4715	1.9	1.8	1.9	1.2

TABLE B-4

BAROMETRIC PRESSURE DATA
Q SAND PUMP TEST
CONVERSE COUNTY, WYOMING

The following data was taken from a barometric pressure monitoring station located about 8 miles east of the test site. A calibration indicated the recorder was reading 0.68 inches too high, however, if corrected, all data would be adjusted accordingly.

Date	Time	Pressure in. Hg.	Date	Time	Pressure in. Hg.
4/6	8 am	25.5	4/11	8 am	25.5
	12 N	25.5		12 N	25.5
	4 pm	25.4		4 pm	25.4
4/7	8 am	25.4	4/12	8 am	25.6
	12 N	25.3		12 N	25.5
	4 pm	25.3		4 pm	25.5
4/8	8 am	25.5	4/13	8 am	25.9
	12 N	25.5		12 N	25.9
	4 pm	25.5		4 pm	26.0
4/9	8 am	25.4	4/14	8 am	26.2
	12 N	25.3		12 N	26.1
	4 pm	25.3		4 pm	26.1
4/10	8 am	25.6			
	12 N	25.5			
	4 pm	25.4			

Hydrology

Attachment C

O-Sand Pilot Pump Test

The pump test at the O-Sand pilot site was conducted to demonstrate the site was suitable for the ISL pilot project. Multiple tests and analysis methods were utilized in responding to NRC and DEQ questions regarding the lower 'O' shale as a confining layer. The calculated O-Sand transmissitivity values varied from 3000 gpd/ft to 7000 gpd/ft with storage coefficients averaging about $2x10^{-4}$. To monitor the effectiveness of the thin lower O shale a monitor well was completed in the lower O-Sand and sampled at two week intervals. Leaching operations began in July 1984 and to date there has been no indication of leach solution movement through the thin lower O-shale, nor have there been any other leach solution excursions at the pilot site. A copy of the O-Sand pump test evaluation as published by NRC in the Environmental Impact Appraisal, except for the tabulated fluid level data, is attached.

UNITED STATES NUCLEAR REGULATORY COMMISSION

ENVIRONMENTAL IMPACT APPRAISAL

BY THE

URANIUM RECOVERY FIELD OFFICE

IN CONSIDERATION OF THE ISSUANCE OF

AN AMENDMENT TO

SOURCE MATERIAL LICENSE NO. SUA-1387 FOR THE

SEQUOYAH FUELS CORPORATION

SOUTH POWDER RIVER BASIN "O" SAND RESEARCH & DEVELOPMENT

IN SITU LEACH PROJECT

DOCKET NO. 40-8768