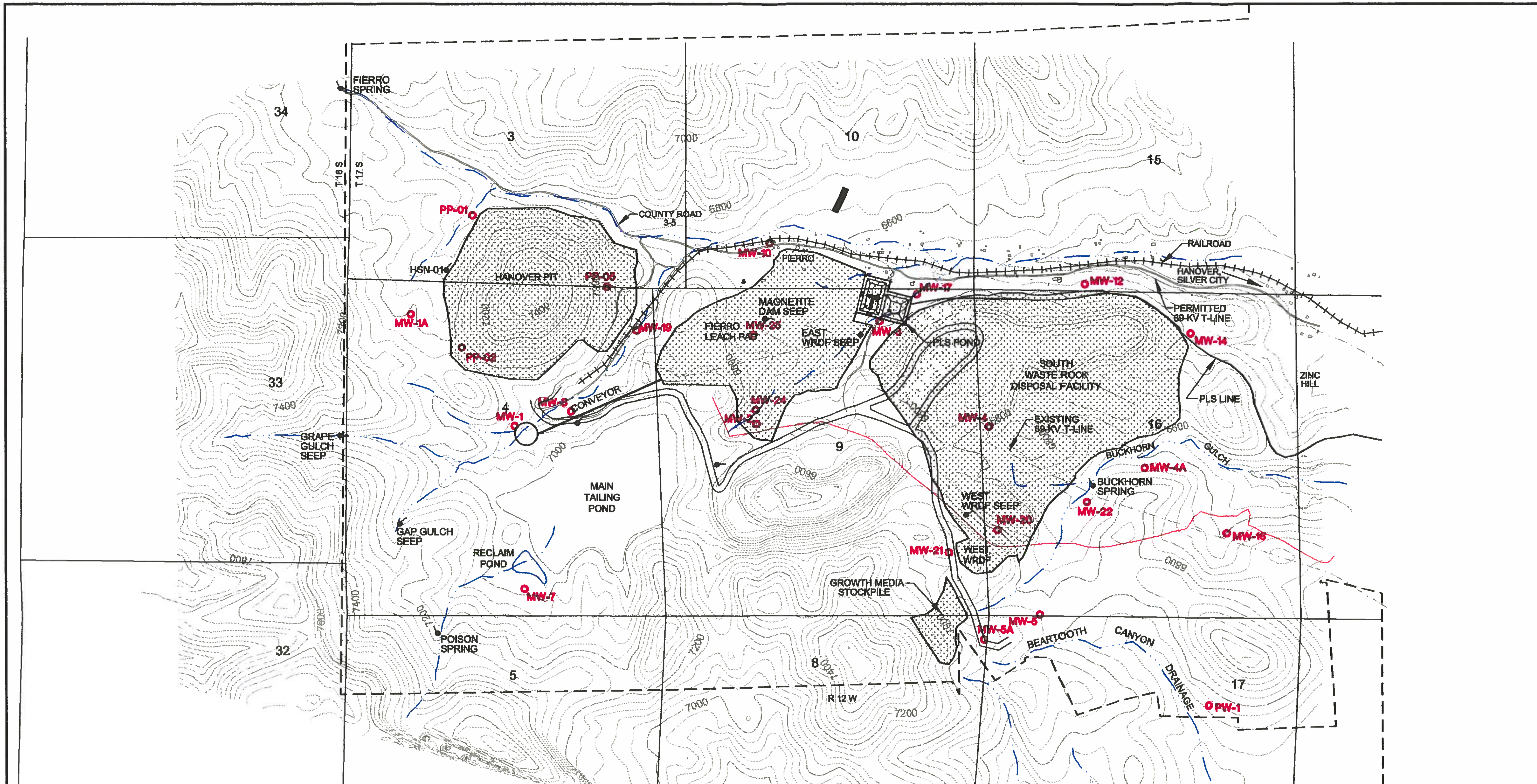
FIGURES



LEGEND

MW-1A LOCATION OF EXISTING MONITORING WELL, PIEZOMETER, OR GROUNDWATER EXPLORATION WELL

NORTH

SCALE IN FEET

1600 0 3200

CONTOUR INTERVAL = 100 FT.

FIGURE A-1
LOCATION OF MONITORING WELLS

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Date:	DECEMBER 1999
Project:	100029\T5
File:	LOCWELLSA1.DWG

Filename: E:\100029\Task5\LOCWELLSA1.dwg
Date: 01/24/2000

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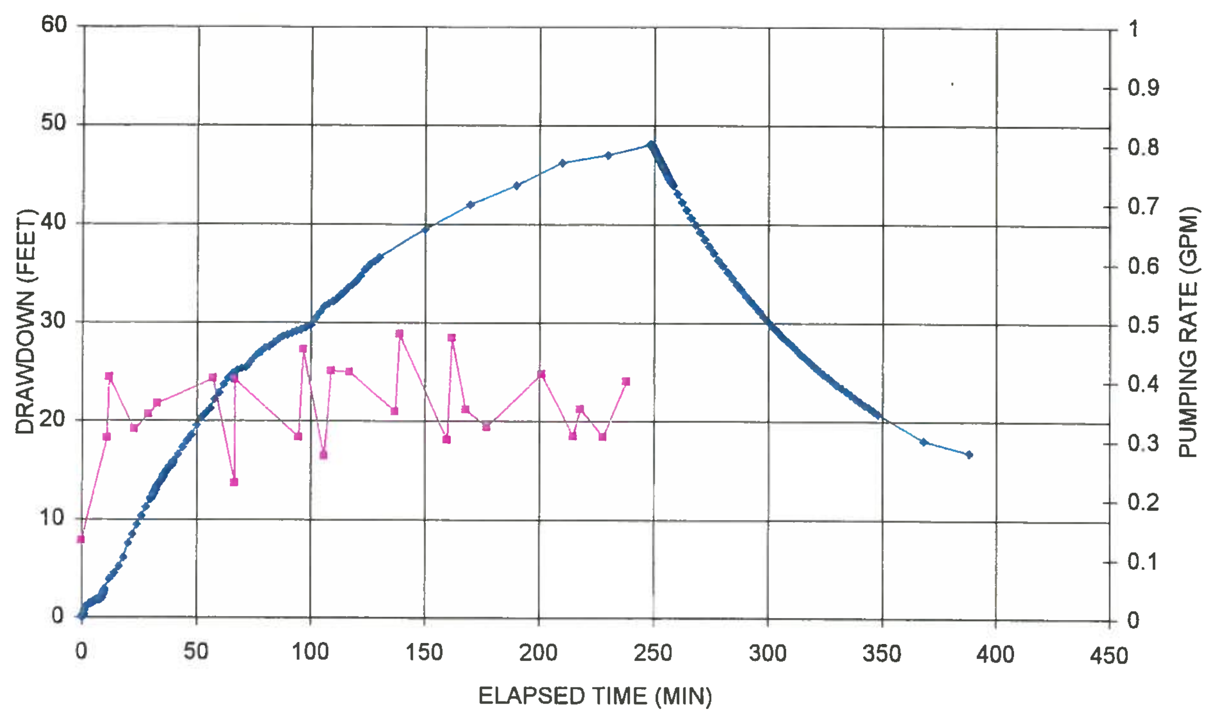
INCORPORATED

FIGURE A-2. TYPICAL EQUIPMENT INSTALLATION FOR AN AQUIFER TEST (MW-2 SHOWN HERE)

DATE: DECEMBER 1999
PROJECT: 100029
FILE:GRAPHSa2-a7.XLS

AQUIFER TEST MW-1
7/1/97



AQUIFER TEST MW-1A
7/3/97

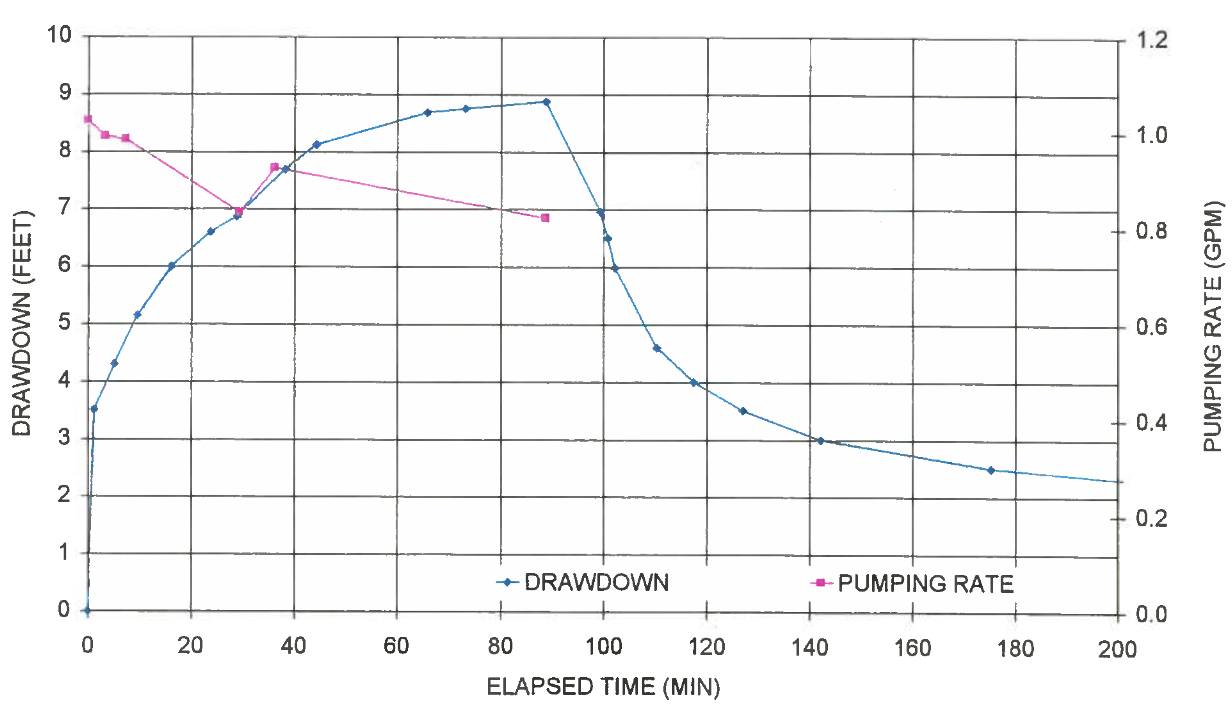


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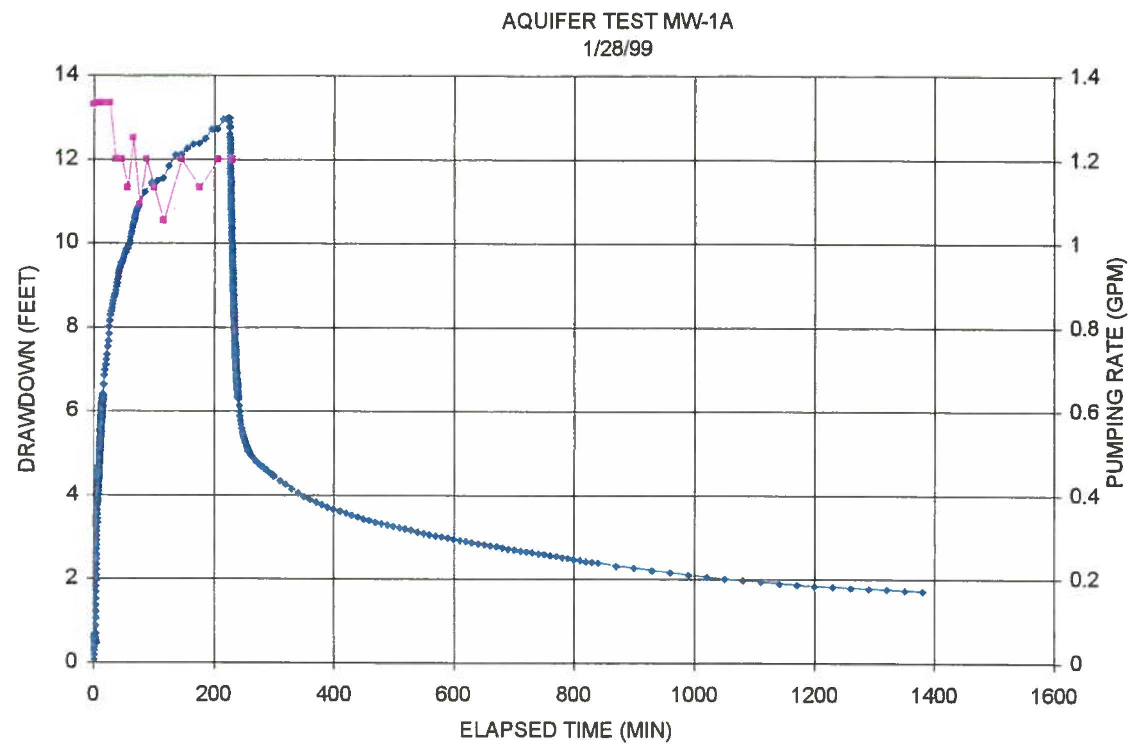
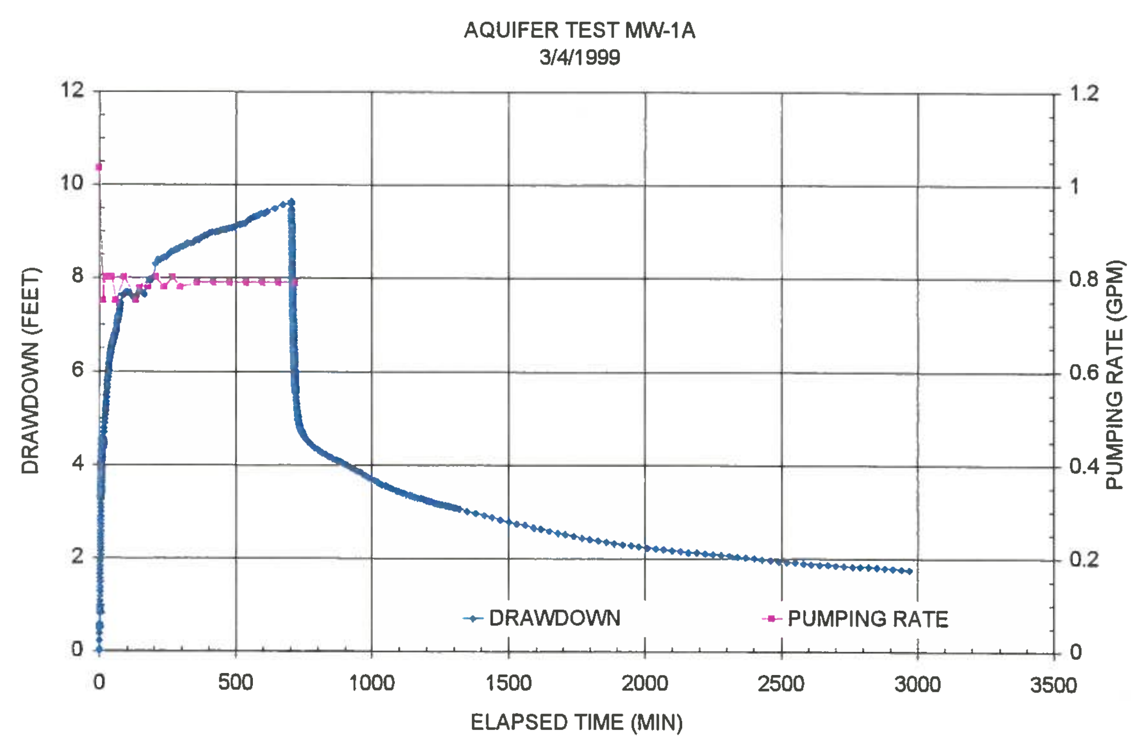
FIGURE A-3. DRAWDOWN AND PUMPING RATES VERSUS TIME (MW-1 AND MW-1A)

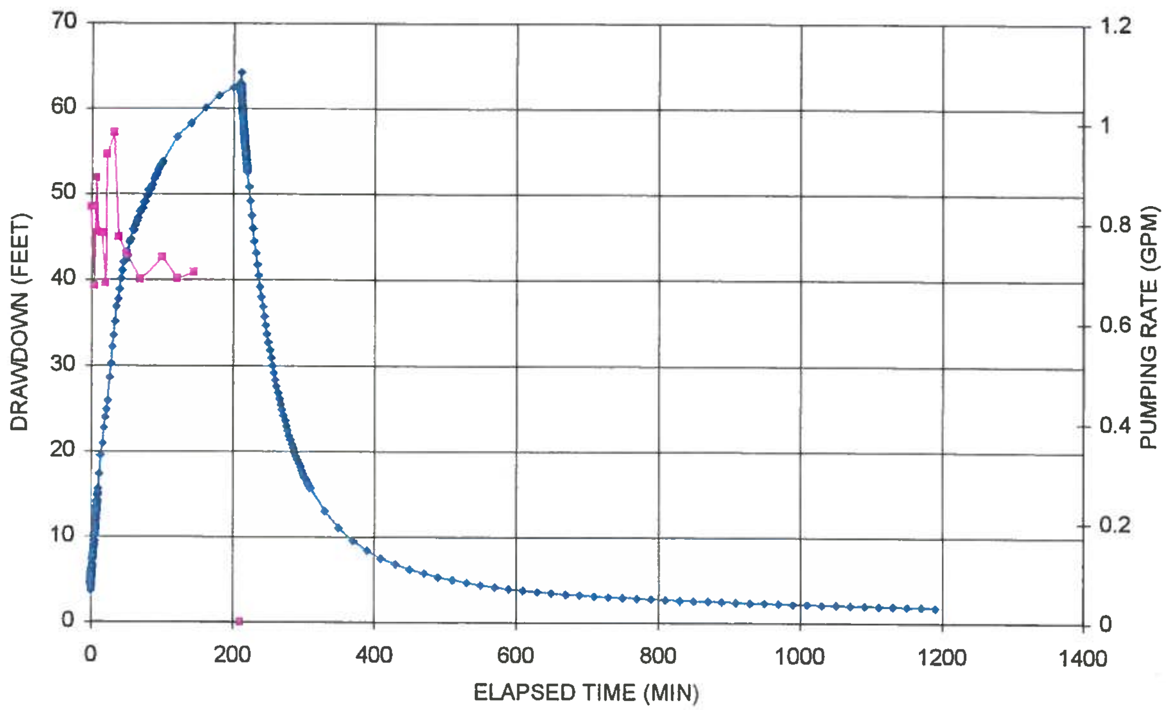
DATE: DECEMBER 1999
PROJECT: 100029
FILE:GRAPHSa2-a7.XLS



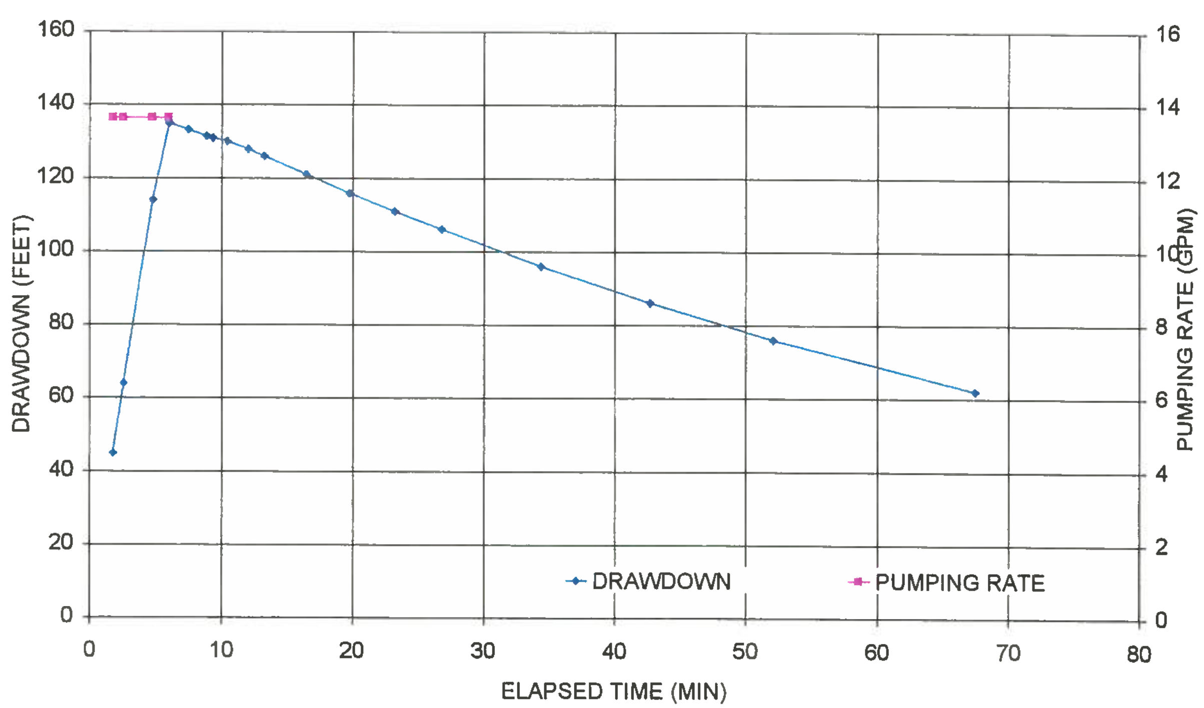


SHEPHERD MILLER INCORPORATED	**FIGURE A-4. DRAWDOWN AND PUMPING RATES VERSUS TIME (MW-1A TESTED 1/99 AND 3/99)**	DATE: DECEMBER 1999 PROJECT: 100029 FILE:GRAPHSa2-a7.XLS

AQUIFER TEST MW-2
7/5/97



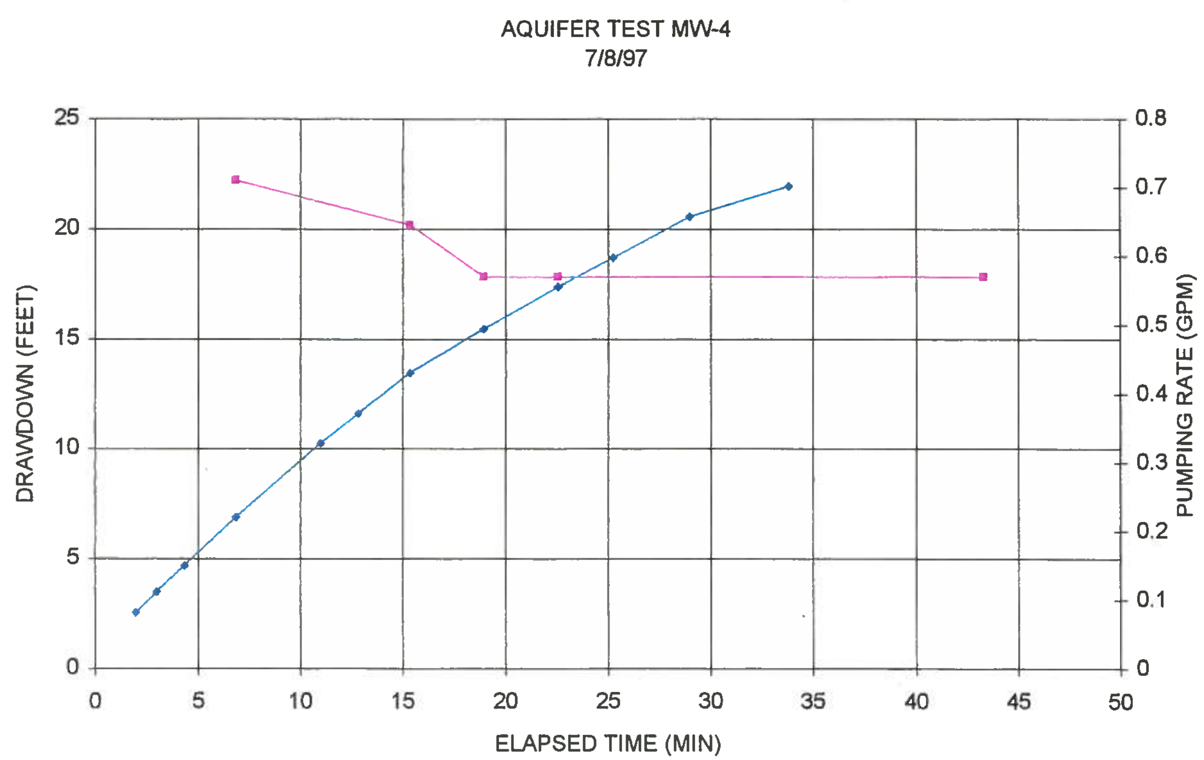
AQUIFER TEST MW-3
7/5/97



SHEPHERD MILLER INCORPORATED

FIGURE A-5. DRAWDOWN AND PUMPING RATES VERSUS TIME (MW-2 AND MW-3)

DATE: DECEMBER 1999
PROJECT: 100029
FILE:GRAPHSa2-a7.XLS



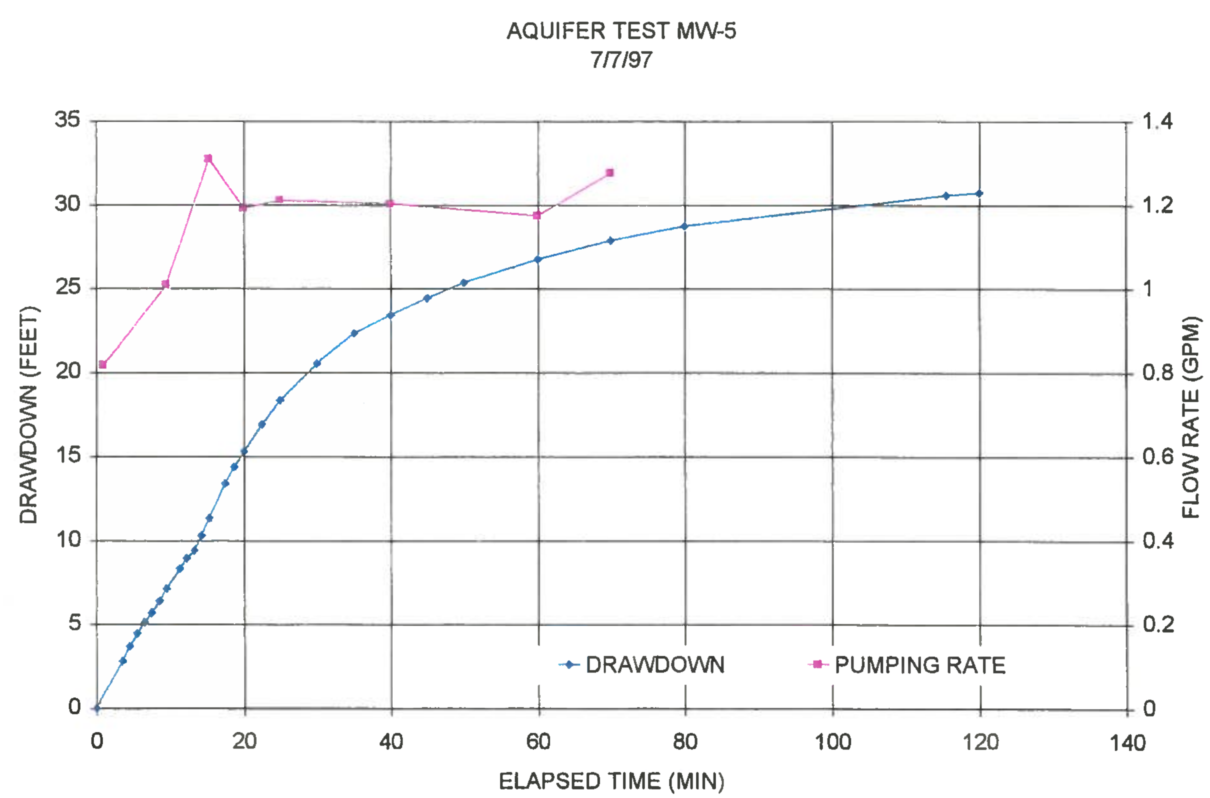


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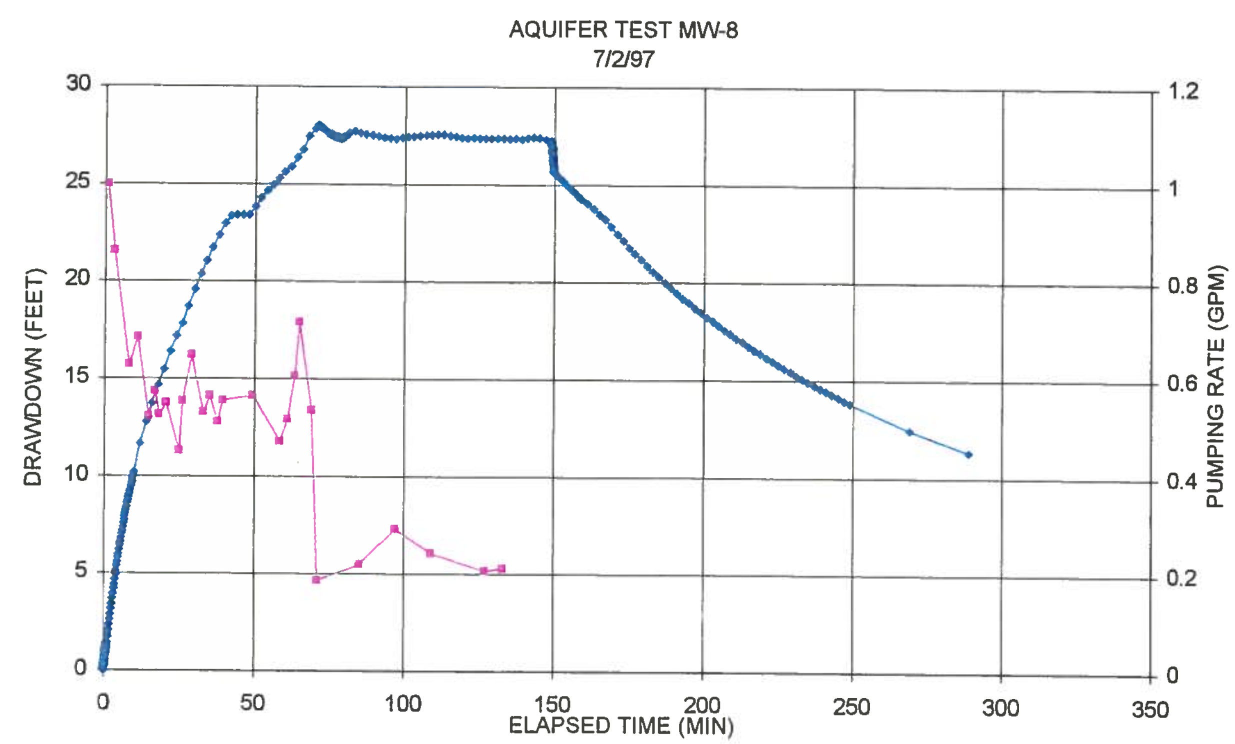
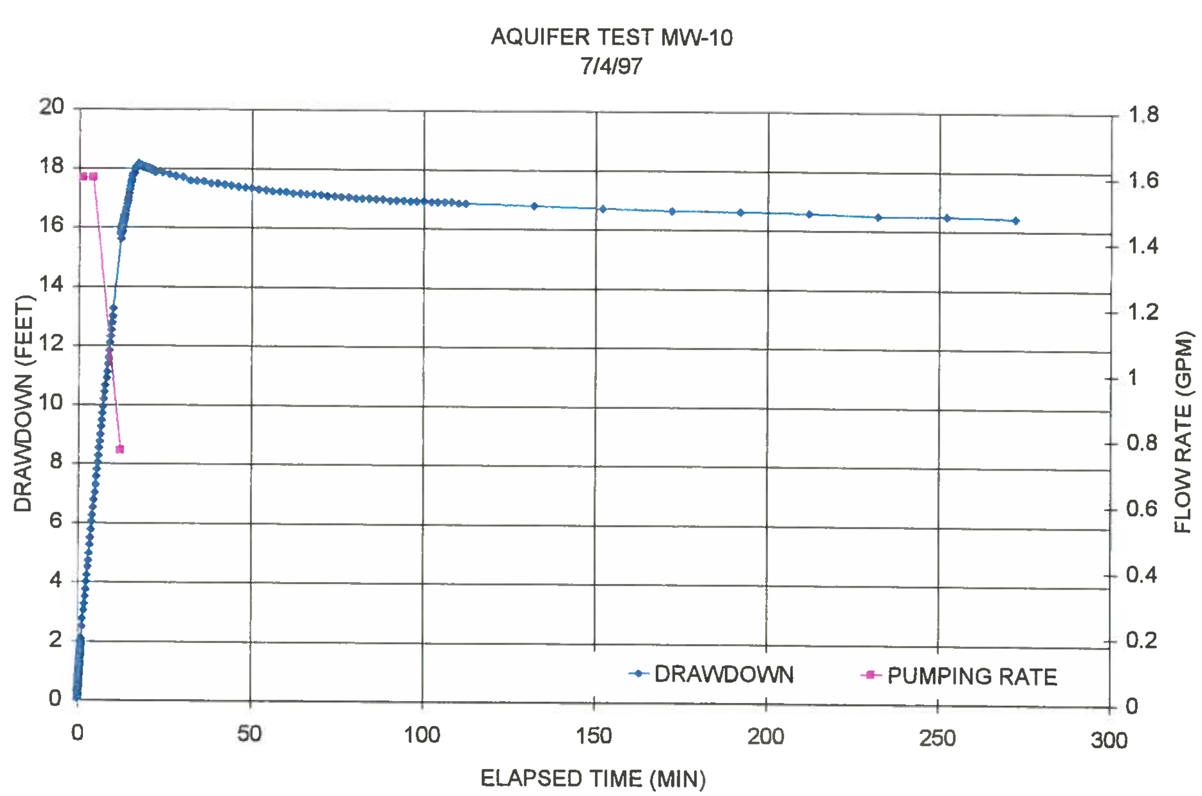
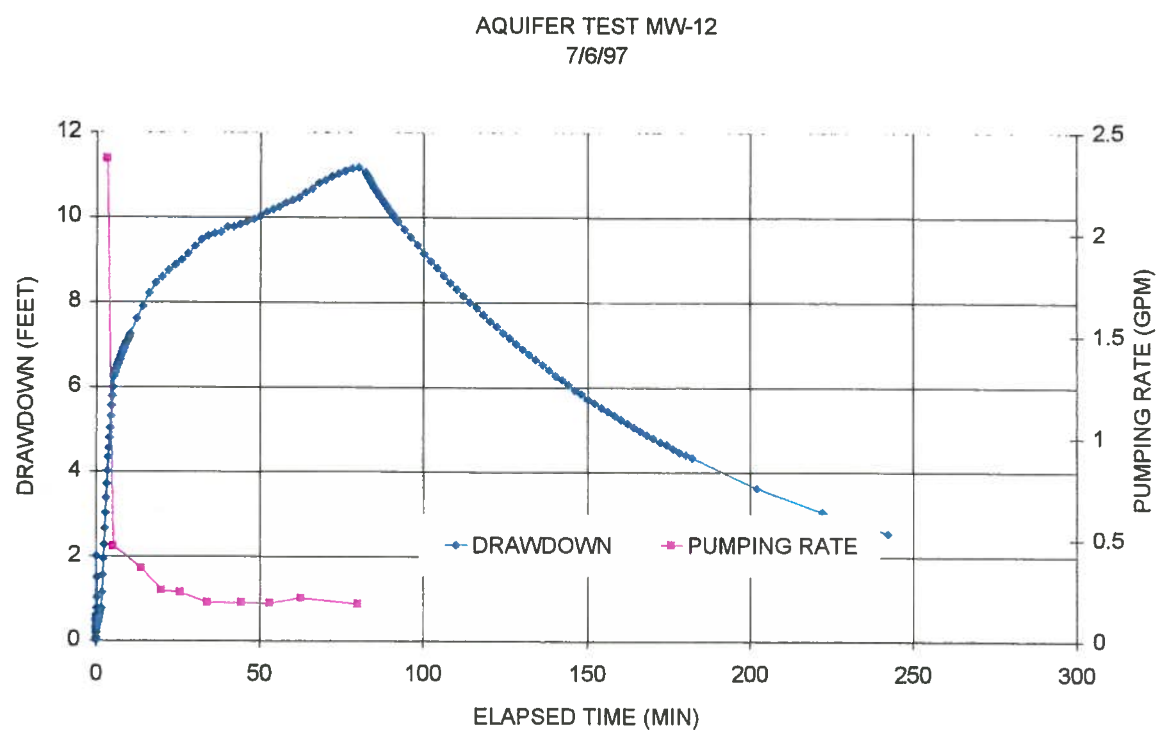
FIGURE A-6. DRAWDOWN AND PUMPING RATES VERSUS TIME (MW-4 AND MW-5)

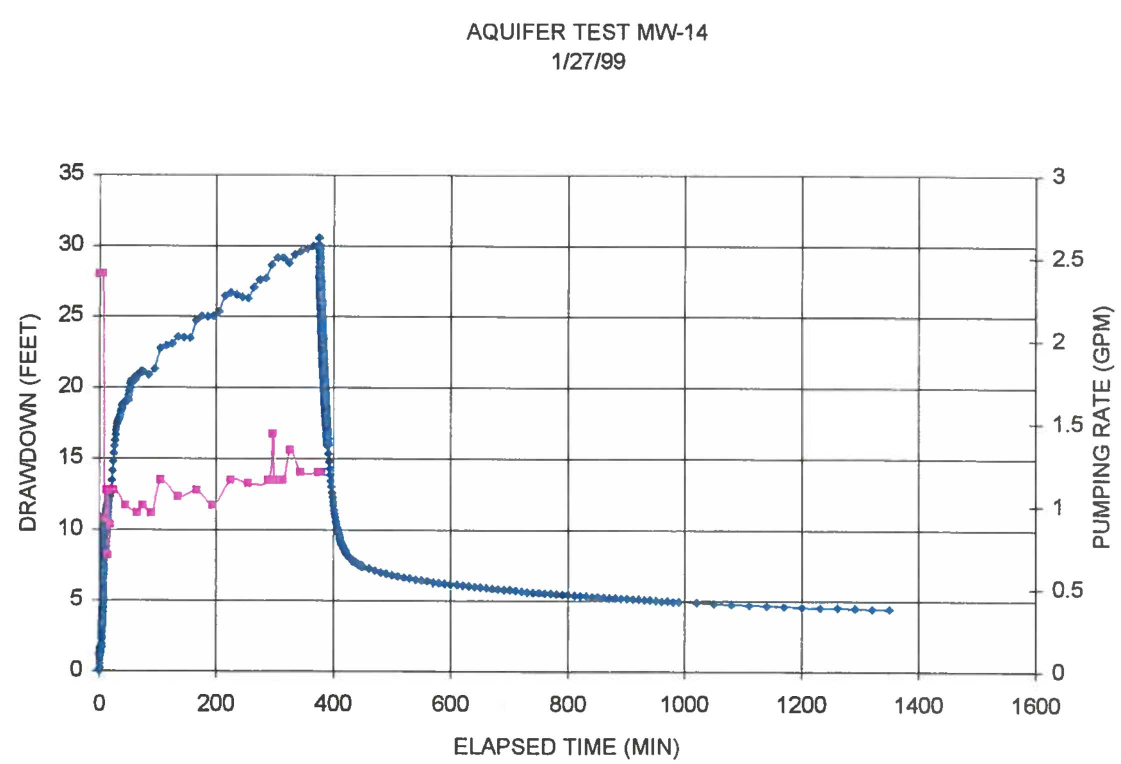
DATE: DECEMBER 1999
PROJECT: 100029
FILE:GRAPHSa2-a7.XLS



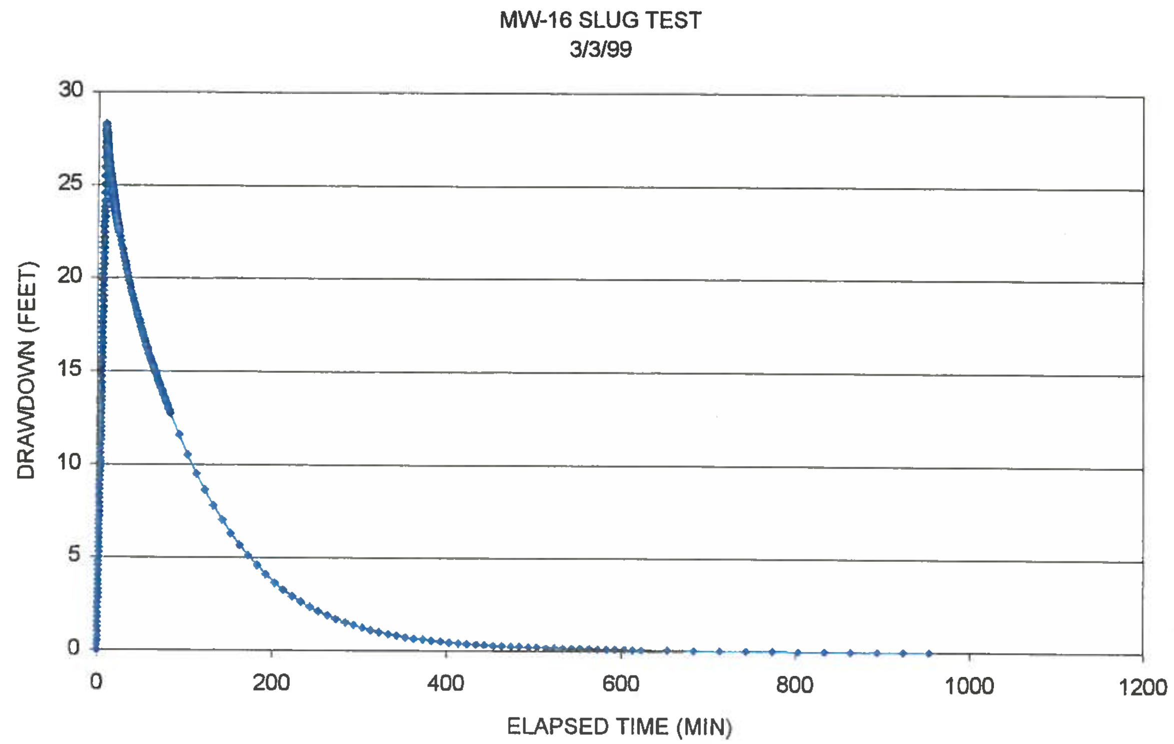


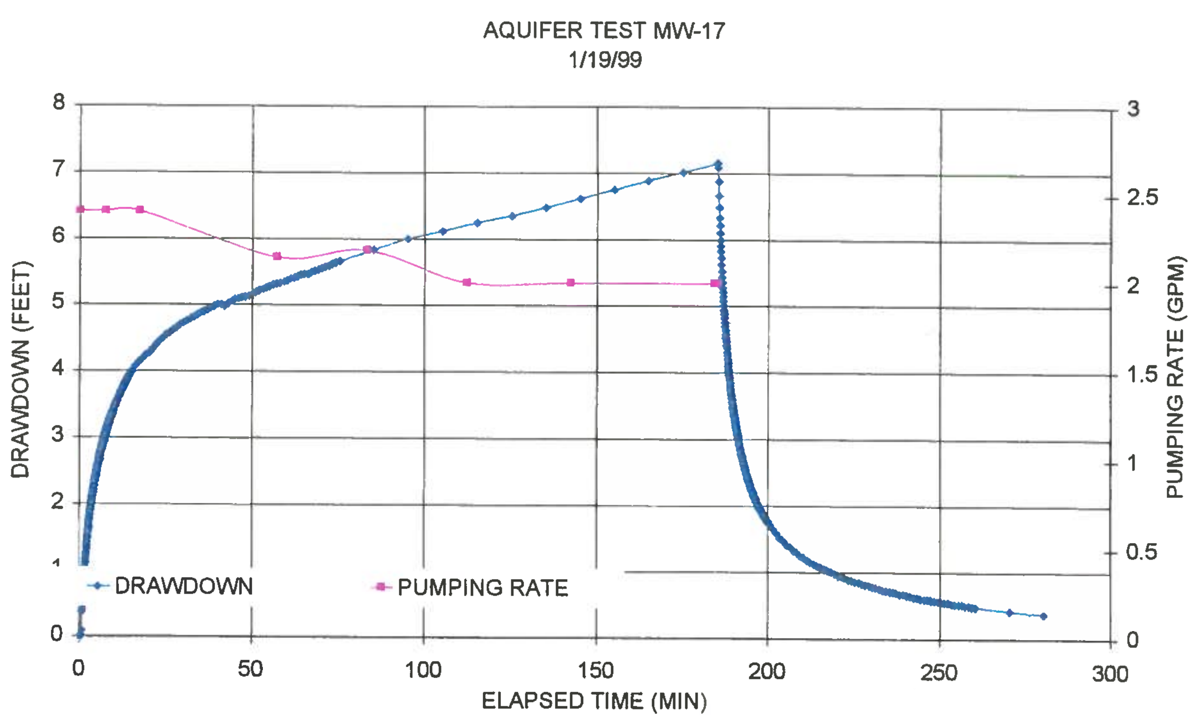
SHEPHERD MILLER INCORPORATED	FIGURE A-7. DRAWDOWN AND PUMPING RATES VERSUS TIME (MW-8 AND MW-10)	DATE: DECEMBER 1999 PROJECT: 100029 FILE:GRAPHSa2-a7.XLS



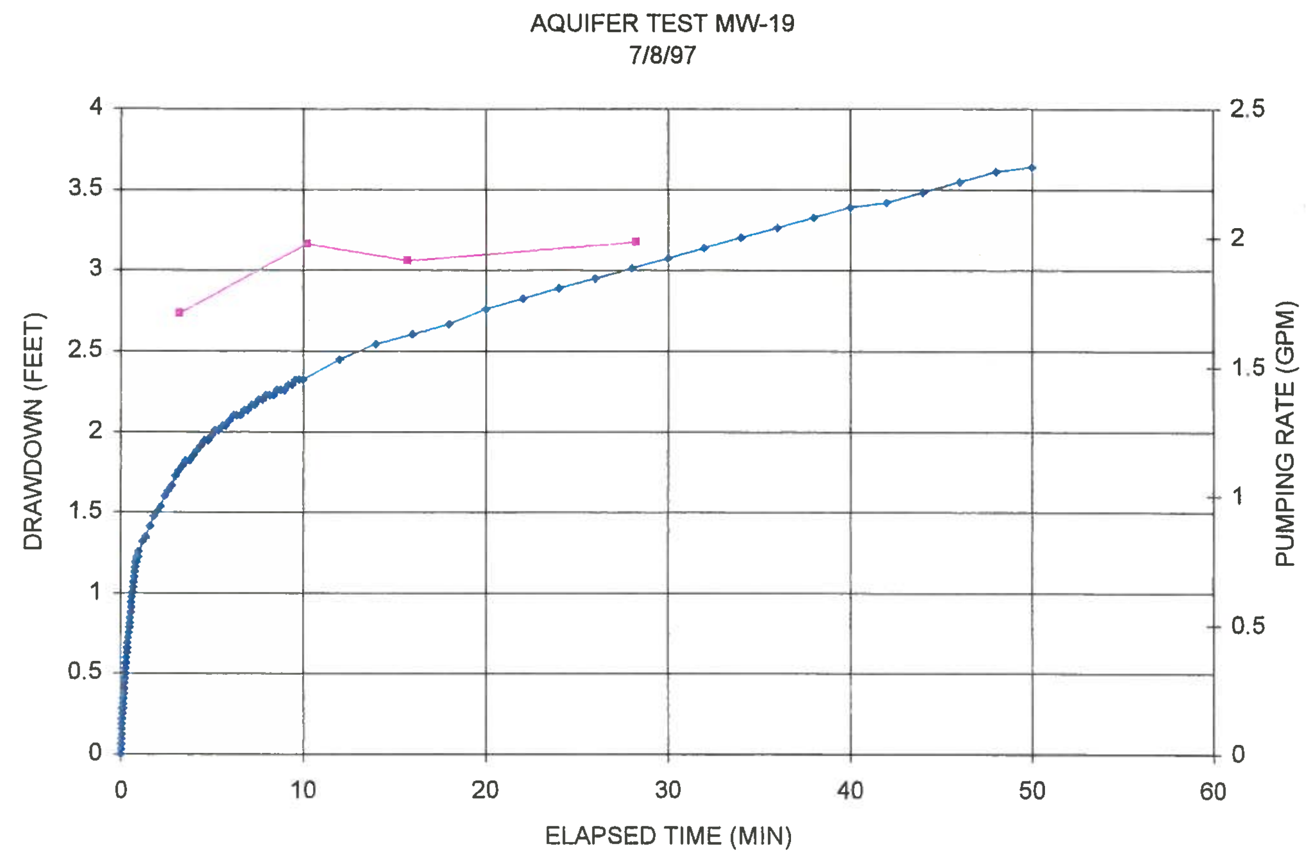


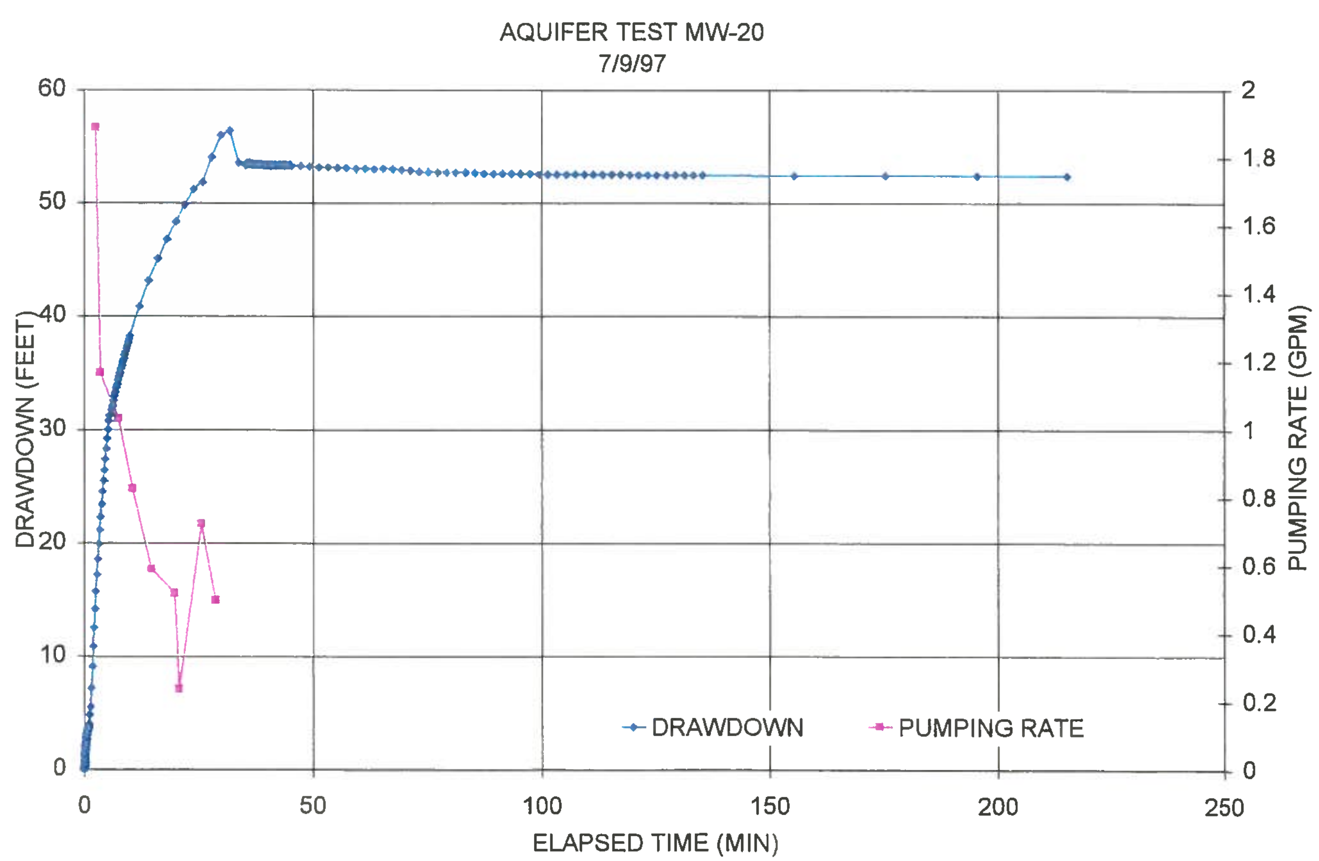
SHEPHERD MILLER INCORPORATED	FIGURE A-8. DRAWDOWN AND PUMPING RATES VERSUS TIME (MW-12 AND MW-14)	DATE: DECEMBER 1999 PROJECT: 100029 FILE:GRAPHSa8-a18.XLS



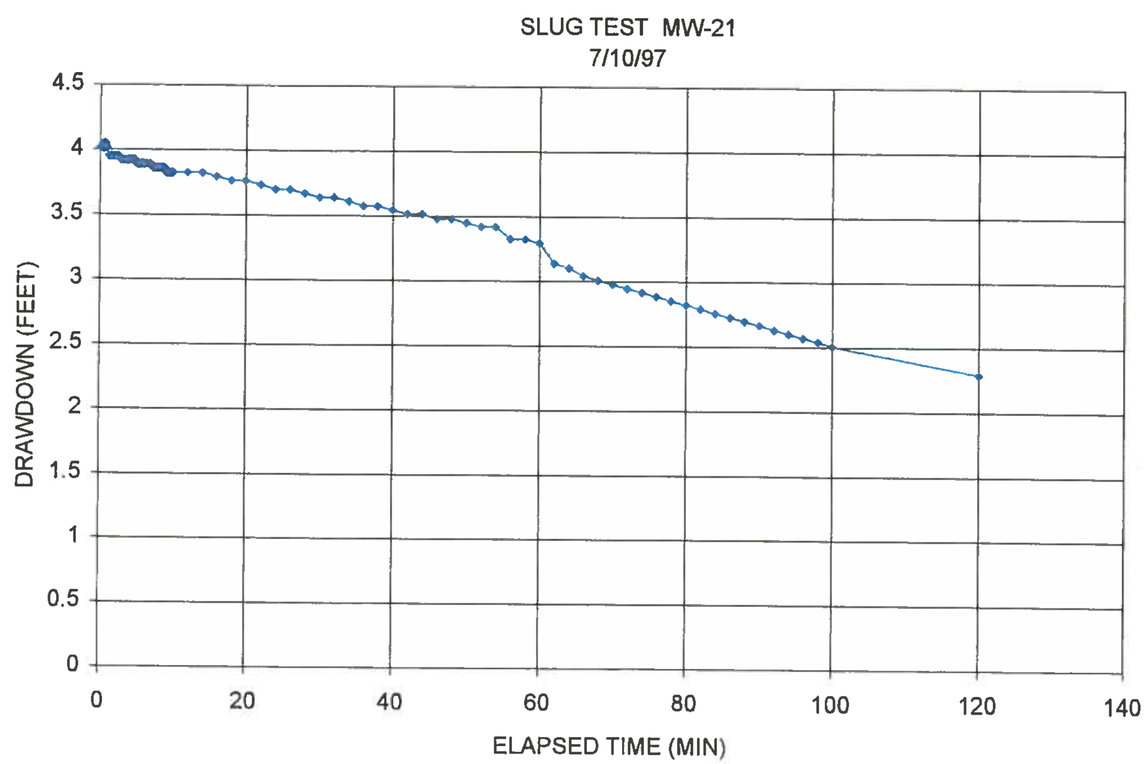


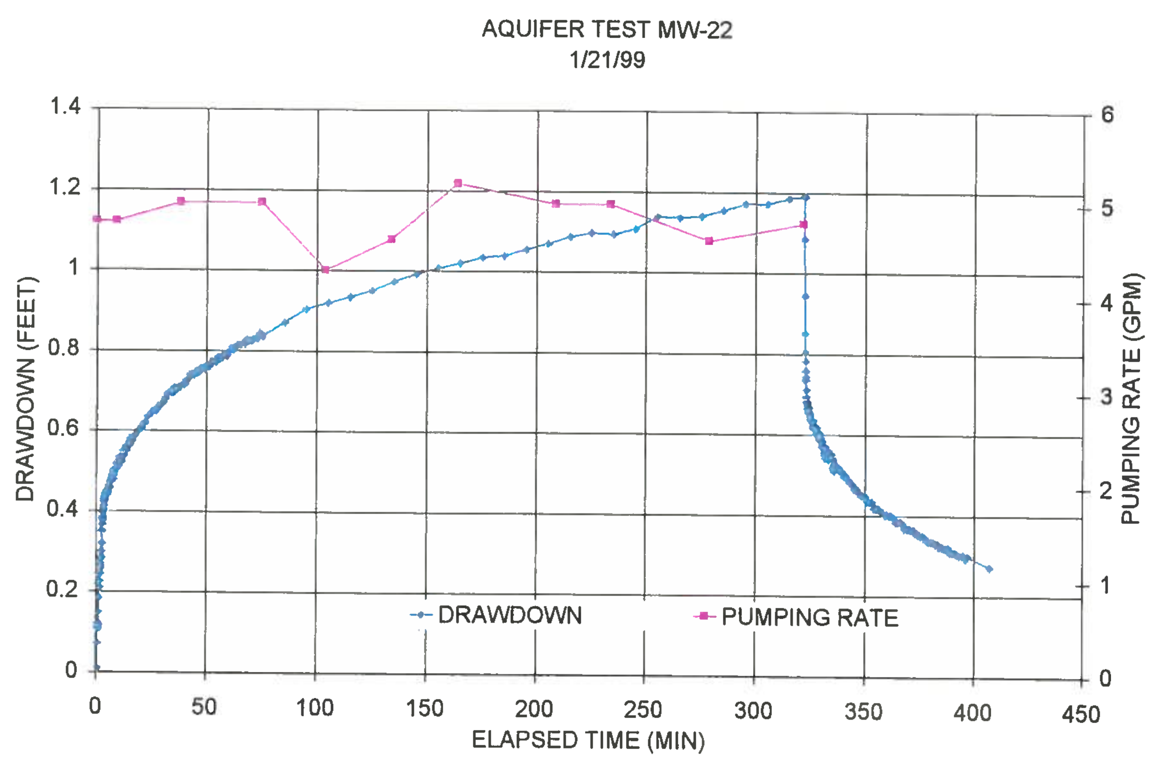
SHEPHERD MILLER INCORPORATED	**FIGURE A-9** **DRAWDOWN AND PUMPING RATES VERSUS TIME** **(MW-16 AND MW-17)**	DATE: DECEMBER 1999 PROJECT: 100029 FILE:GRAPHSa8-a18.XLS



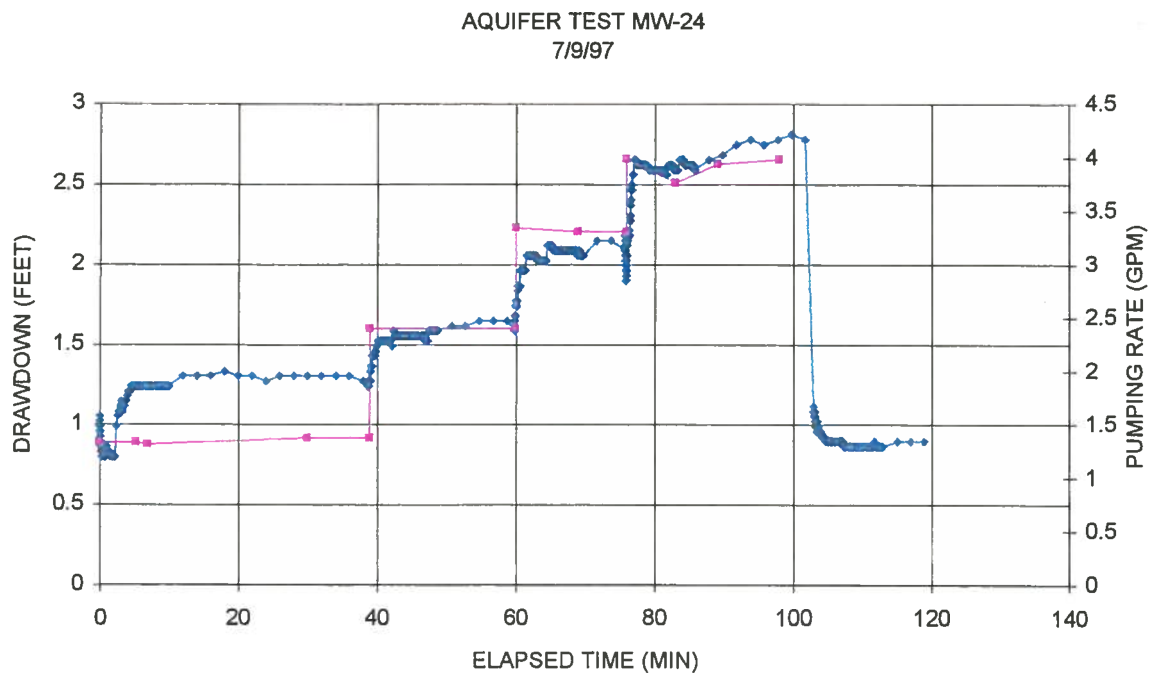


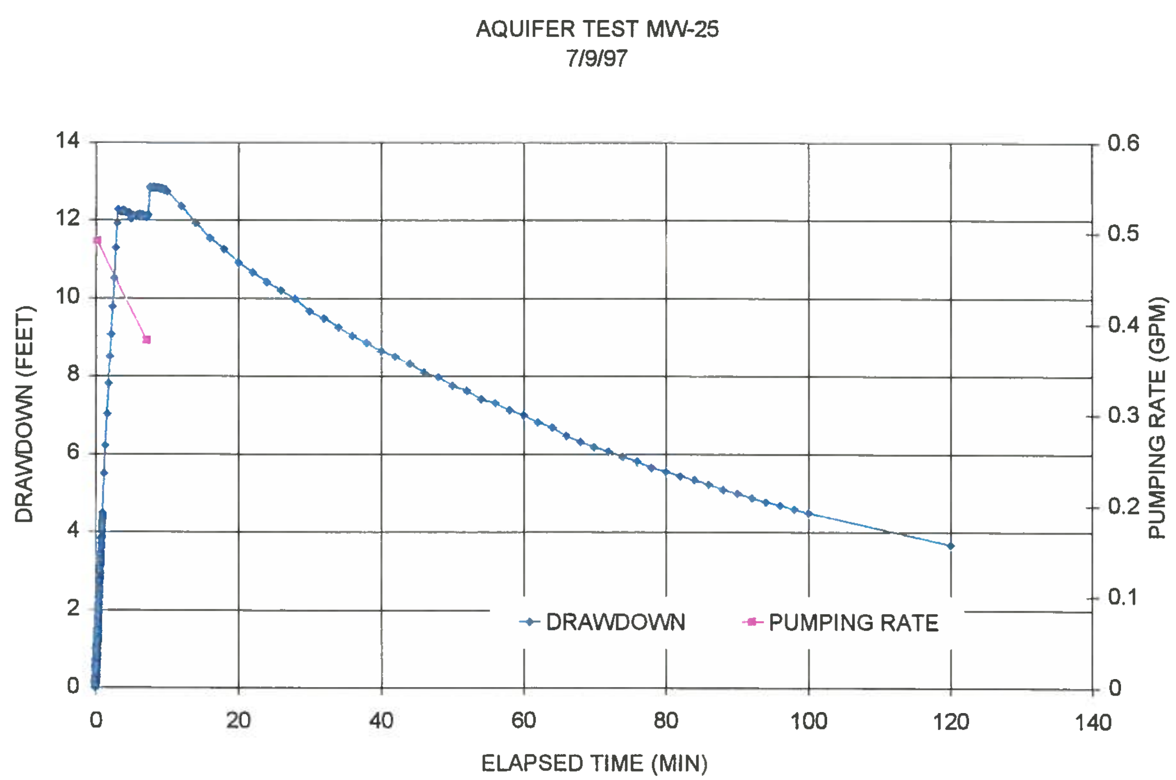
SHEPHERD MILLER INCORPORATED	FIGURE A-10. DRAWDOWN AND PUMPING RATES VERSUS TIME (MW-19 AND MW-20)	DATE: DECEMBER 1999 PROJECT: 100029 FILE:GRAPHSa8-a18.XLS





SHEPHERD MILLER INCORPORATED	**FIGURE A-11. DRAWDOWN AND PUMPING RATES VERSUS TIME (MW-21 AND MW-24)**	DATE: DECEMBER 1999 PROJECT: 100029 FILE:GRAPHSa8-a18.XLS





SHEPHERD MILLER INCORPORATED	**FIGURE A-12. DRAWDOWN AND PUMPING RATES VERSUS TIME (MW-24 AND MW-25)**	DATE: DECEMBER 1999 PROJECT: 100029 FILE:GRAPHSa8-a18.XLS

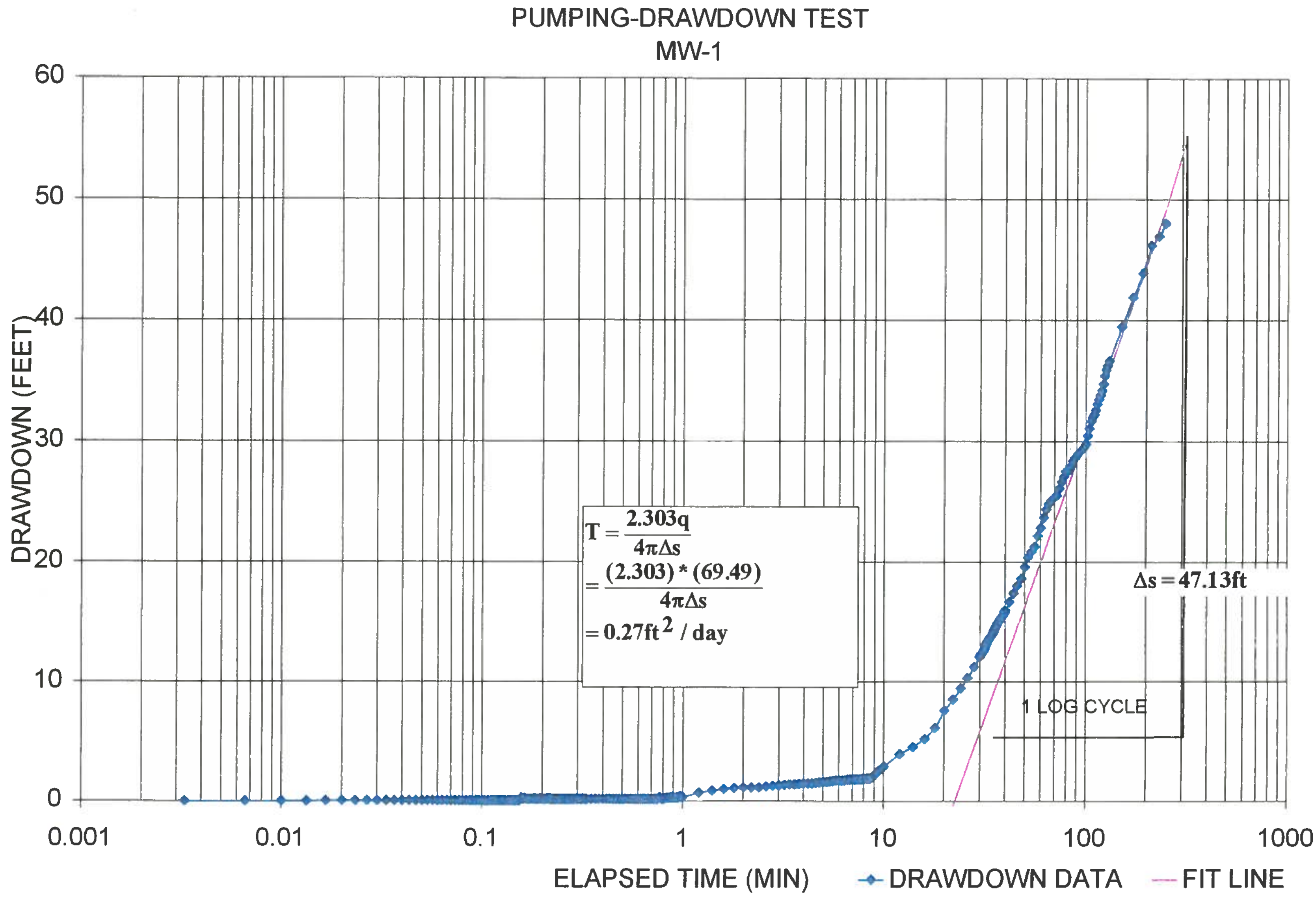


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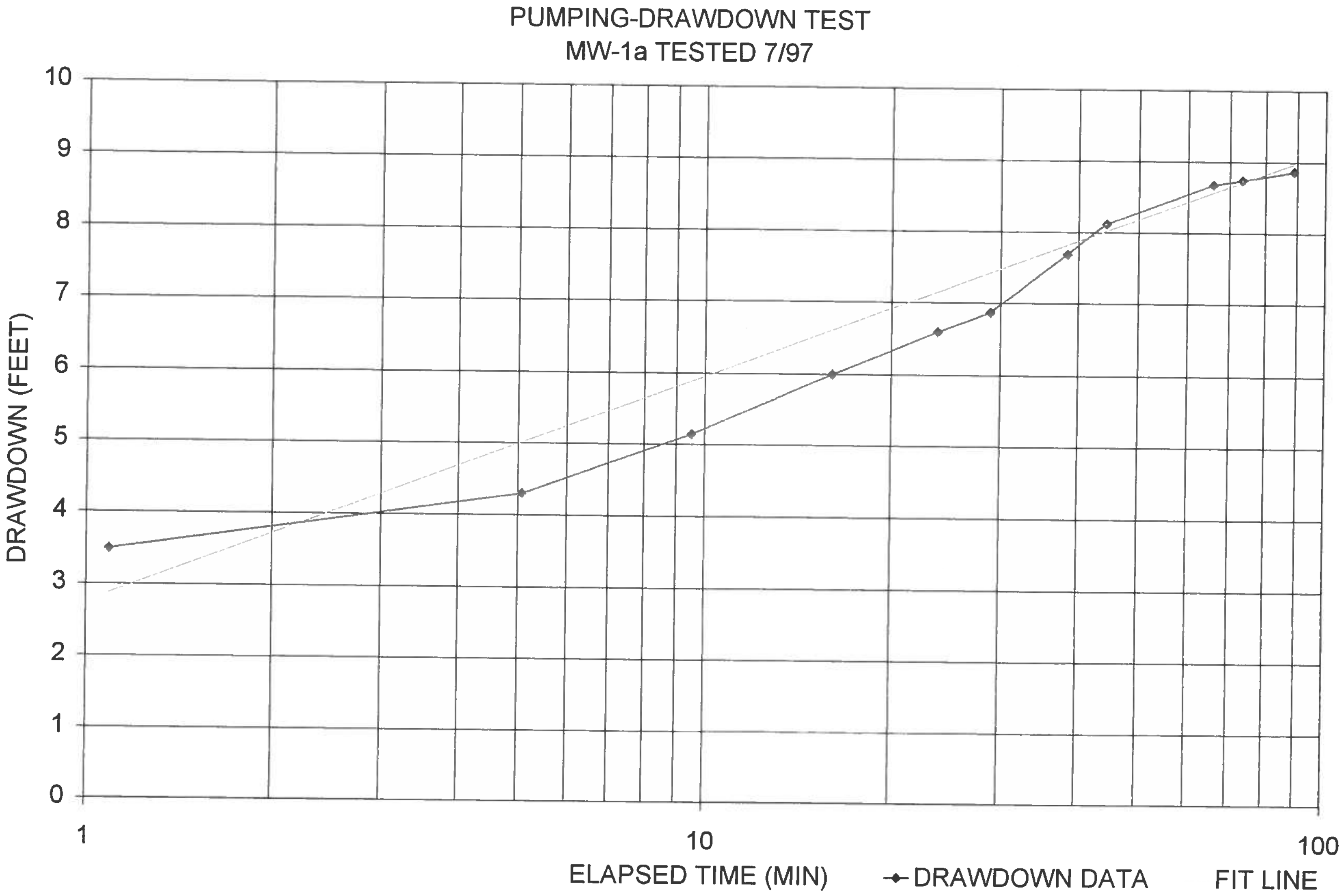
FIGURE A-13
JACOB ANALYSIS ON MW-1

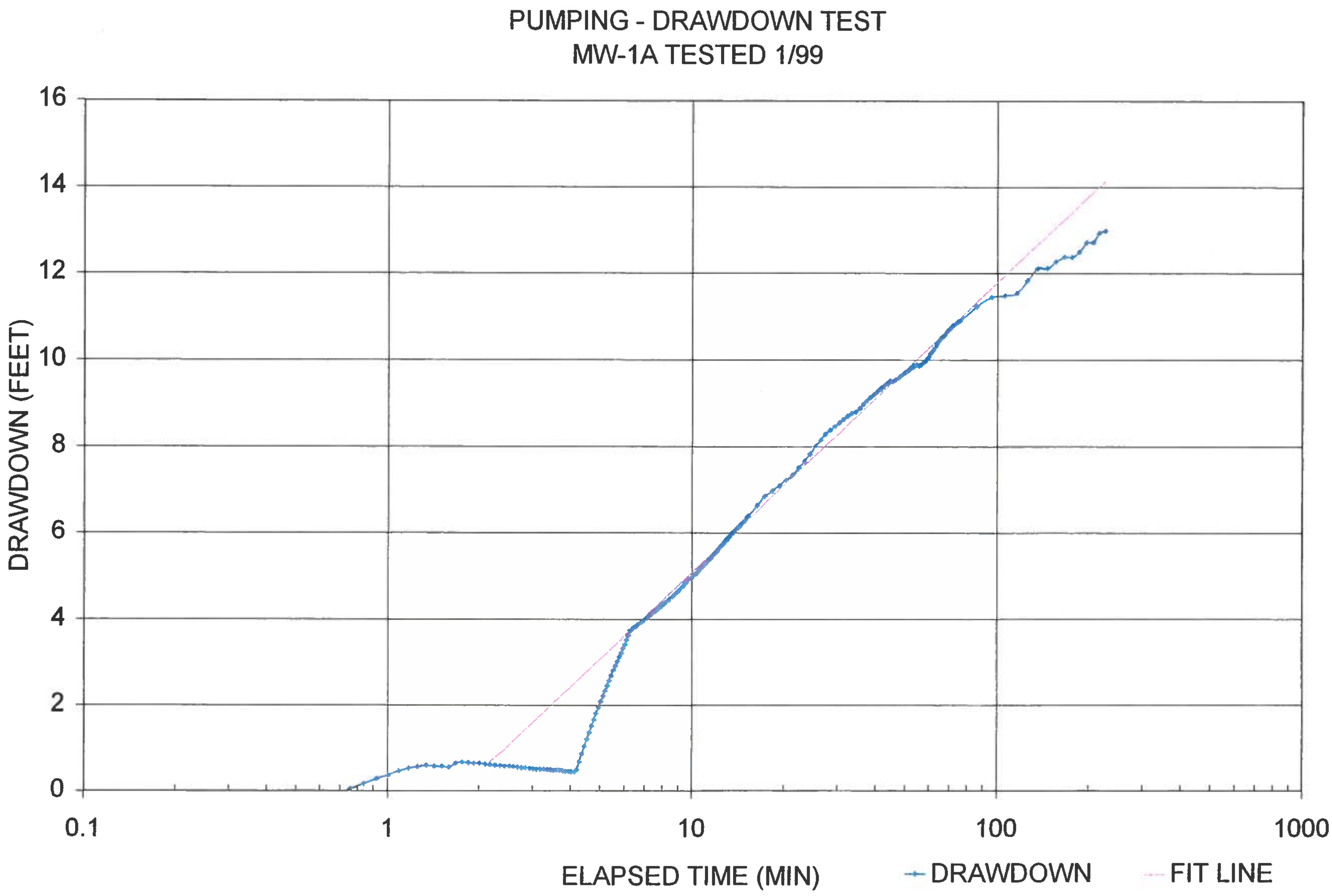
DATE: DECEMBER 1999
PROJECT: 100029
FILE:GRAPHSa8-a18.XLS



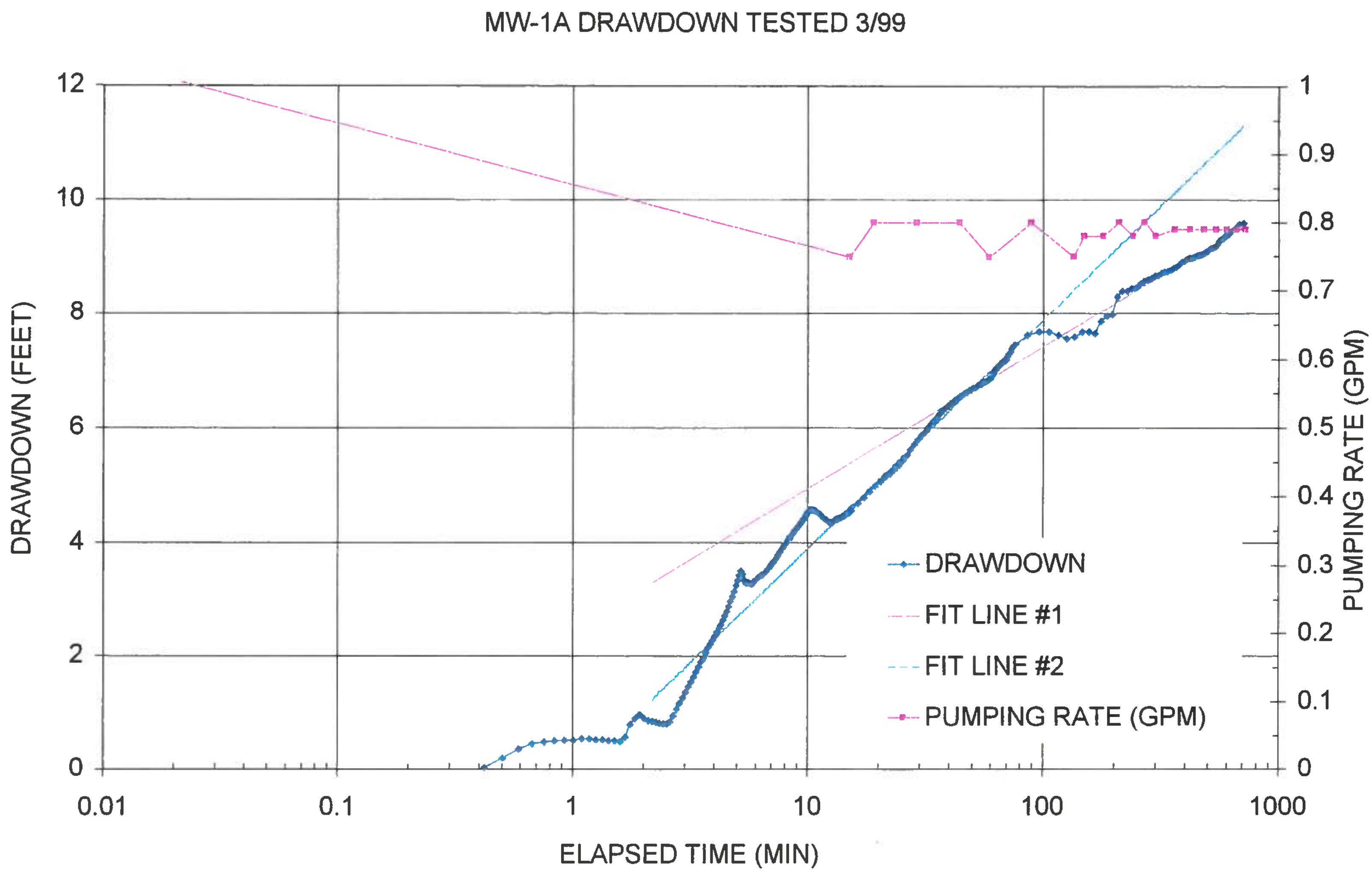
SHEPHERD MILLER INCORPORATED

FIGURE A-14
JACOB ANALYSIS ON MW-1A TESTED 7/97

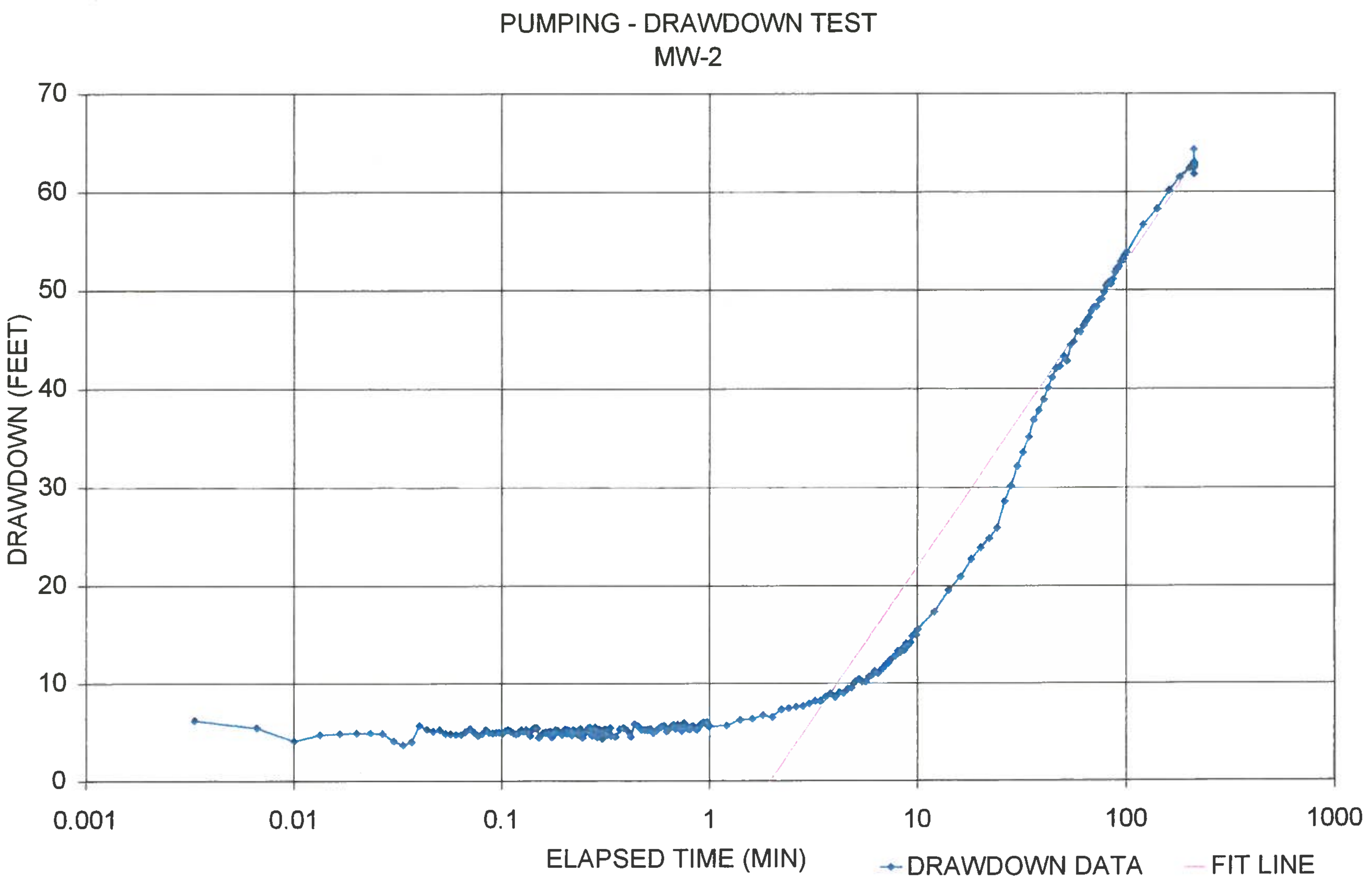
DATE: DECEMBER 1999
PROJECT: 100029
FILE:GRAPHSa8-a18.XLS



SHEPHERD MILLER INCORPORATED	**FIGURE A-15** **JACOB ANALYSIS ON MW-1A TESTED ON 1/99**	DATE: DECEMBER 1999 PROJECT: 100029 FILE:GRAPHSa8-a18.XLS



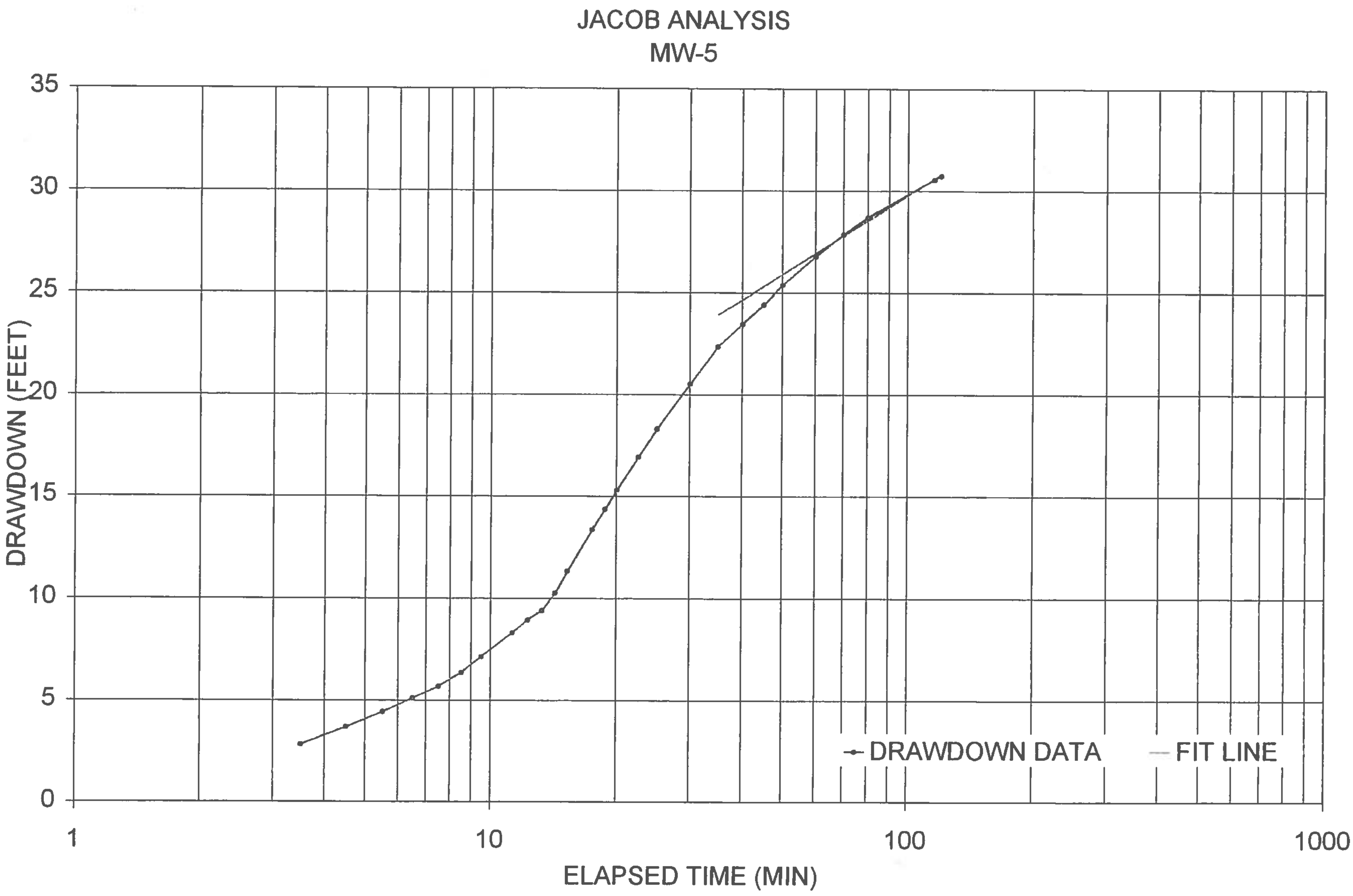
SHEPHERD MILLER INCORPORATED	**FIGURE A-16** **JACOB ANALYSIS ON MW-1A TESTED ON 3/99**	DATE: DECEMBER 1999 PROJECT: 100029 FILE:GRAPHSa8-a18.XLS



SHEPHERD MILLER INCORPORATED

FIGURE A-17
JACOB ANALYSIS ON MW-2

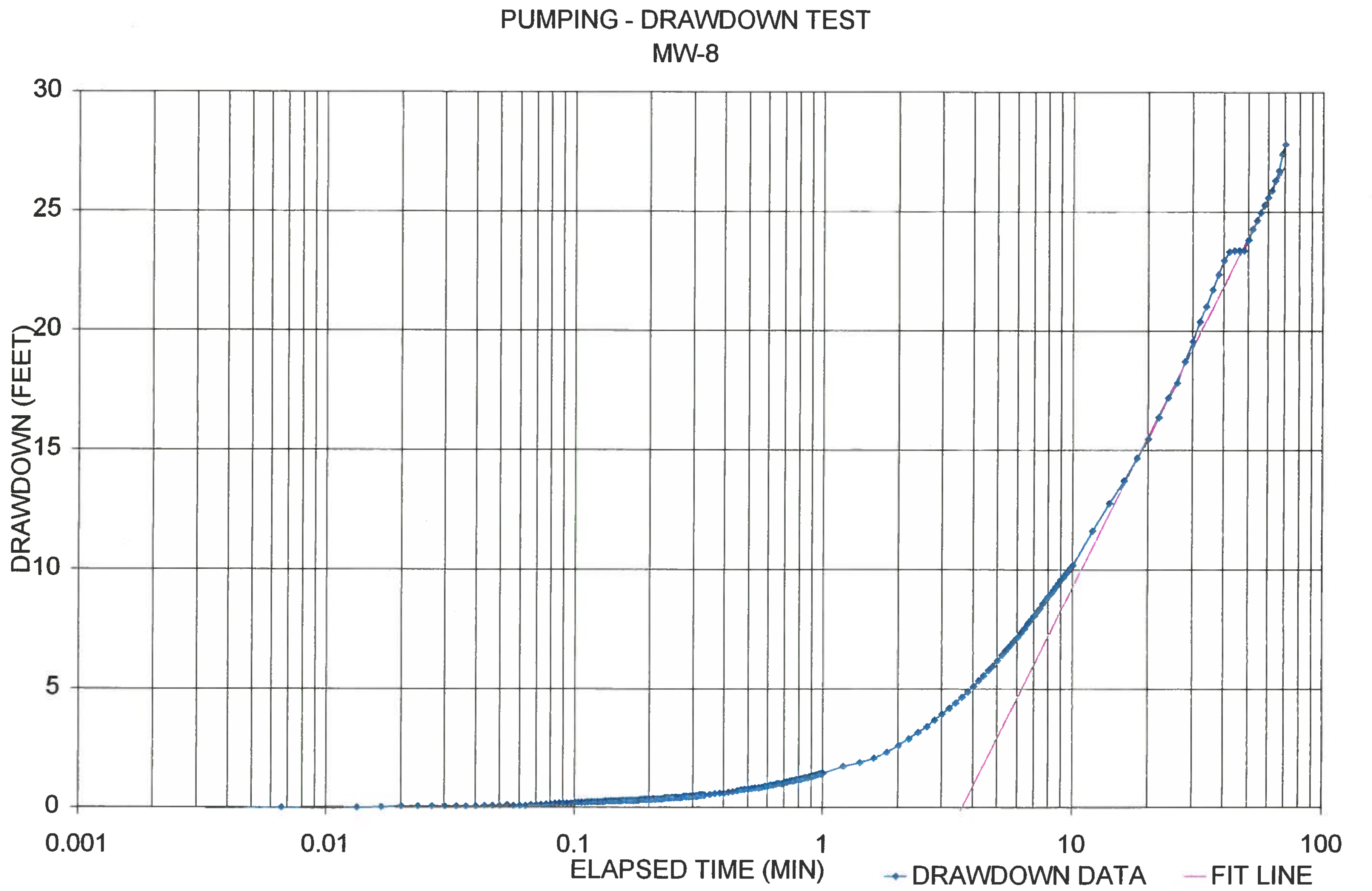
DATE: DECEMBER 1999
PROJECT: 100029
FILE:GRAPHSa8-a18.XLS



SHEPHERD MILLER INCORPORATED

FIGURE A-18
JACOB ANALYSIS ON MW-5

DATE: DECEMBER 1999
PROJECT: 100029
FILE:GRAPHSa8-a18.XLS



SHEPHERD MILLER INCORPORATED	**FIGURE A-19** **JACOB ANALYSIS ON MW-8** **(first pumping phase)**	DATE: DECEMBER 1999 PROJECT: 100029 FILE:GRAPHSa19-a25.XLS

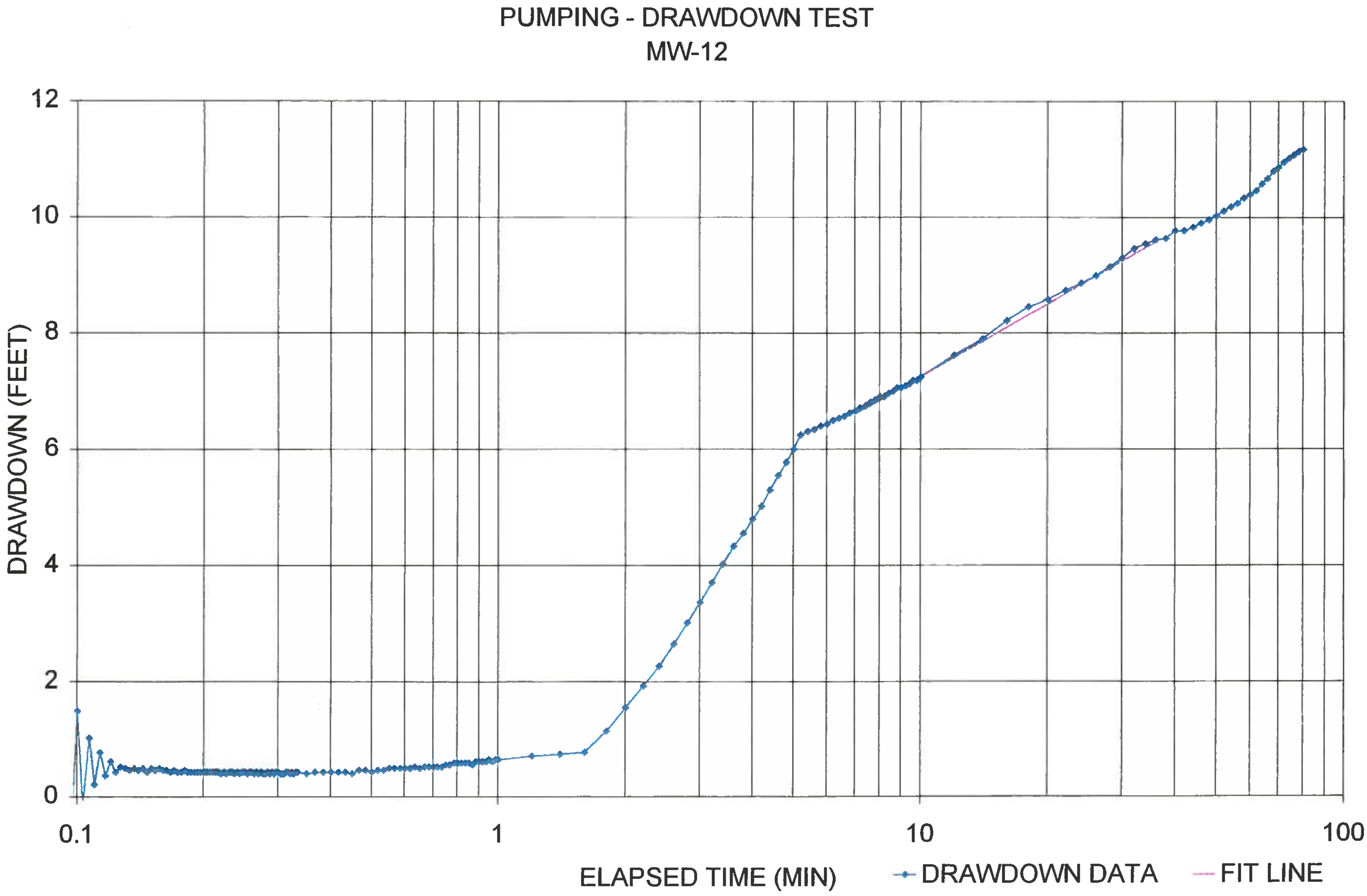


	FIGURE A-20 **JACOB ANALYSIS ON MW-12**	DATE: DECEMBER 1999 PROJECT: 100029 FILE:GRAPHSa19-a25.XLS

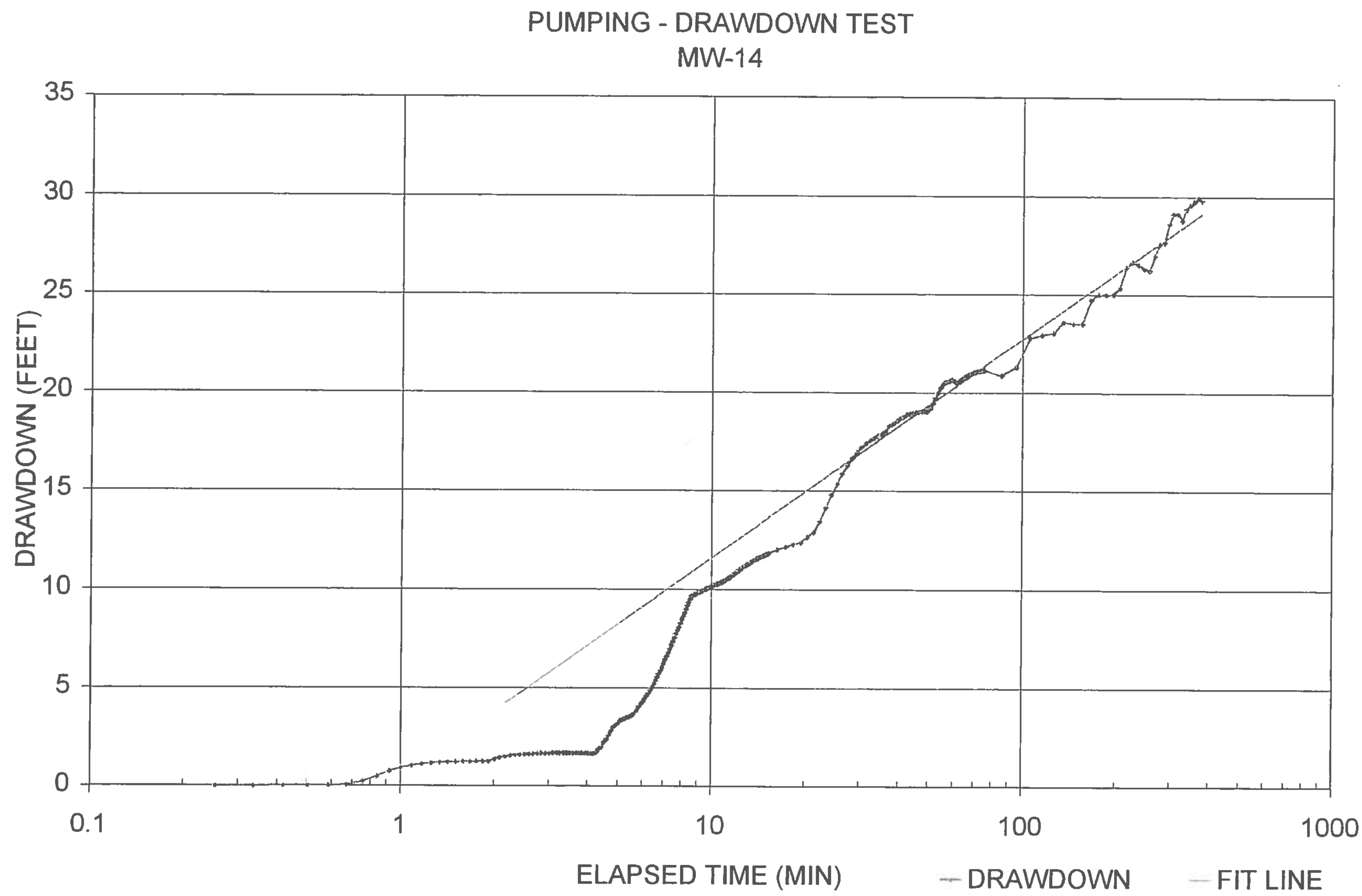


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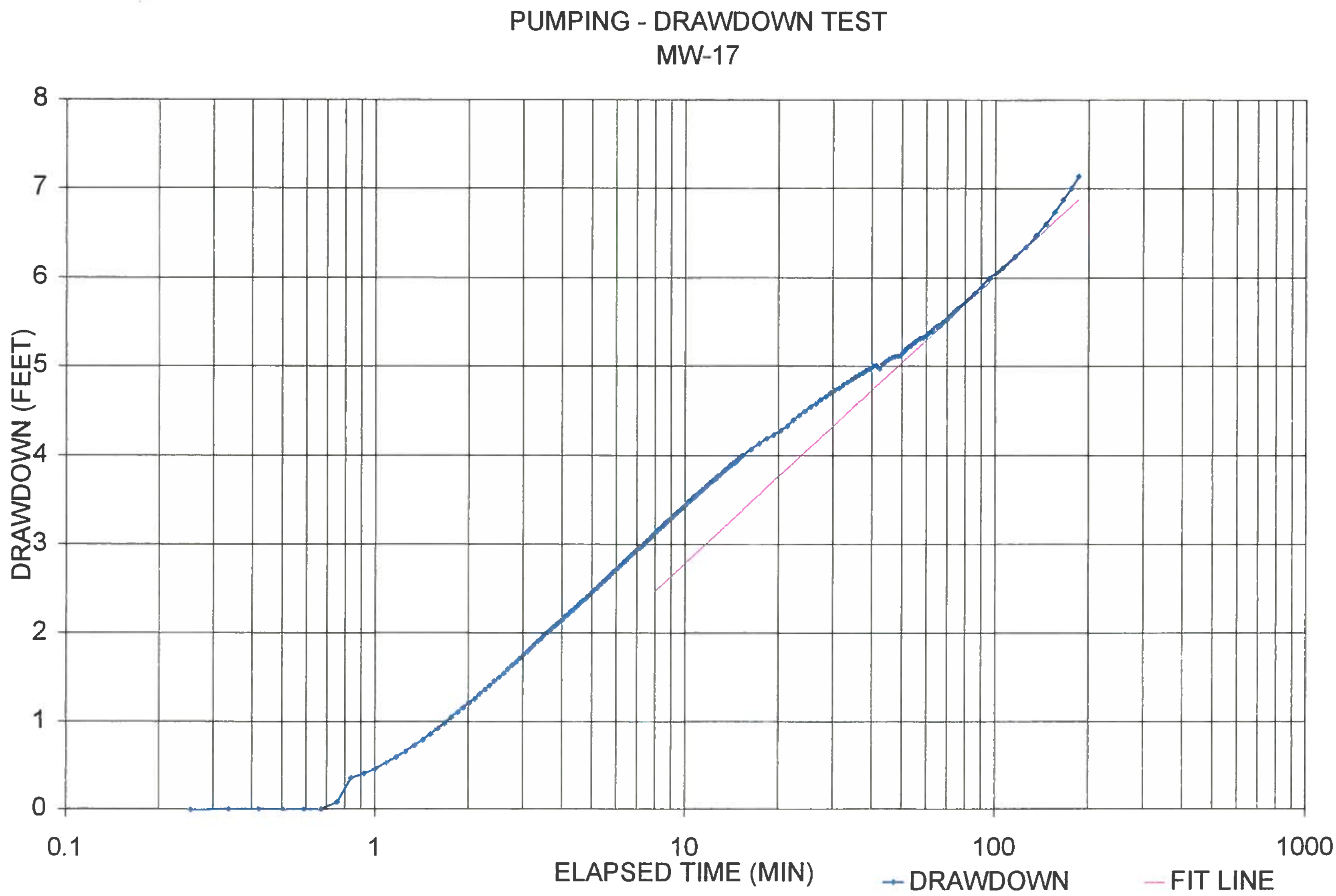
FIGURE A-21
JACOB ANALYSIS ON MW-14

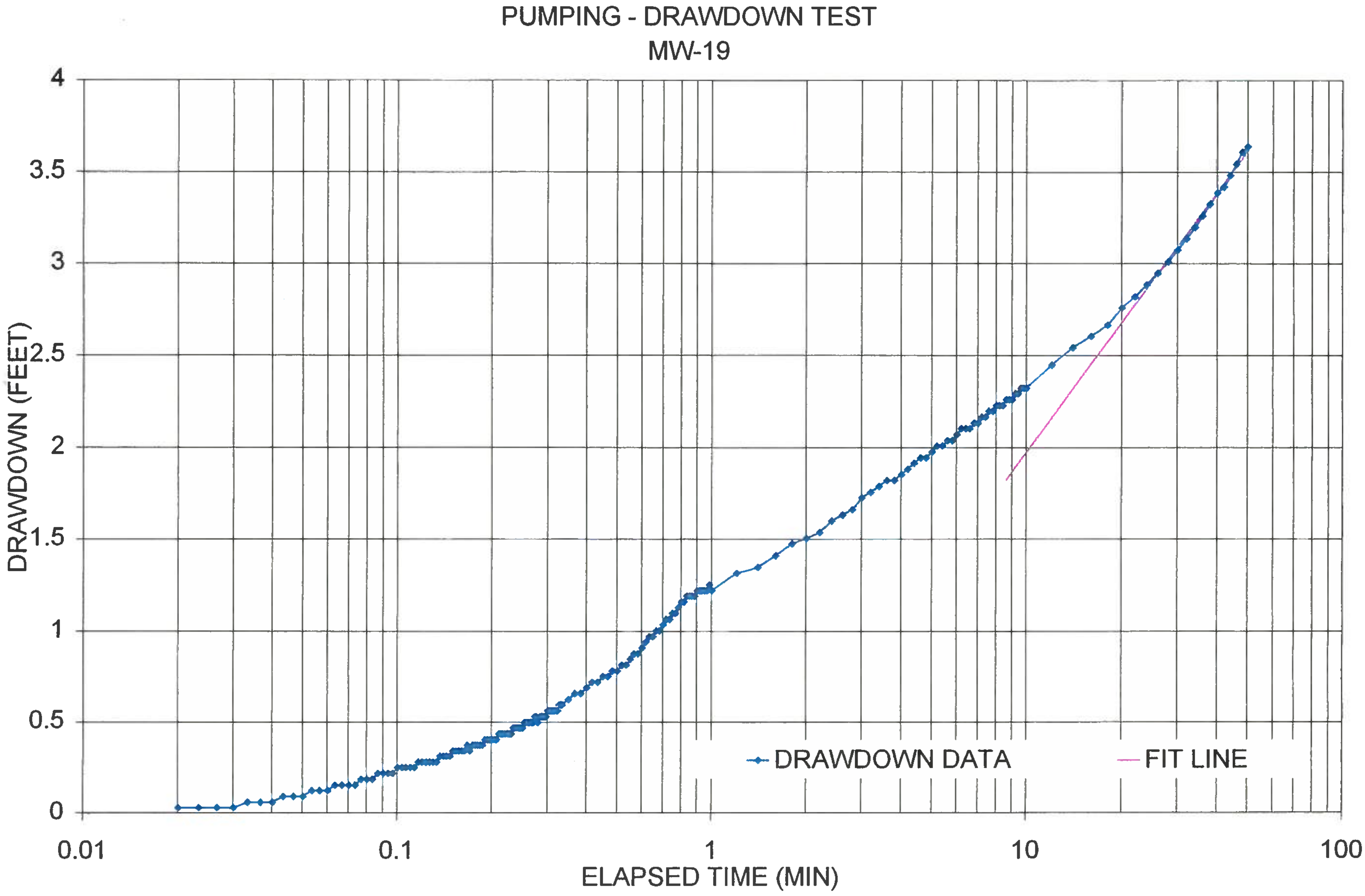
DATE: DECEMBER 1999
PROJECT: 100029
FILE:GRAPHSa19-a25.XLS



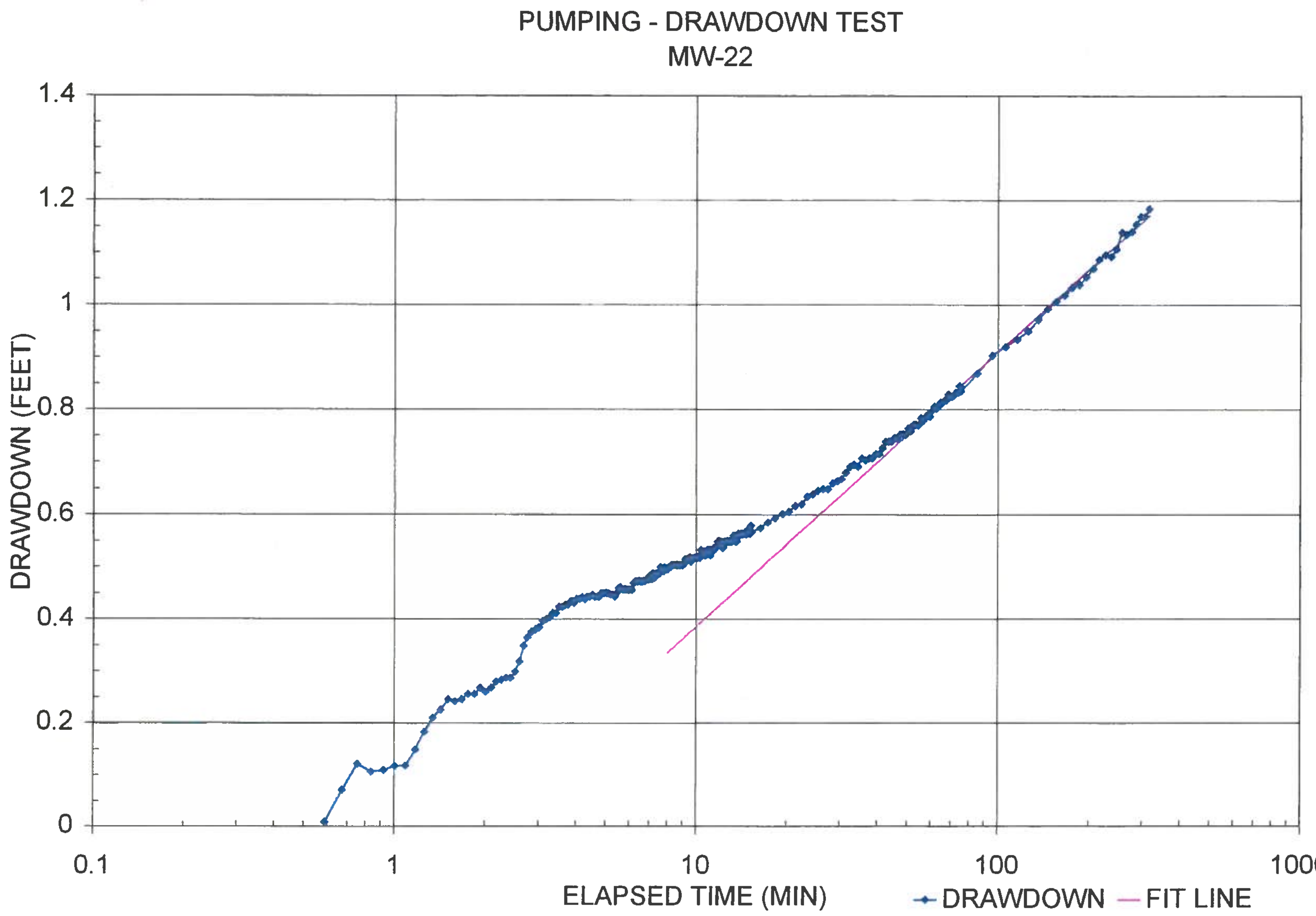
SHEPHERD MILLER
INCORPORATED

FIGURE A-22
JACOB ANALYSIS ON MW-17

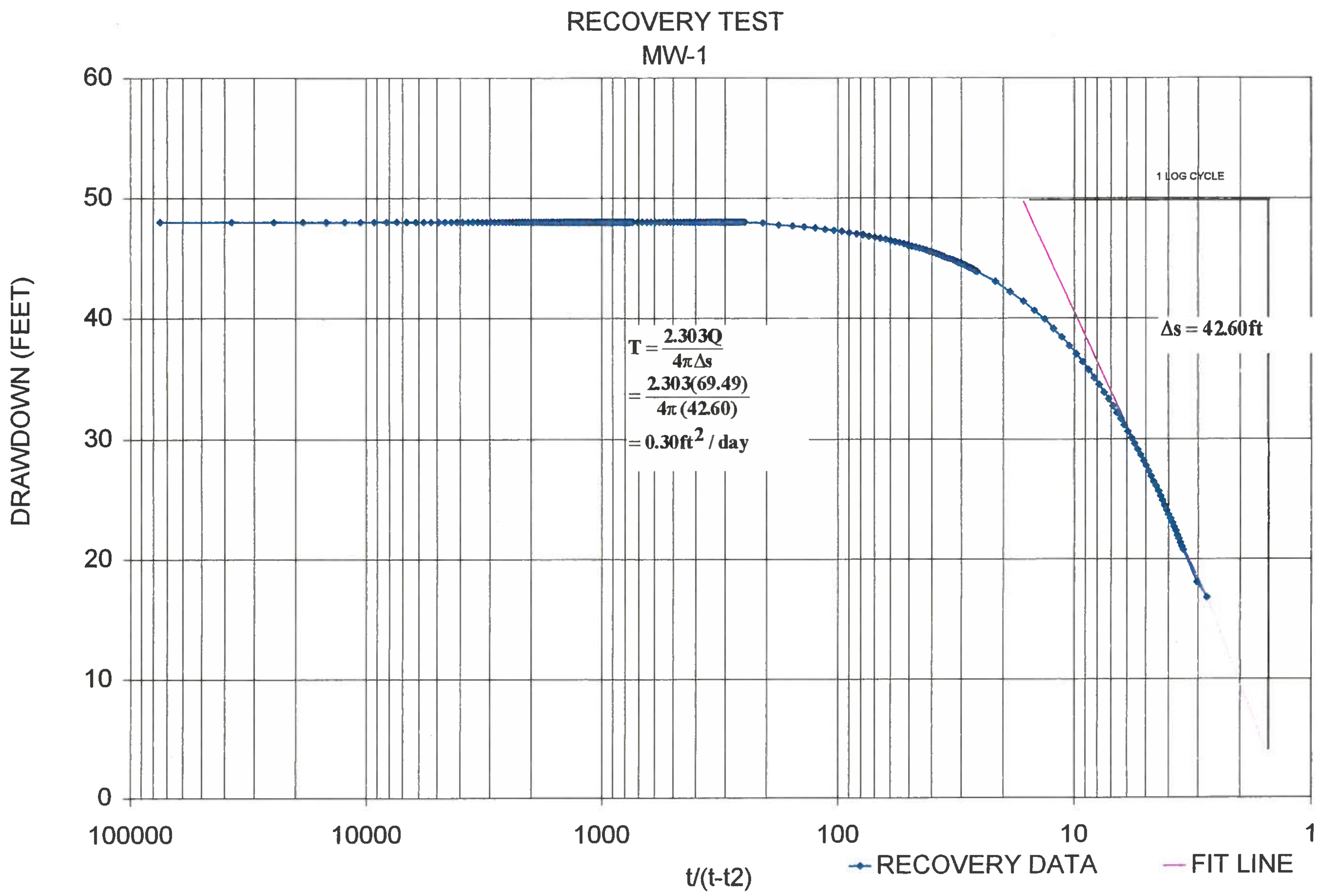
DATE: DECEMBER 1999
PROJECT: 100029
FILE:GRAPHSa19-a25.XLS



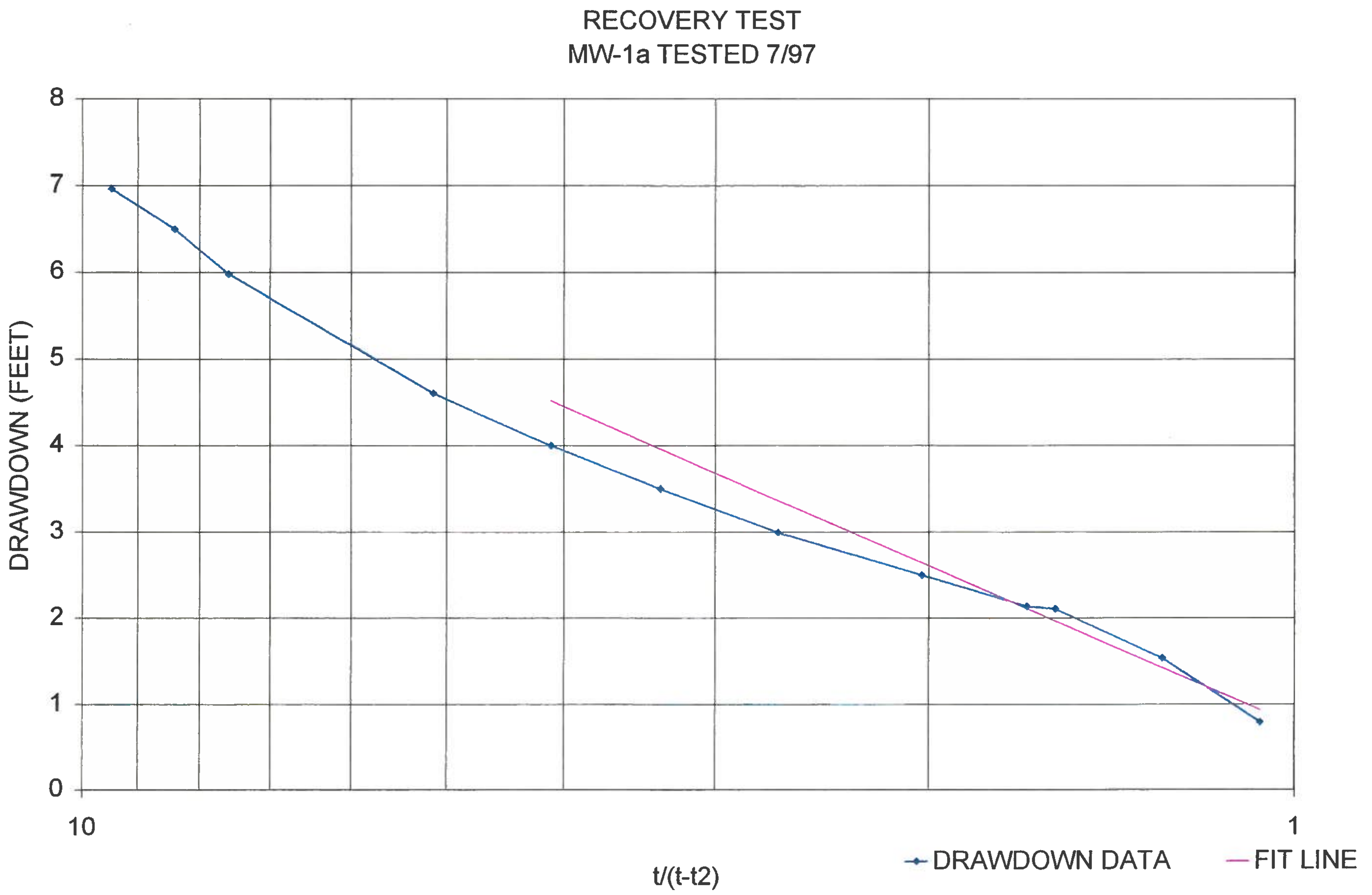
SHEPHERD MILLER INCORPORATED	**FIGURE A-23** **JACOB ANALYSIS ON MW-19**	DATE: DECEMBER 1999 PROJECT: 100029 FILE:GRAPHSa19-a25.XLS



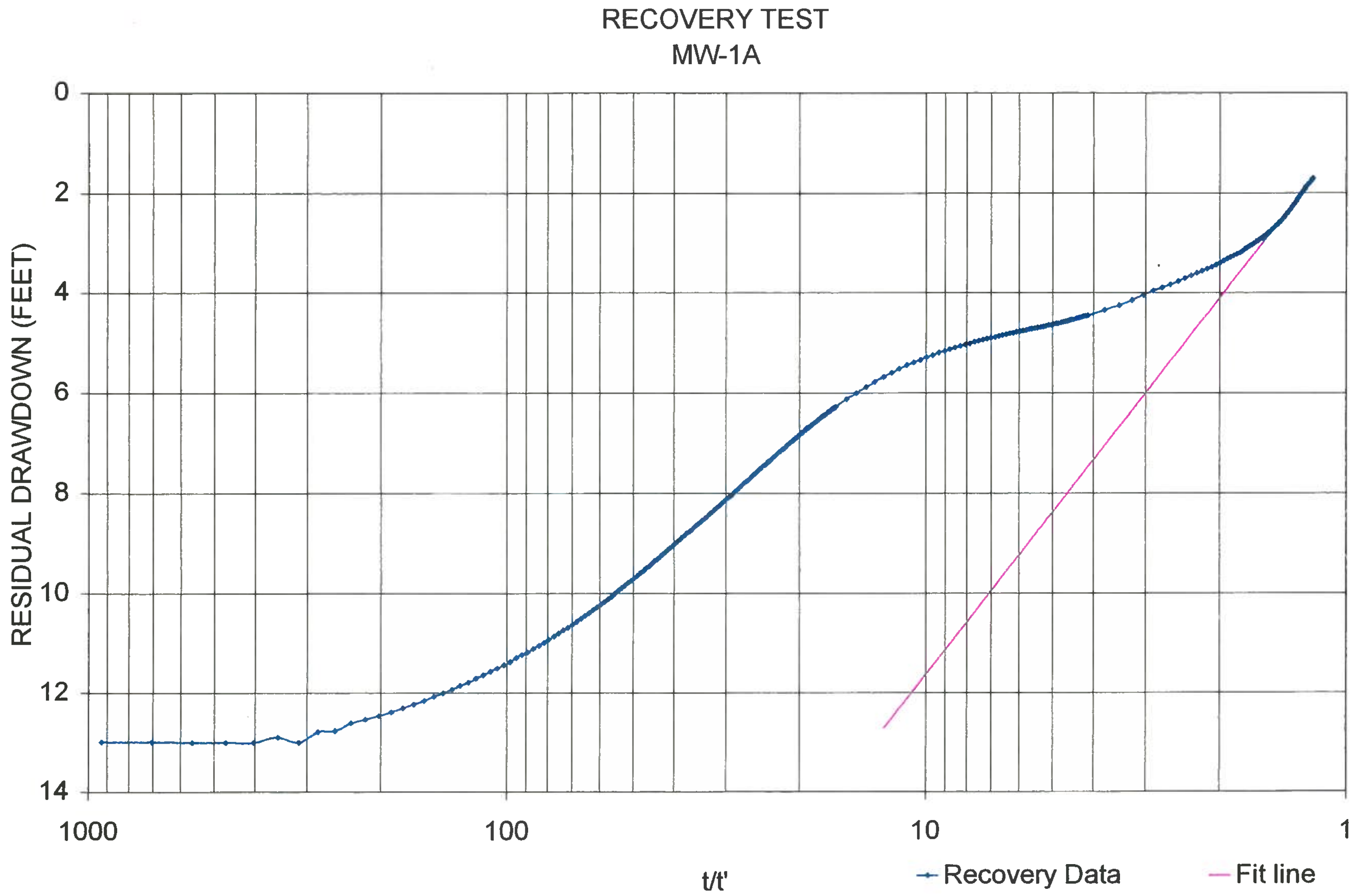
SHEPHERD MILLER INCORPORATED	**FIGURE A-24** **JACOB ANALYSIS ON MW-22**	DATE: DECEMBER 1999 PROJECT: 100029 FILE:GRAPHSa19-a25.XLS



SHEPHERD MILLER INCORPORATED	**FIGURE A-25** **THEIS RECOVERY ANALYSIS ON MW-1**	DATE: DECEMBER 1999 PROJECT: 100029 FILE:GRAPHSa19-a25.XLS



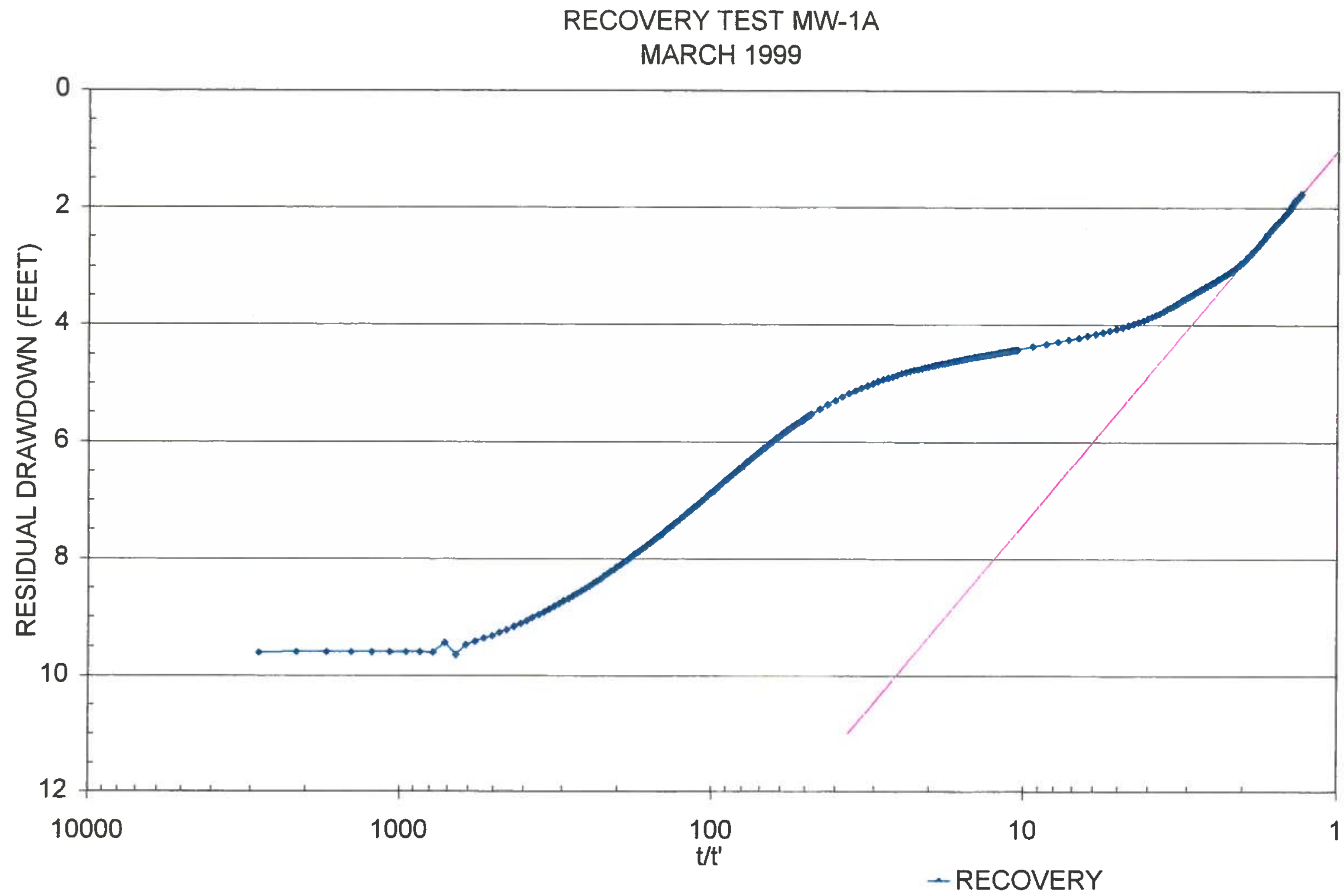
SHEPHERD MILLER INCORPORATED	**FIGURE A-26** **THEIS RECOVERY ANALYSIS ON MW-1a TESTED 7/97**	DATE: DECEMBER 1999 PROJECT: 100029 FILE:GRAPHSa26-a43.XLS



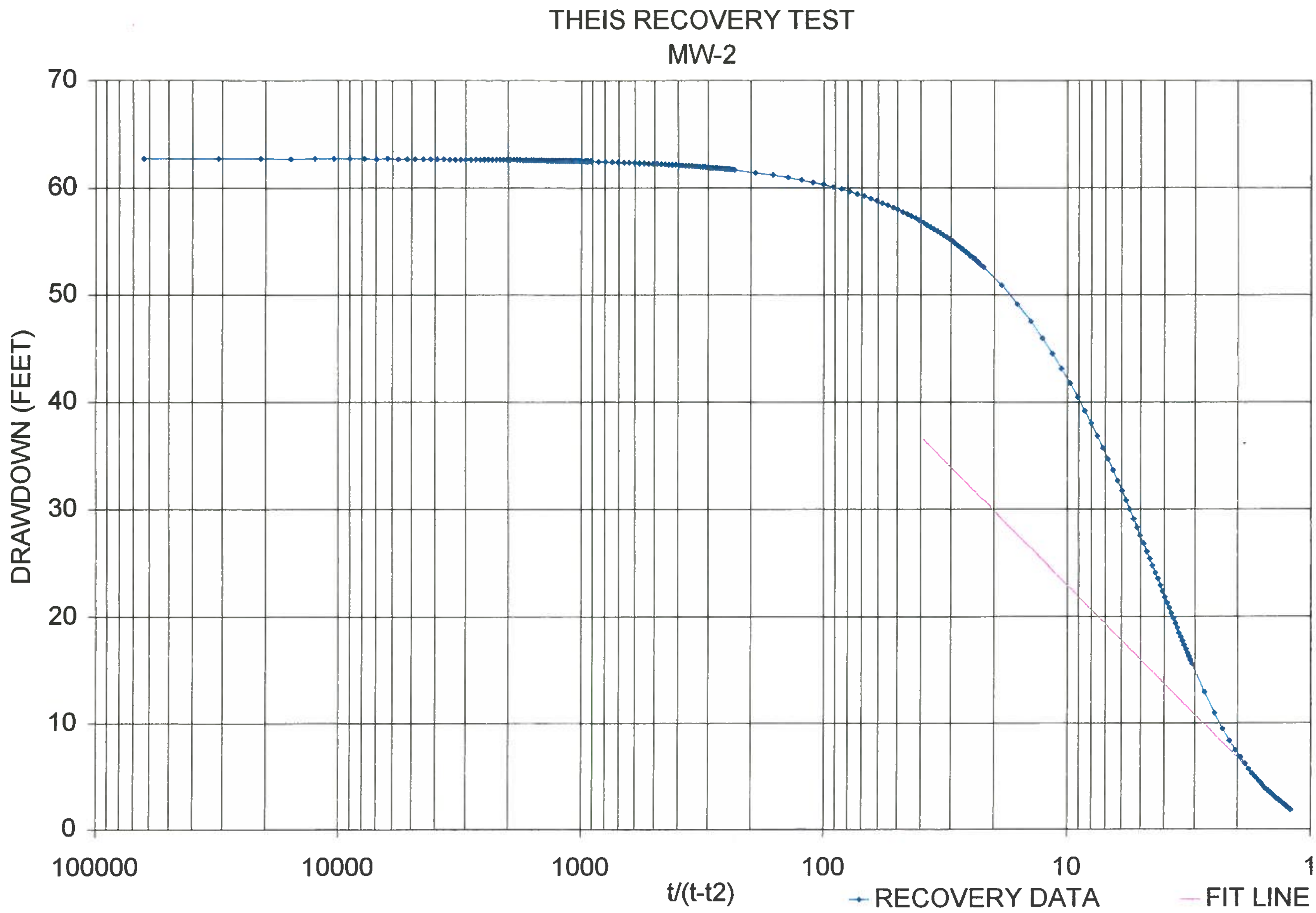
SHEPHERD MILLER
INCORPORATED

FIGURE A-27
THEIS RECOVERY ANALYSIS ON MW-1A TESTED 1/99

DATE: DECEMBER 1999
PROJECT: 100029
FILE:GRAPHSa26-a43.XLS



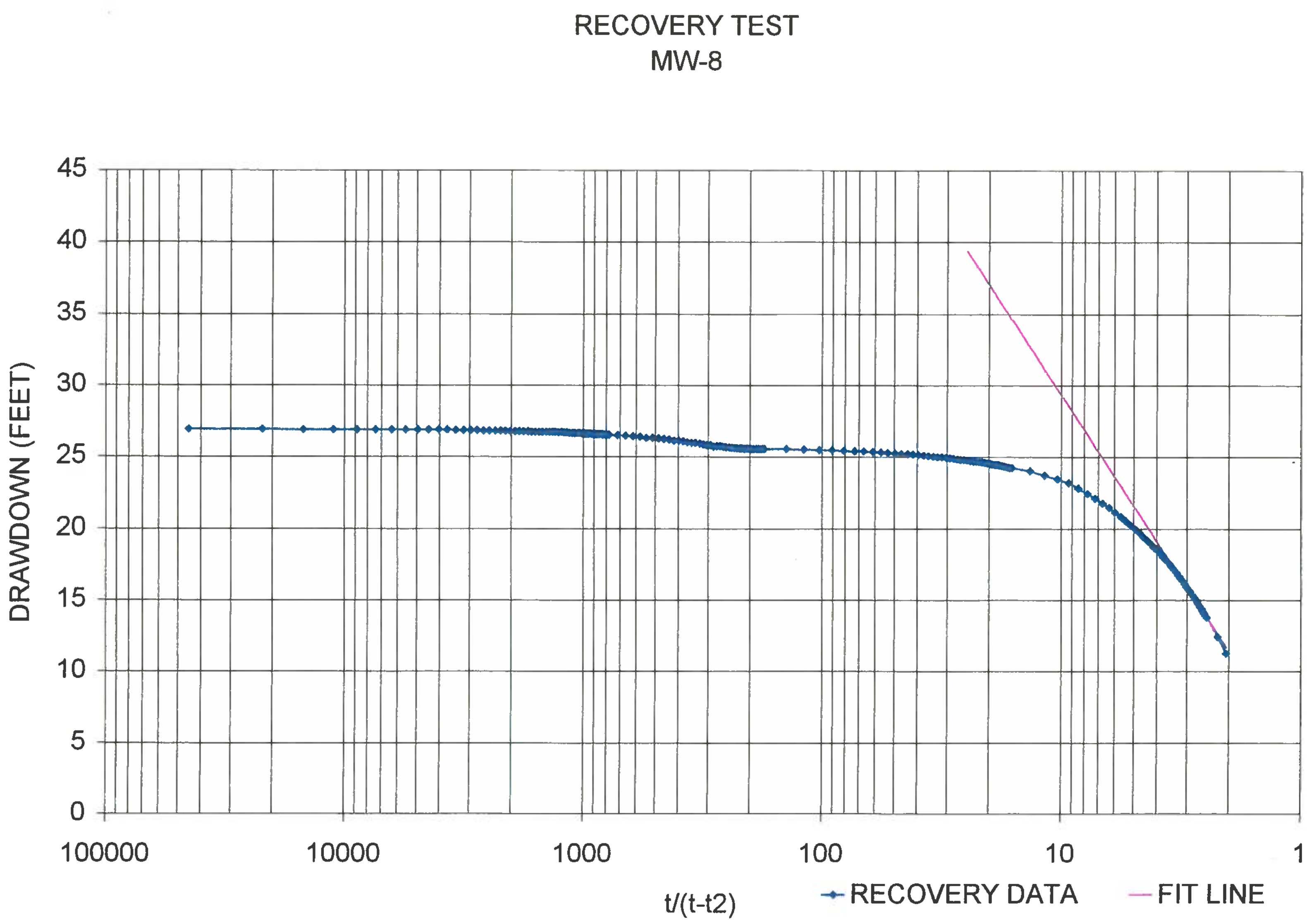
SHEPHERD MILLER INCORPORATED	**FIGURE A-28** **THEIS RECOVERY ANALYSIS ON MW-1A** **TESTED 3/99**	DATE: DECEMBER 1999 PROJECT: 100029 FILE:GRAPHSa26-a43.XLS



SHEPHERD MILLER INCORPORATED

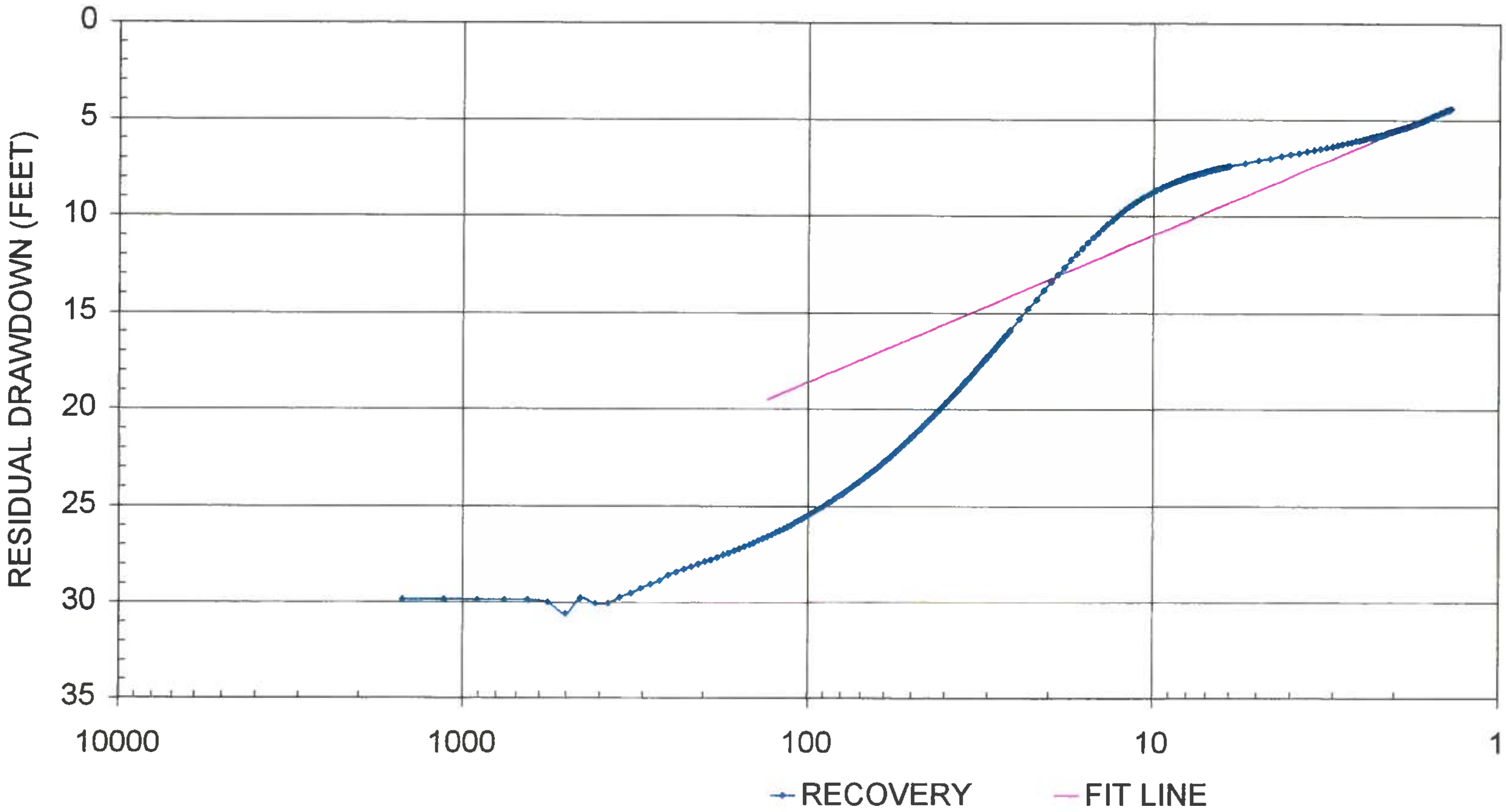
FIGURE A-29
THEIS RECOVERY ANALYSIS ON MW-2

DATE: DECEMBER 1999
PROJECT: 100029
FILE:GRAPHSa26-a43.XLS

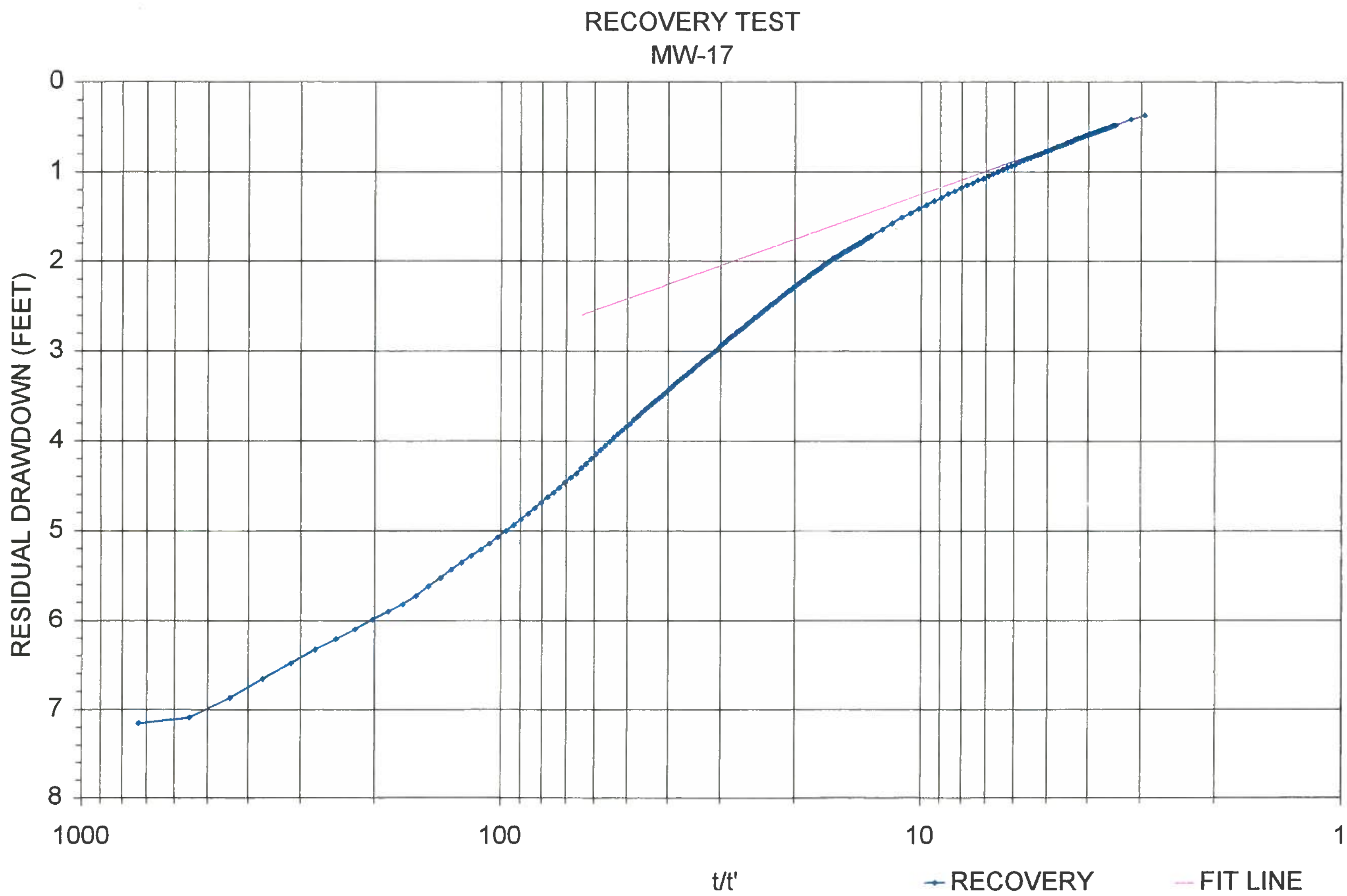


SHEPHERD MILLER INCORPORATED	**FIGURE A-30** **THEIS RECOVERY ANALYSIS ON MW-8**	DATE: DECEMBER 1999 PROJECT: 100029 FILE:GRAPHSa26-a43.XLS

RECOVERY TEST
MW-14



SHEPHERD MILLER INCORPORATED	**FIGURE A-31** **THEIS RECOVERY ANALYSIS ON MW-14**	DATE: DECEMBER 1999 PROJECT: 100029 FILE:GRAPHSa26-a43.XLS



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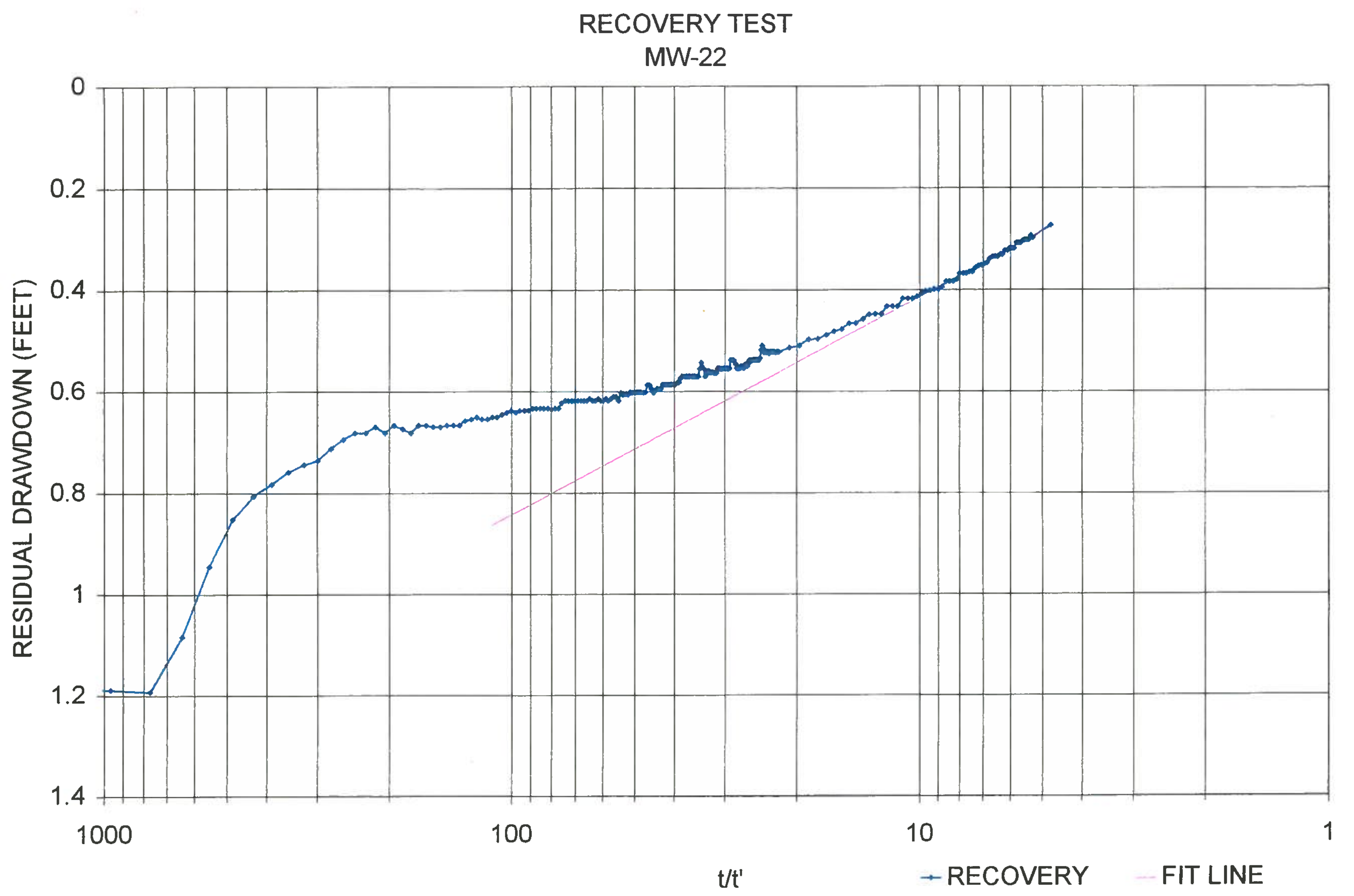
INCORPORATED

FIGURE A-32
THEIS RECOVERY ANALYSIS ON MW-17

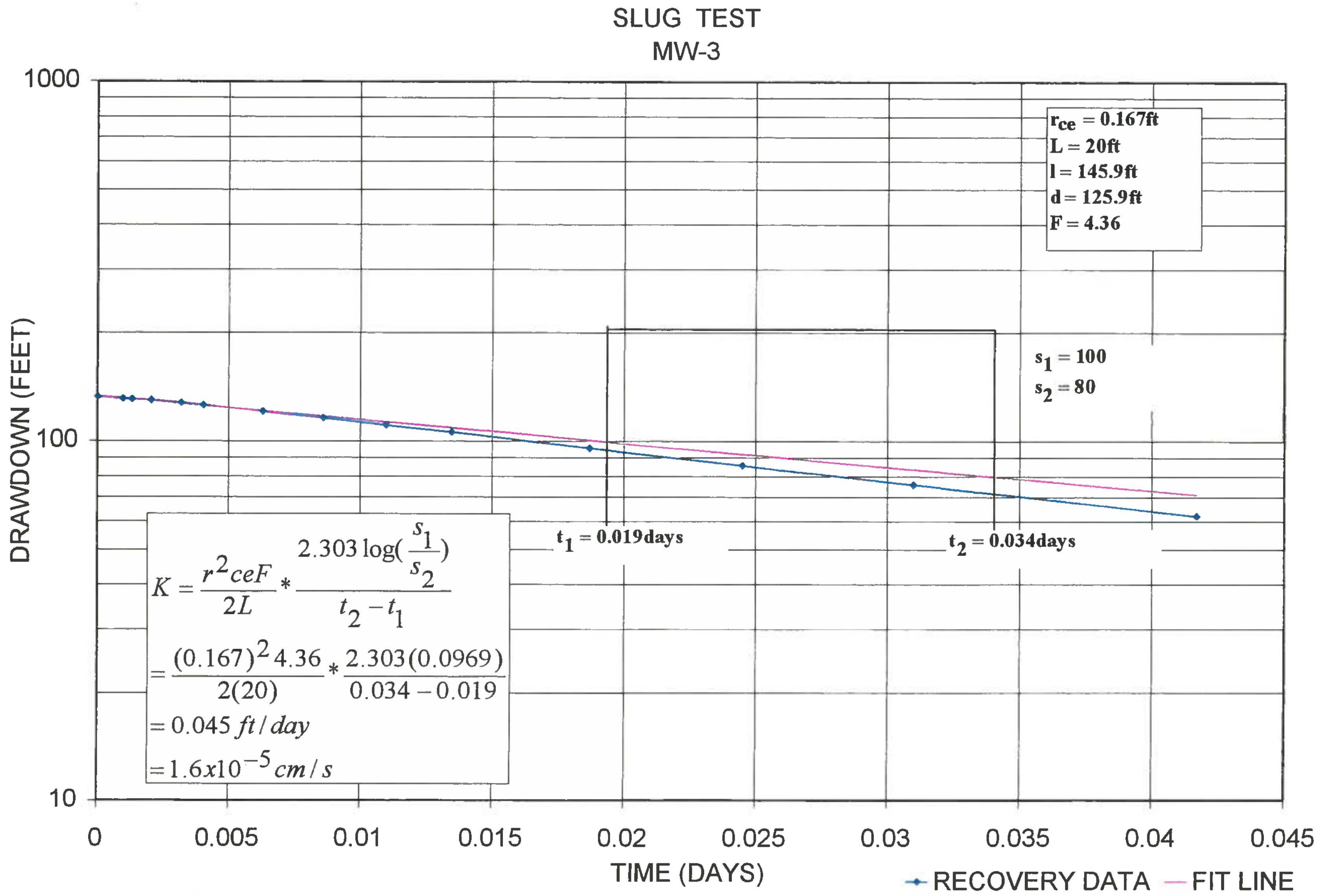
DATE: DECEMBER 1999
PROJECT: 100029
FILE:GRAPHSa26-a43.XLS



SHEPHERD MILLER
INCORPORATED

FIGURE A-33
THEIS RECOVERY ANALYSIS ON MW-22

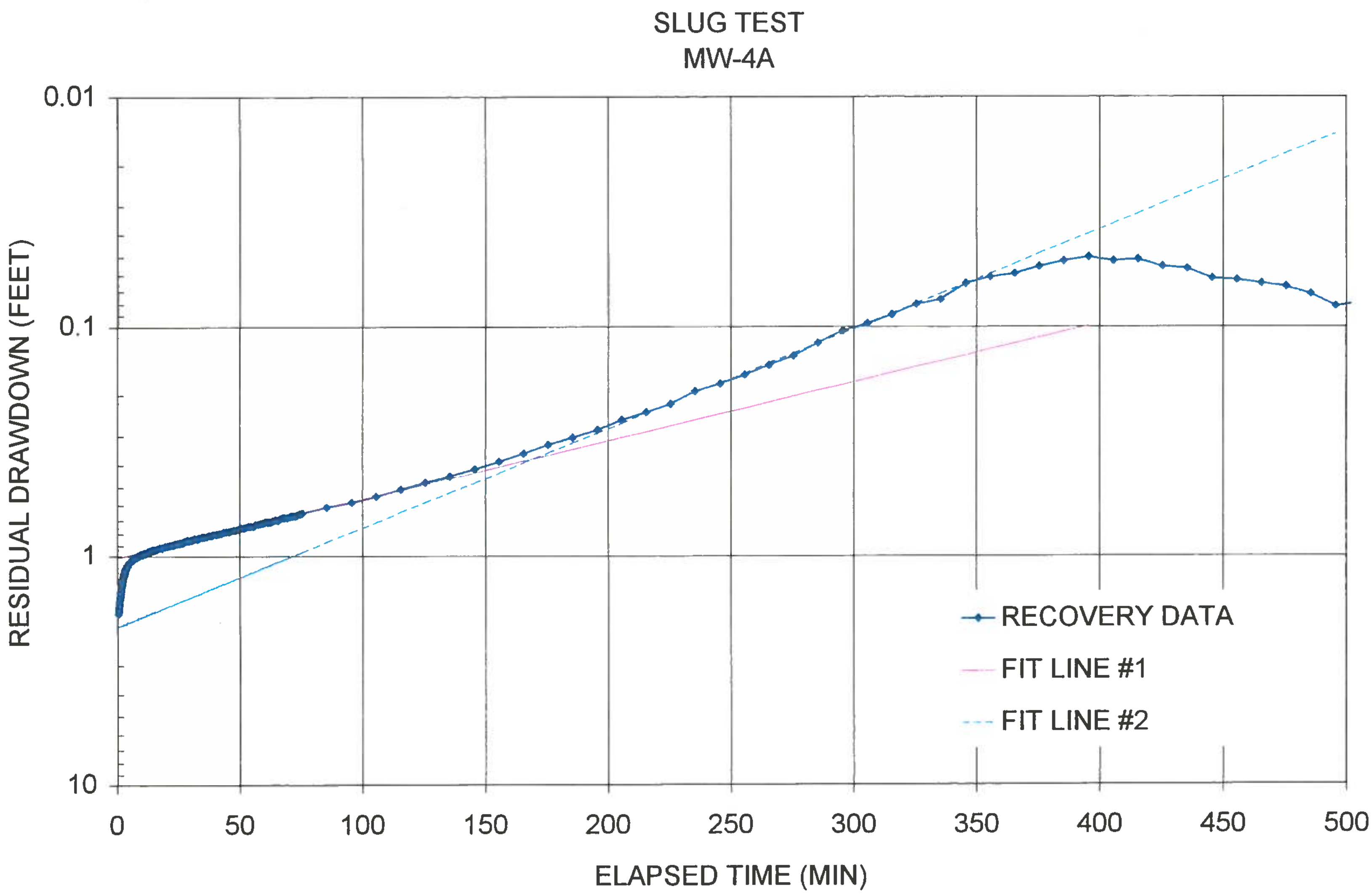
DATE: DECEMBER 1999
PROJECT: 100029
FILE:GRAPHSa26-a43.XLS



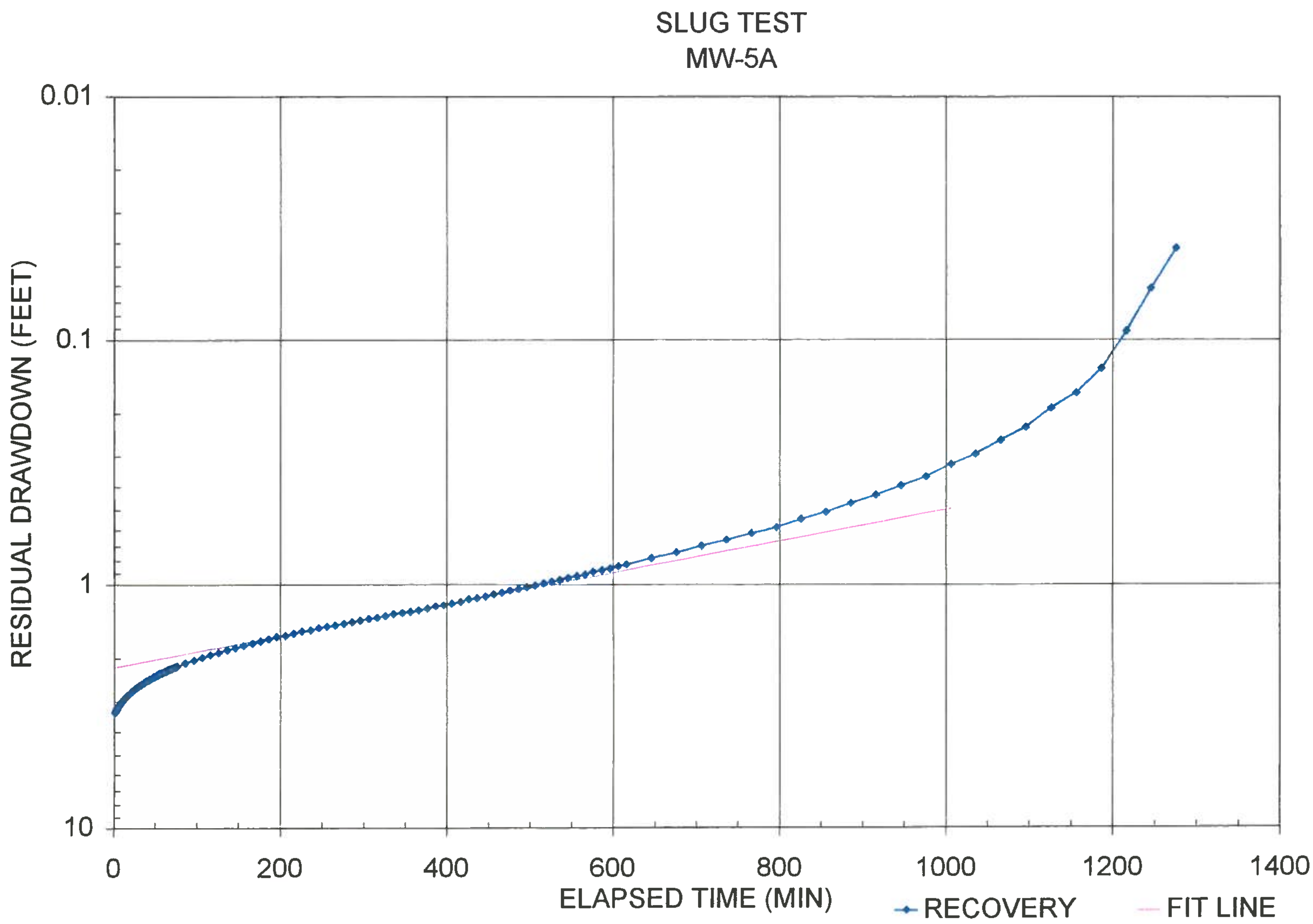
SHEPHERD MILLER INCORPORATED

FIGURE A-34
HVORSLEV ANALYSIS ON MW-3

DATE: DECEMBER 1999
PROJECT: 100029
FILE:GRAPHSa26-a43.XLS

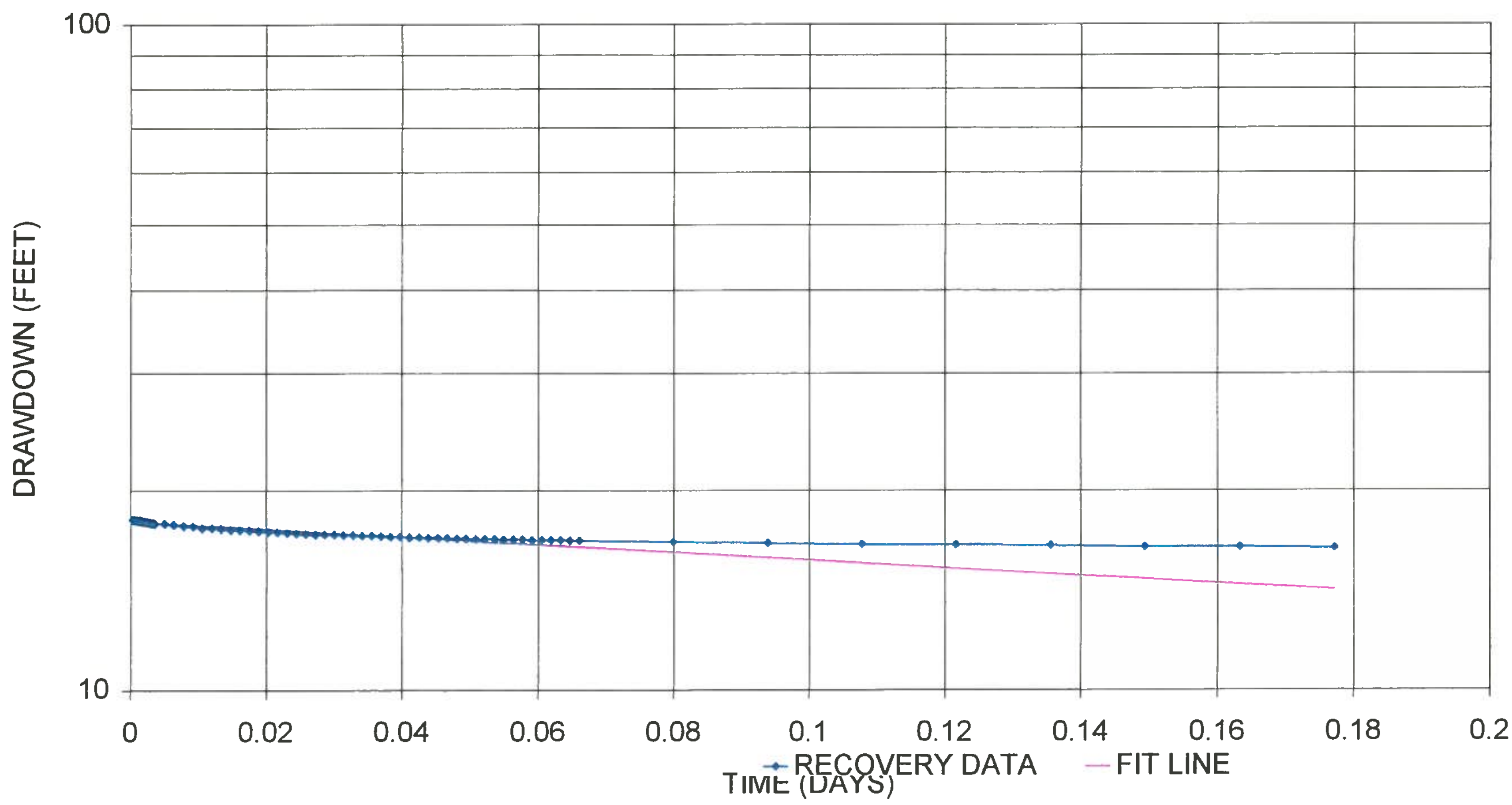


SHEPHERD MILLER INCORPORATED	**FIGURE A-35** **HVORSLEV ANALYSIS ON MW-4A**	DATE: DECEMBER 1999 PROJECT: 100029 FILE:GRAPHSa26-a43.XLS



SHEPHERD MILLER INCORPORATED	**FIGURE A-36** **HVORSLEV ANALYSIS ON MW-5A**	DATE: DECEMBER 1999 PROJECT: 100029 FILE:GRAPHSa26-a43.XLS

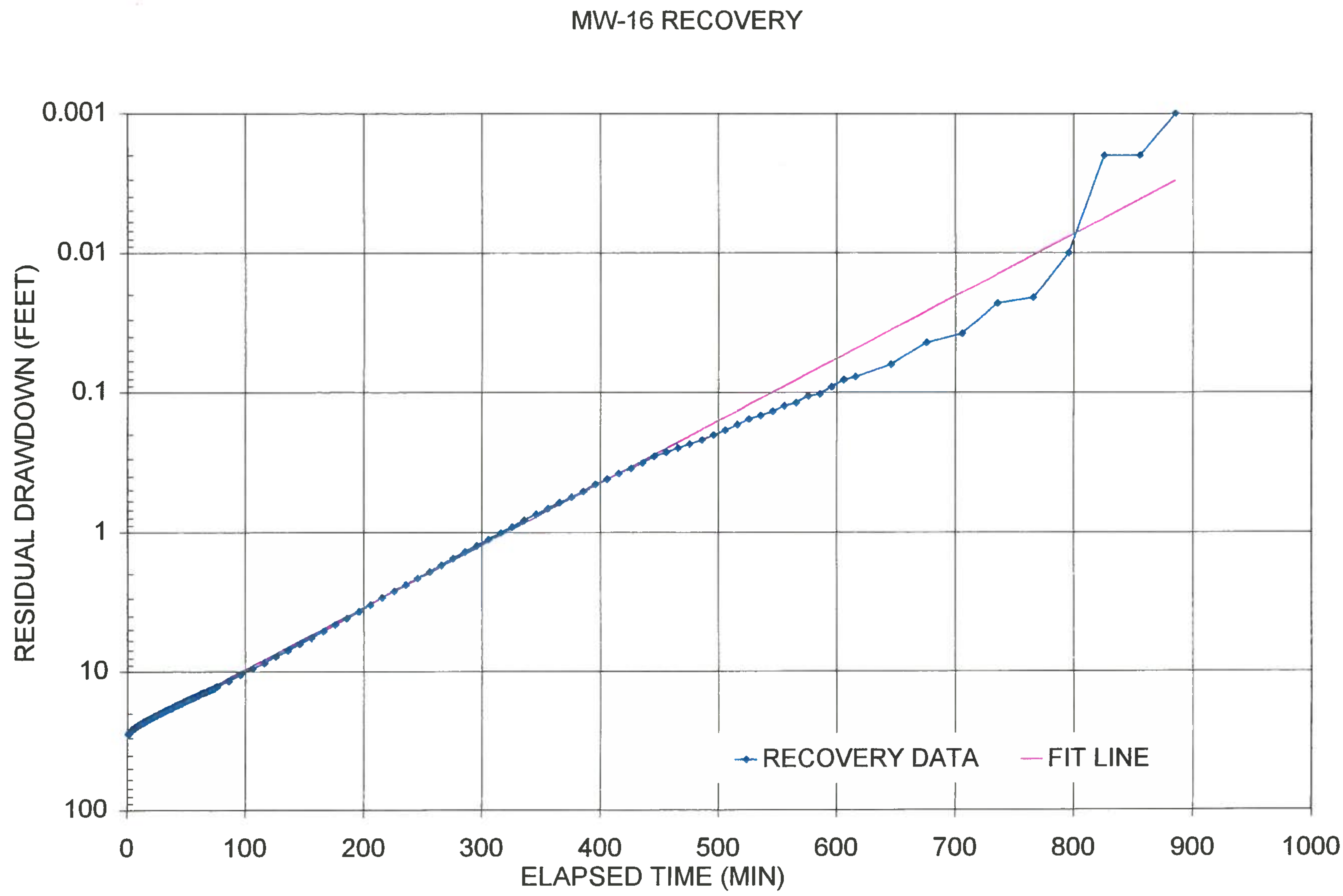
SLUG TEST
MW-10



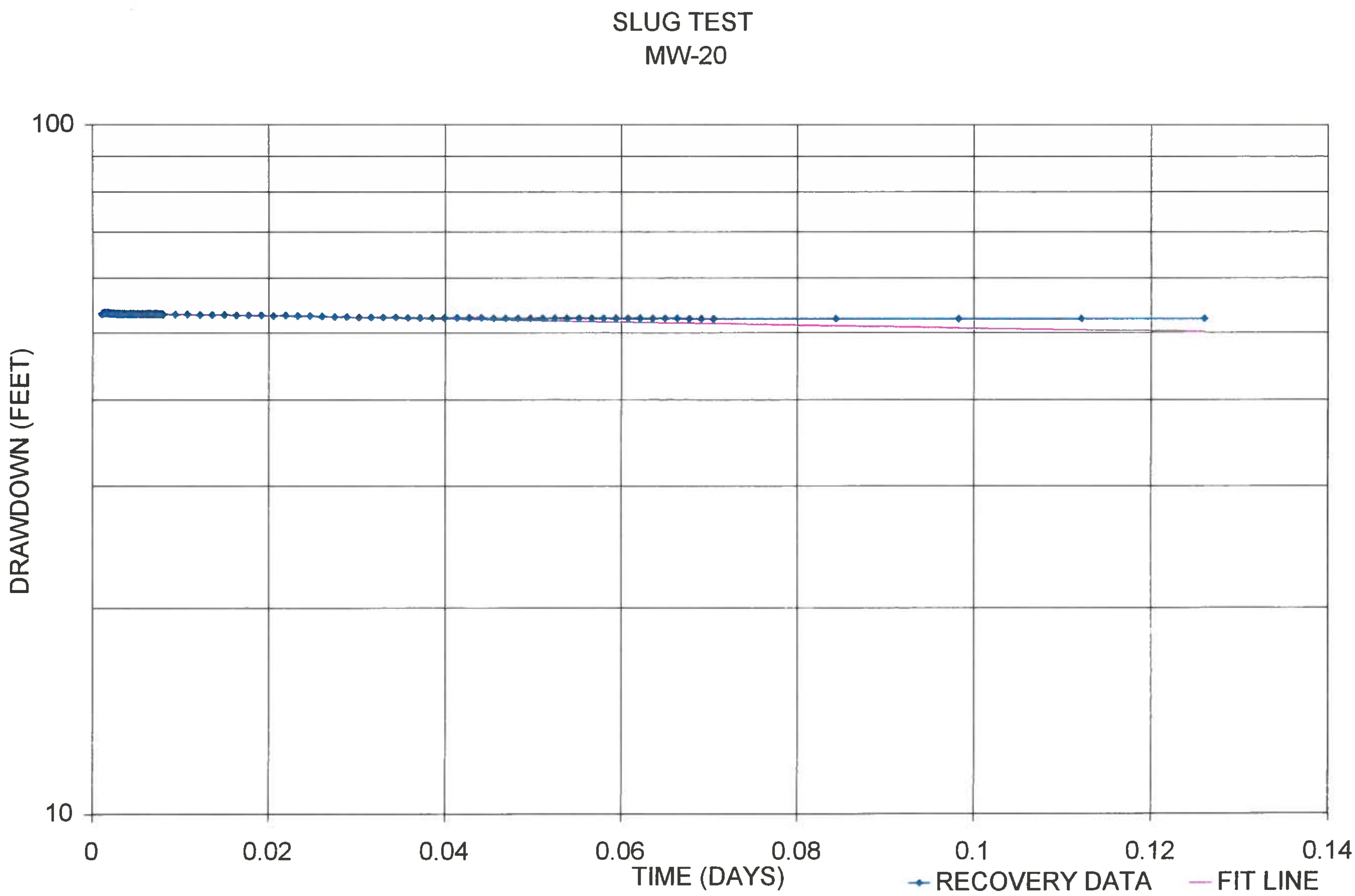
SHEPHERD MILLER
INCORPORATED

FIGURE A-37
HVORSLEV ANALYSIS ON MW-10

DATE: DECEMBER 1999
PROJECT: 100029
FILE:GRAPHSa26-a43.XLS



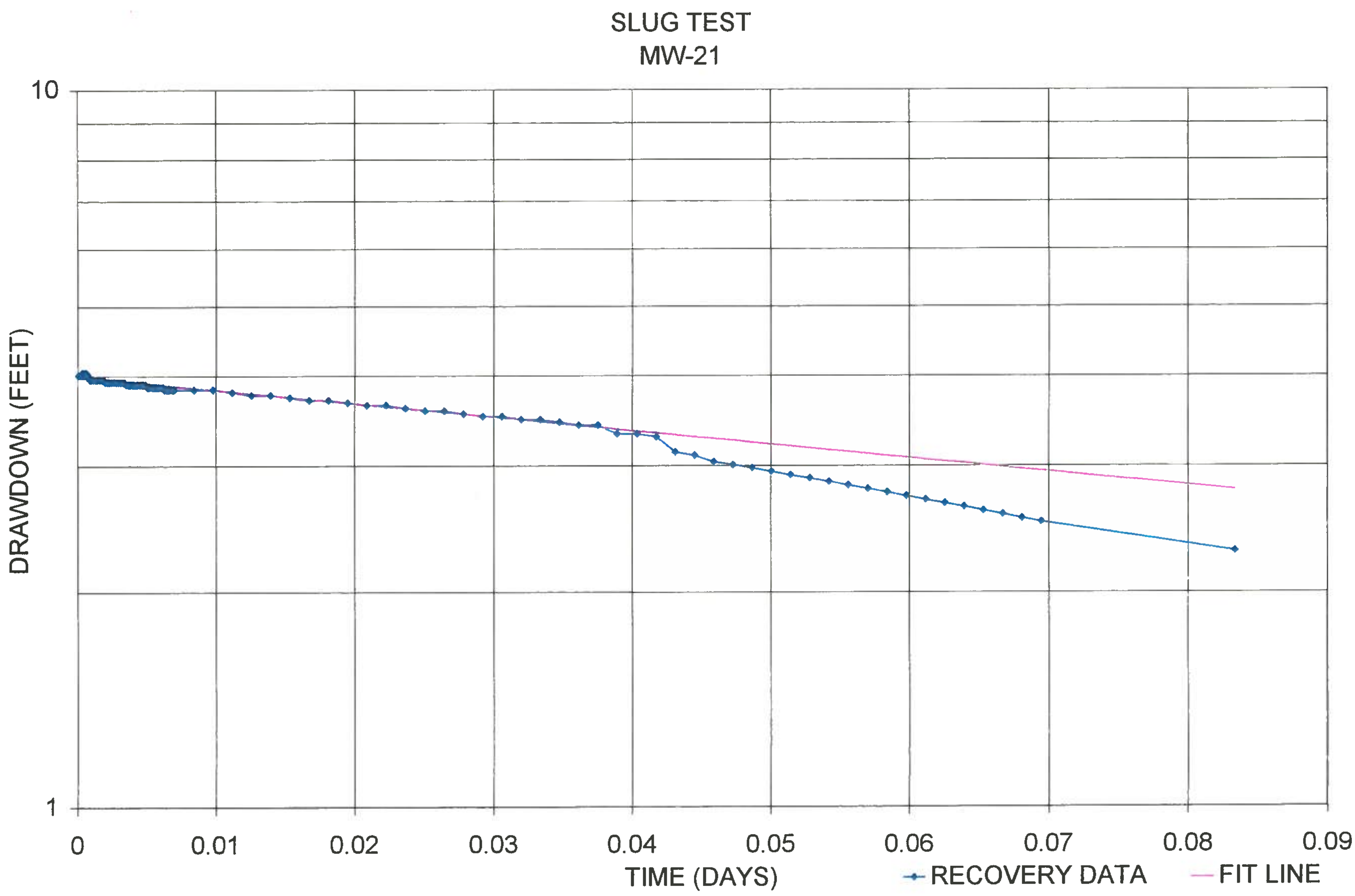
SHEPHERD MILLER INCORPORATED	**FIGURE A-38** **HVORSLEV ANALYSIS ON MW-16**	DATE: DECEMBER 1999 PROJECT: 100029 FILE:GRAPHSa26-a43.XLS



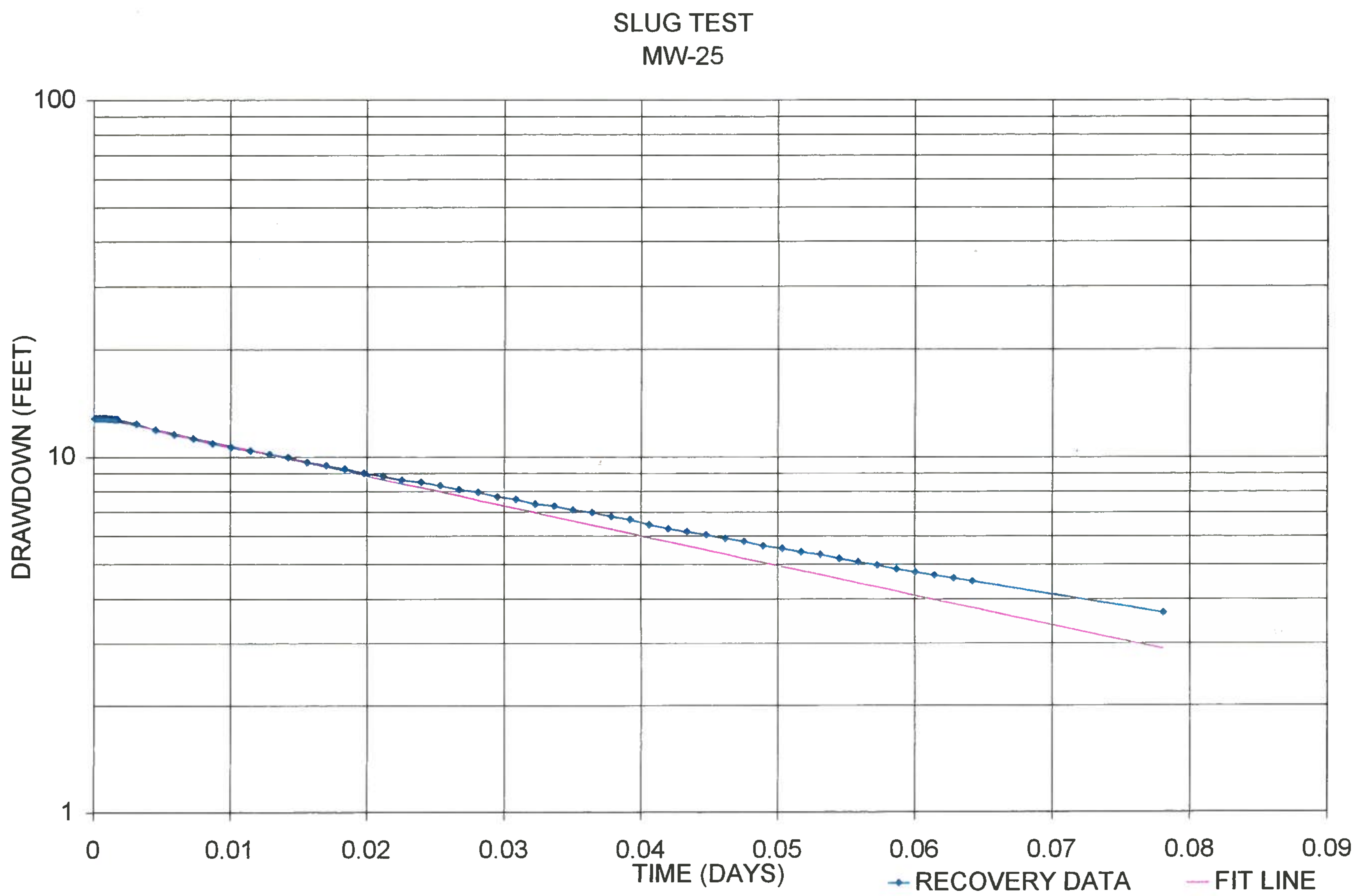
SHEPHERD MILLER
INCORPORATED

FIGURE A-39
HVORSLEV ANALYSIS ON MW-20

DATE: DECEMBER 1999
PROJECT: 100029
FILE:GRAPHSa26-a43.XLS



SHEPHERD MILLER INCORPORATED	**FIGURE A-40** **HVORSLEV ANALYSIS ON MW-21**	DATE: DECEMBER 1999 PROJECT: 100029 FILE:GRAPHSa26-a43.XLS



SHEPHERD MILLER
INCORPORATED

FIGURE A-41
HVORSLEV ANALYSIS ON MW-25

DATE: DECEMBER 1999
PROJECT: 100029
FILE:GRAPHSa26-a43.XLS

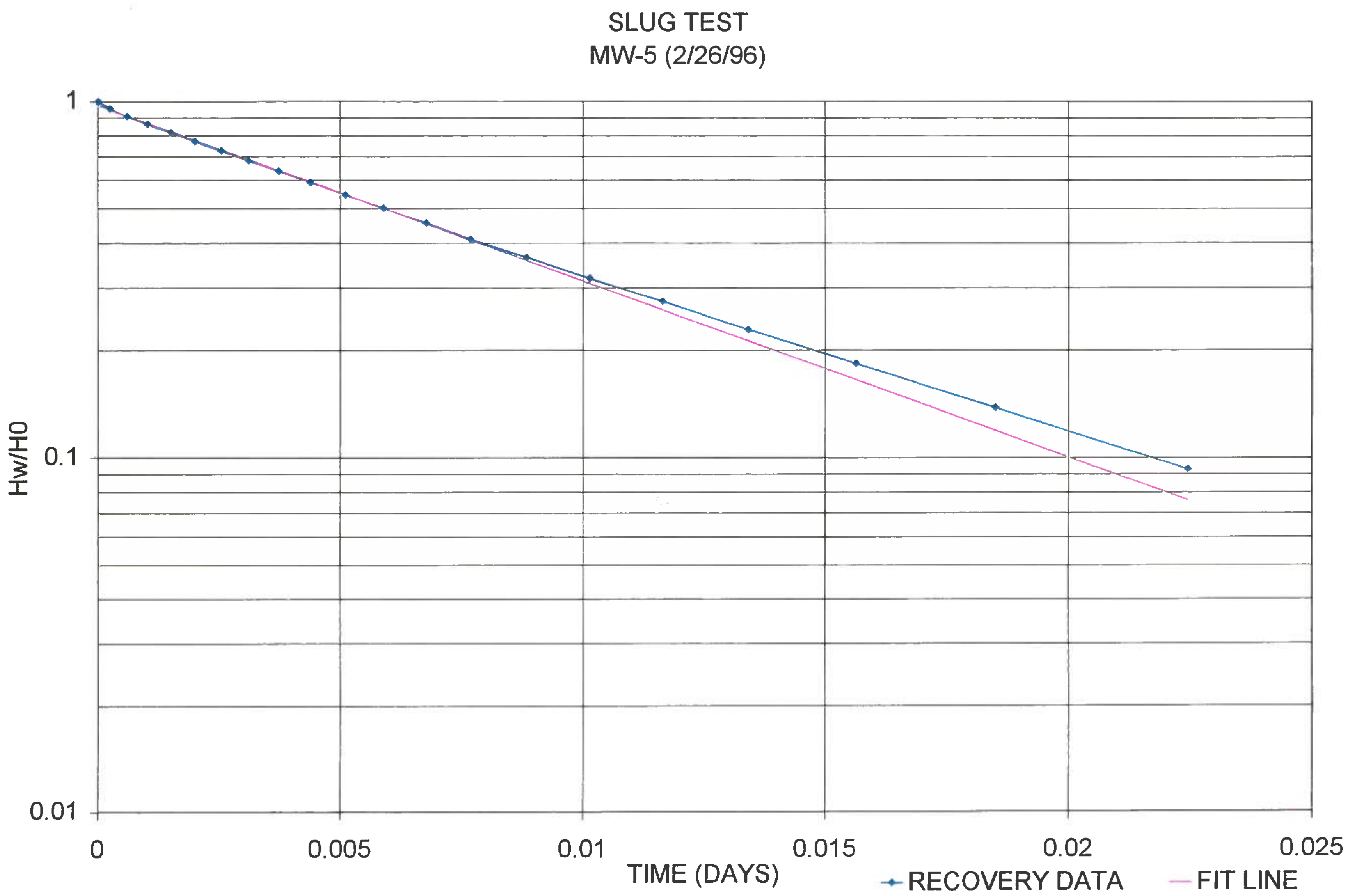


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FIGURE A-42
HVORSLEV ANALYSIS ON FEBRUARY 1996 DATA FROM MW-5

DATE: DECEMBER 1999
PROJECT: 100029
FILE:GRAPHSa26-a43.XLS

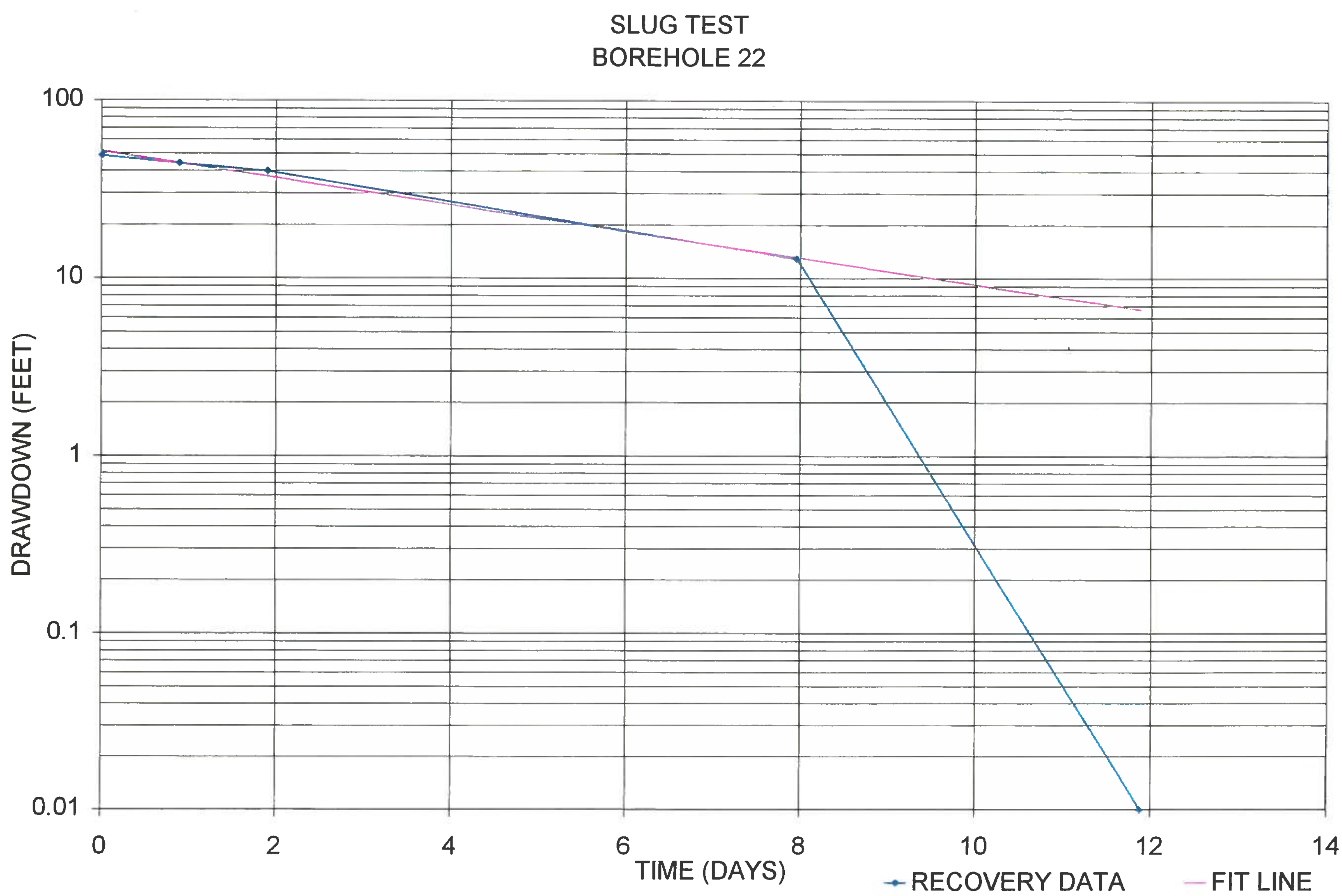

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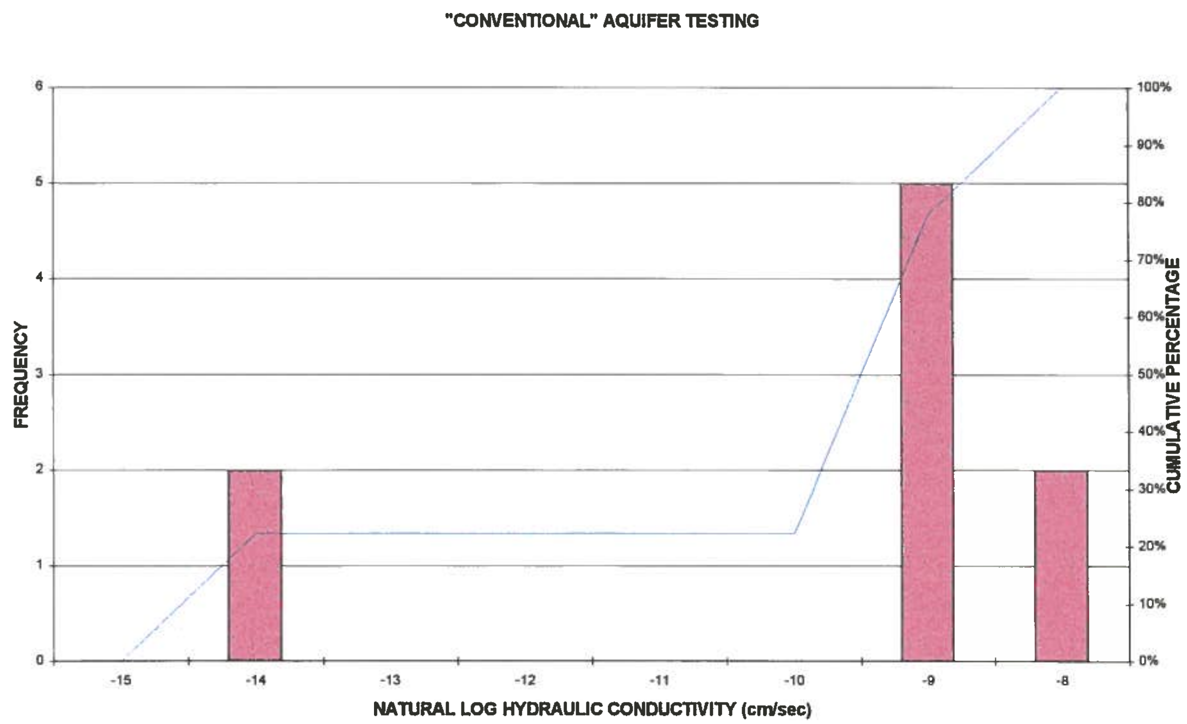
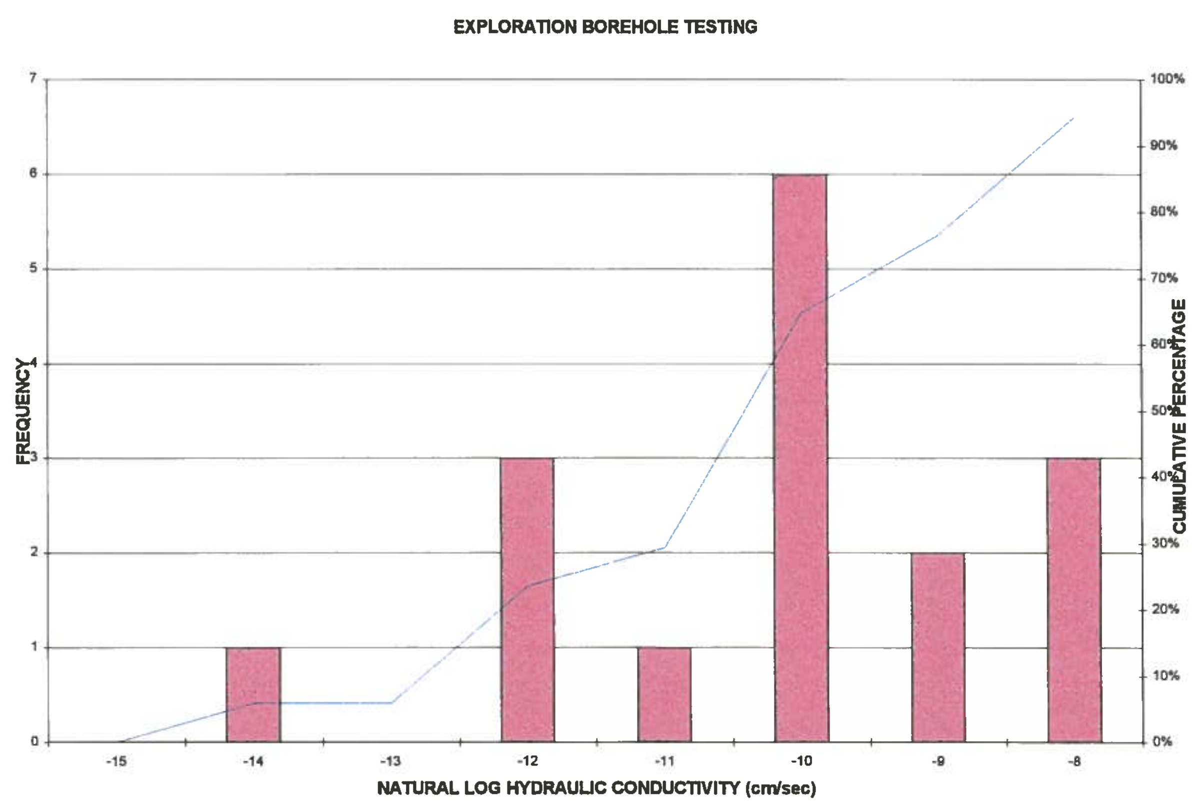
FIGURE A-43
HVORSLEV ANALYSIS ON BOREHOLE-22

DATE: DECEMBER 1999
PROJECT: 100029
FILE:GRAPHSa26-a43.XLS





SHEPHERD MILLER INCORPORATED	FIGURE A-44. HYDRAULIC CONDUCTIVITY ESTIMATES FOR THE COLORADO FORMATION	DATE: DECEMBER 1999 PROJECT: 100029 FILE: GRAPH A44.XLS

TABLES

Table A-1 Summary of Aquifer Testing Times and Flow Rates

Monitoring Well	Test Beginning and End Dates	Time			Elapsed Time			Time Weighted Average Pumping Rate (gpm)	Drawdown at End of Pumping (feet)	Drawdown at End of Recovery (feet)
		Begin Pumping	End Pumping	End Recovery	Total Test Time (min)	Pumping Time (min)	Recovery Time (min)			
MW-1	7/1-7/1/97	13:23	17:35	19:51	388	251.3	136.7	0.361	48.03	16.79
MW-1A	7/3-7/4/97	8:31	10:10	7:51	1400	99	1301	0.886	8.87	0.79
MW-1A	1/28-1/29/99	10:34	14:30	10:10	1416	236	1180	1.2	13.0	1.7
MW-1A	3/4-3/6/99	10:31	22:35	12:35	3004	724	2280	0.79	9.8	1.7
MW-2	7/5-7/6/97	11:39	15:10	7:29	1190	211	979	0.721	62.84	1.85
MW-3	7/5-7/5/97	15:58	16:04	17:05	67	6.0	61	13.6	95.62	24.32
MW-4	7/8-7/8/97	13:02	13:36	13:36	34	34	0	0.617	21.93	-
MW-4A	2/3-2/3/99	N/A	10:01	14:45	278	N/A	278	Rising Head Test	1.8	0.0
MW-5	7/7-7/7/97	13:30	15:30	N/A	120	120	0	1.19	30.74	-
MW-5A	2/4-2/5/99	N/A	14:20	12:26	1,321	N/A	1,321	Rising Head Test	3.3	0.04
MW-8	7/2-7/2/97	9:30	12:00	14:20	290	150	140	0.39[a]	26.94	11.30
MW-10	7/4-7/4/97	12:38	12:56	17:11	273	18	255	1.16	18.16	16.42
MW-12	7/6-7/6/97	9:25	10:47	13:28	243	82	161	0.345	11.17	2.56
MW-14	1/27-1/28/99	9:44	16:05	8:30	1366	381	985	1.11	29.8	4.42
MW-16	3/3-3/4/99	16:45	16:54	8:42	954	8.6	945	Rising Head Test	27	0.0
MW-17	1/19-1/19/99	13:07	16:13	17:51	284	186	98	2.1	7.2	0.37
MW-19	7/8-7/8/97	9:19	10:10	10:10	51	51	0	1.93	3.64	-
MW-20	7/9-7/9/97	15:43	16:39	19:19	216	56	160	0.671	53.55	52.39
MW-21	7/10-7/10/97	10:21	10:21	12:21	120	0	120	Instantaneous	4.01	2.29
MW-22	1/21-1/21/99	10:06	15:30	17:00	414	324	90	4.83	1.19	0.27
MW-24	7/9-7/9/97	8:30	10:12	10:29	119	102	17	Stepped	2.75	-
MW-25	7/9-7/9/97	11:25	11:33	13:26	121	8	113	0.438	12.83	3.67

(a) MW-8: 0-70 min; $Q \approx 0.59$ gpm First Step
70-149 min; $Q = 0.22$ gpm Second Step
Weighted Average = 0.39 gpm

Table A-2 Borehole Completion Information

Monitoring Well	Total Well Depth (feet bgs)	Top of Open Interval (feet bgs)	Borehole Diameter (feet)	Casing Diameter (feet)	Pump Type Used in Testing	Depth to Water at Beginning of Pumping (feet btc)	Depth to Water at End of Pumping (feet btc)
MW-1	235	205	0.67	0.33	Portable	7.11	55.14
MW-1A[1]	80	37	0.67	0.33	Portable	52.1	60.97
MW-1A[2]	80	37	0.67	0.33	Portable	51.4	64.4
MW-1A[3]	80	37	0.67	0.33	Portable	52.72	62.5
MW-2	235	205	0.67	0.33	Dedicated	31.16	94
MW-3	150	125	0.67	0.33	Dedicated	4.08	99.7
MW-4	225	170	0.67	0.33	Dedicated	164.6	186.6
MW-4A	129	106	0.67	0.33	Portable	116.6	118.4
MW-5	255	225	0.67	0.33	Dedicated	199.47	230.21
MW-5A	130	97	0.67	0.33	Portable	116.0	119.3
MW-8	65	44	0.67	0.33	Portable	22.88	49.82
MW-10	40	8	0.67	0.33	Dedicated	17.41	35.57
MW-12	75	54	0.67	0.33	Dedicated	53.87	65.04
MW-14	120	87	0.67	0.33	Portable	52.2	82
MW-16	77	40	0.67	0.33	Portable	46	73
MW-17	28.5	2.5	0.67	0.33	Portable	8.77	15.6
MW-19	28	13.3	0.67	0.33	Portable	19.78	23.42
MW-20	125	73.6	0.50	0.17	Portable	54.87	108.42
MW-21	90	54.8	0.50	0.17	Portable	85.34	89.35
MW-22	40	12	0.67	0.33	Portable	20.0	21.19
MW-24	30	7	0.50	0.17	Portable	19.15	21.9
MW-25	25	4	0.50	0.17	Portable	9.72	22.55

[1] Test date from July 1997
[2] Test data from January 1999
[3] Test data from March 1999
bgs = below ground surface
btc = below to of casing

Table A-3 Results of Field Measurements

Sample Identification	Date	Parameter	Value	Units	Comments
MW-1	01-Jul-97	Depth to Water	7.11	feet	-
MW-1A	03-Jul-97	Depth to Water	52.1	feet	-
MW-2	05-Jul-97	Depth to Water	31.16	feet	-
MW-3	05-Jul-97	Depth to Water	4.08	feet	-
MW-5	07-Jul-97	Depth to Water	199.47	feet	-
MW-8	02-Jul-97	Depth to Water	22.88	feet	-
MW-10	04-Jul-97	Depth to Water	17.41	feet	-
MW-12	06-Jul-97	Depth to Water	53.87	feet	-
MW-19	08-Jul-97	Depth to Water	19.78	feet	-
MW-20	09-Jul-97	Depth to Water	54.87	feet	-
MW-21	10-Jul-97	Depth to Water	85.34	feet	-
MW-24	09-Jul-97	Depth to Water	19.15	feet	-
MW-25	09-Jul-97	Depth to Water	9.72	feet	-
MW-4	08-Jul-97	Depth to Water	164.64	feet	-
MW-1A	03-Jul-97	Electrical Conductivity	850	µmhos/cm	T = 17.8 °C
MW-2	05-Jul-97	Electrical Conductivity	1509	µmhos/cm	T = 20.2 °C
MW-3	05-Jul-97	Electrical Conductivity	1227	µmhos/cm	T = 17.2 °C
MW-5	07-Jul-97	Electrical Conductivity	-	µmhos/cm	Sample Spilled
MW-8	02-Jul-97	Electrical Conductivity	2660	µmhos/cm	T = 21.9 °C
MW-10	04-Jul-97	Electrical Conductivity	1115	µmhos/cm	T = 21.3 °C
MW-12	06-Jul-97	Electrical Conductivity	1771	µmhos/cm	T = 19.6 °C
MW-19	08-Jul-97	Electrical Conductivity	2540	µmhos/cm	T = 15.9 °C
MW-20	09-Jul-97	Electrical Conductivity	1856	µmhos/cm	T = 18.2 °C
MW-21	10-Jul-97	Electrical Conductivity	1840	µmhos/cm	T = 18.0 °C
MW-24	09-Jul-97	Electrical Conductivity	1805	µmhos/cm	T = 17.1 °C
MW-25	09-Jul-97	Electrical Conductivity	3330	µmhos/cm	T = 28.4 °C
MW-4	08-Jul-97	Electrical Conductivity	862	µmhos/cm	T = 20.7 °C
MW-1A	03-Jul-97	pH (field)	6.86	-	T = 18.5 °C
MW-2	05-Jul-97	pH (field)	7.74	-	T = 20.2 °C
MW-3	05-Jul-97	pH (field)	7.47	-	T = 15.9 °C
MW-5	07-Jul-97	pH (field)	6.84	-	T=19.4 °C
MW-8	02-Jul-97	pH (field)	6.7	-	T = 22.1 °C
MW-10	04-Jul-97	pH (field)	6.97	-	T = 22.2 °C
MW-12	06-Jul-97	pH (field)	7.23	-	T = 19.8 °C
MW-19	08-Jul-97	pH (field)	6.63	-	T = 16.4 °C
MW-20	09-Jul-97	pH (field)	7	-	T = 18.9 °C
MW-21	10-Jul-97	pH (field)	5.87	-	T = 18.4 °C
MW-24	09-Jul-97	pH (field)	5.27	-	T = 17.7 °C
MW-25	09-Jul-97	pH (field)	5.94	-	T = 28.3 °C
MW-4	08-Jul-97	pH (field)	7.41	-	T = 20.2 °C

Table A-4 Aquifer Hydraulic Property Estimates from the Jacob Method

Monitoring Well	Q gpm	T feet^2/day	Aquifer thickness (feet)	K feet/day	K cm/s
MW-1	0.36	2.7×10^{-1}	210.97	1.3×10^{-3}	4.5×10^{-7}
MW-1A[1]	0.89	9.80	23.57	4.2×10^{-1}	1.5×10^{-4}
MW-1A[2]	1.2	6.33	23.6	2.7×10^{-1}	9.5×10^{-5}
MW-1A[3]	0.79	7.0 - 11.2	24	$(2.9 - 4.7) \times 10^{-1}$	$(1.0 - 1.7) \times 10^{-4}$
MW-2	0.72	8.2×10^{-1}	148.92	5.5×10^{-3}	1.95×10^{-6}
MW-5	1.9	3.25	40.16	8.1×10^{-2}	2.85×10^{-5}
MW-8	0.59	9.95×10^{-1}	28.12	3.5×10^{-2}	1.25×10^{-5}
MW-12	0.35	2.90	15.54	1.9×10^{-1}	6.6×10^{-5}
MW-14	1.11	3.52	54.4	6.5×10^{-2}	2.3×10^{-5}
MW-17	2.1	23.0	19.2	1.2	4.2×10^{-4}
MW-19	1.89	29.0	6.40	4.54	1.6×10^{-3}
MW-22	4.83	325	30.9	10.5	3.7×10^{-3}

[1] Test data from July 1997

[2] Test data from January 1999

[3] Test data from March 1999. A possible recharging boundary condition was noted in the drawdown data at late-times as evident by the change in slope of the straight-line portion A range in conductivity is reported.

Table A-5 Aquifer Hydraulic Properties Estimated from the Theis Recovery Method

Monitoring Well	T feet^2/day	Aquifer thickness (feet)	K feet/day	K cm/s
MW-1	0.30	210.97	1.4×10^{-3}	5.0×10^{-7}
MW-1A[1]	5.10	26.95	1.9×10^{-1}	6.7×10^{-5}
MW-1A[2]	3.92	23.6	1.7×10^{-1}	5.7×10^{-5}
MW-1A[3]	4.36	24	1.8×10^{-1}	6.4×10^{-5}
MW-2	1.1	149.0	7.4×10^{-3}	2.6×10^{-6}
MW-3	5.1	78.5	6.5×10^{-3}	2.3×10^{-6}
MW-8	0.55	28.12	1.95×10^{-2}	6.9×10^{-6}
MW-14	5.13	54.4	9.4×10^{-2}	3.3×10^{-5}
MW-17	44.4	19.2	2.32	8.2×10^{-4}
MW-22	398	30.9	12.9	4.6×10^{-3}

[1] Test data from July 1997

[2] Test data from January 1999

[3] Test data from March 1999

Table A-6 Aquifer Hydraulic Properties Estimated from Specific Capacity Method

Monitoring Well	Q gpm	s feet	T = Q/s feet^2/day	b= $\frac{hw + ho}{2}$ feet	K feet/day	K cm/s
MW-8	0.23	27.8	1.58	28.12	2.73 x 10^{-2}	9.6 x 10^{-6}
MW-24	1.35	1.27	204.13	13.21	15.5	5.5 x 10^{-3}
MW-24	2.40	1.74	265.20	12.98	20.4	7.2 x 10^{-3}
MW-24	3.32	1.96	325.80	12.87	25.3	8.9 x 10^{-3}
MW-24	3.91	2.78	271.31	12.46	21.8	7.7 x 10^{-3}

Table A-7 Hydraulic Conductivity Estimated from Slug Test Analysis

Monitoring Well	C --	K feet/day	K cm/sec
MW-4A	2.3	4.4 x 10^{-2}	1.5 x 10^{-5}
MW-5A	2.3	1.1 x 10^{-2}	3.9 x 10^{-6}
MW-10	3.1	4.7 x 10^{-3}	1.6 x 10^{-6}
MW-16	5	3.0 x 10^{-2}	1.1 x 10^{-5}
MW-20	6.2	4.6 x 10^{-4}	1.6 x 10^{-7}
MW-21	1.7	2.1 x 10^{-2}	7.3 x 10^{-6}
MW-25	3.0	4.2 x 10^{-2}	1.5 x 10^{-5}

Table A-8 Aquifer Hydraulic Properties Estimated from Aquifer Test During 1996 Field Event

Monitoring Well	C	K feet/day	K cm/s	Method
MW-3	2.9	4.6 x 10^{-2}	1.6 x 10^{-5}	Hvorslev
MW-5	3	3.1 x 10^{-1}	1.1 x 10^{-4}	Hvorslev
Borehole-22	5	7.7 x 10^{-4}	2.7 x 10^{-7}	Hvorslev

Table A-9 Summary of Aquifer Testing Analyses

Monitoring Well	Well Location	Jacob Analysis (cm/s)	Theis Recovery (cm/s)	Specific Capacity (cm/s)	Slug Test (cm/s)	Probable Geologic Formation Associated with Test Interval
MW-1	W. of Mine Office	4.5×10^{-7}	5.0×10^{-7}	-	-	Colorado Formation
MW-1A[1]	N. of Hanover Mountain	1.5×10^{-4}	6.7×10^{-5}	-	-	Colorado Formation
MW-1A[2]	N. of Hanover Mountain	9.5×10^{-5}	5.7×10^{-5}	-	-	Colorado Formation
MW-1A[3]	N. of Hanover Mountain	1.6×10^{-4}	6.4×10^{-5}	-	-	Colorado Formation
MW-2	S. of Tailings	2.0×10^{-6}	2.6×10^{-6}	-	-	Hanover-Fierro Stock
MW-3	S. of MW-2	-	-	-	1.6×10^{-5}	Hanover-Fierro Stock
MW-4	S. of South Waste Rock Dump	-	-	-	-	Montoya-Fusselman Dolomite
MW-4A		-	-	-	1.5×10^{-5}	Syenodiorite porphyry
MW-5	S. of West Waste Rock Dump	2.9×10^{-5}	-	-	-	Lake Valley Limestone
MW-5A		-	-	-	3.9×10^{-6}	Barringer fault in Colorado fm
MW-8	W. of Fan Discharge	1.3×10^{-5}	6.9×10^{-6}	9.61×10^{-6}	-	Hanover-Fierro Stock
MW-10	E. of Church	-	-	-	1.6×10^{-6}	Hanover-Fierro Stock and Alluvium
MW-12	E. of South Waste Rock Dump	6.6×10^{-5}	-	-	-	Hanover-Fierro Stock
MW-14		2.3×10^{-5}	3.3×10^{-5}	-	-	Hanover-Fierro Stock
MW-16		-	-	-	1.1×10^{-5}	Hornblende quartz diorite
MW-17		4.2×10^{-4}	8.2×10^{-4}	-		Hanover-Fierro Stock

Table A-9 (continued) Summary of Aquifer Testing Analyses

Monitoring Well	Well Location	Jacob Analysis (cm/s)	Theis Recovery (cm/s)	Specific Capacity (cm/s)	Slug Test (cm/s)	Best Estimate (cm/s)	Probable Geologic Formation Associated with Test Interval
MW-19	SE. of Rubber Pond	1.6×10^{-3}	-	-	-	-	Alluvium
MW-20	E. West Waste Rock Dump	-	-	-	1.6×10^{-7}	-	Percha Shale
MW-21	Pierson-Barnes Area	-	-	-	7.3×10^{-6}	-	Upper Lake Valley Formation
MW-22		3.7×10^{-3}	4.6×10^{-3}	-	-		Percha shale & unknown diorite
MW-24	E. of MW-2	-	-	7.3×10^{-3}	-	-	Alluvium
MW-25	S. of Magnetite Dam	-	-	-	1.5×10^{-5}	-	Alluvium and Hanover-Fierro Stock
PP-01	NE. Hanover Mountain	-	-	1×10^{-5}	-	-	Colorado Formation
PP-02	NW. Hanover Mountain	-	-	7×10^{-7}	-	-	Colorado Formation
PP-05	S. Hanover Mountain	-	-	1.5×10^{-5}	-	-	Colorado Formation
PP-05	S. Hanover Mountain	-	-	4.2×10^{-5}	-	-	Beartooth Quartzite
Borehole-22	NW. Tailings Reclaim Pond	-	-	-	2.7×10^{-7}	-	Syenodiorite Sill
WTH-1		-	5×10^{-5}	-	-	-	Various
WTH-2		-	$1.6\text{-}16 \times 10^{-5}$	-	-	-	Various
WTH-6		-	$4.7\text{-}5.5 \times 10^{-5}$	-	-	-	Various
PW-1[4]		-	-	-	-	1×10^{-5}	Lake Valley Limestone

[1] Test data from July 1997

[2] Test data from January 1999

[3] Test data from March 1999

[4] Based on Schafer Associates (1995a)

Table A-10. Summary Results from Specific Capacity Analysis on Exploration Borehole Data.

Formation	Minimum Hydraulic Conductivity (cm/sec)	Maximum Hydraulic Conductivity (cm/sec)	Geometric Mean Hydraulic Conductivity (cm/sec)	Number of Measurements
Cs	-	-	3.87×10^{-5}	1
Percha Shale	-	-	3.18×10^{-5}	1
Intrusive	-	-	1.87×10^{-5}	1
Fault in Colorado Fm	-	-	2.54×10^{-5}	1
Beartooth Fm	1.21×10^{-6}	2.57×10^{-5}	4.60×10^{-6}	3
Colorado Fm	1.80×10^{-5}	1.67×10^{-4}	5.88×10^{-5}	6
El Paso Fm	1.35×10^{-5}	2.36×10^{-5}	1.66×10^{-5}	4
Oswaldo Fm	4.24×10^{-6}	7.69×10^{-6}	5.71×10^{-6}	2
Syrena Fm	9.47×10^{-7}	9.93×10^{-5}	1.52×10^{-5}	17
Montoya - Fusselman Fm	1.94×10^{-5}	4.42×10^{-5}	2.69×10^{-5}	3
Continental Breccia - Colorado Fm	-	-	7.02×10^{-5}	1
Hanover Fierro Stock - Fusselman Fm	-	-	2.79×10^{-4}	1
Hanover Fierro Stock	-	-	8.09×10^{-5}	1
Overall	9.47×10^{-7}	2.79×10^{-4}	2.11×10^{-5}	45

BASELINE CHARACTERIZATION OF THE HYDROLOGY, GEOLOGY, AND GEOCHEMISTRY OF THE PROPOSED CONTINENTAL MINE EXPANSION PROJECT

APPENDICES A-D

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APPENDIX A

SHORT-TERM AQUIFER TESTING, CONTINENTAL MINE, GRANT COUNTY, NEW MEXICO

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December 1999

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APPENDIX A
SHORT-TERM AQUIFER TESTING,
CONTINENTAL MINE,
GRANT COUNTY, NEW MEXICO

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1.0 INTRODUCTION

With technical input provided by Shepherd Miller, Inc. (SMI), Cobre Mining Company, Inc. (Cobre) conducted short-term aquifer pumping tests on over 20 monitoring wells located at the Continental Mine site (see Figure A-1). The main objective of the short-term aquifer testing program was to estimate the hydraulic properties of different geologic units in which the wells are completed. SMI and others will use these estimated properties to assess potential impacts from the proposed Continental Mine expansion. This document describes the short-term aquifer testing and analysis procedures, which Cobre may use in the future to perform additional short-term aquifer tests.

2.0 DESCRIPTION OF FIELD WORK

2.1 Work Plan

Two series of short-term aquifer tests were performed on 21 wells at the Continental Mine site. The first series of tests were performed on 14 monitoring wells according to the 1997 SMI work plan (SMI, 1997a). SMI conducted these tests in conjunction with the Cobre third-quarter water-quality sampling event beginning the first week in July 1997. The second series of tests were performed on 6 monitoring wells and one water test hole in accordance with the 1998 SMI scope of work (SMI, 1998). The second series was performed by Daniel B. Stephens & Associates (DBS&A) on the monitor wells installed during summer 1998 as part of State requirements to provide additional potentiometric surface and water quality information, and to provide additional hydraulic conductivity data using a reasonably rapid, and accurate method.

In general, the aquifer tests consisted of pumping the well for 2 to 4 hours at a constant rate while monitoring the associated drawdown over time. The pumping rate was selected or adjusted so that drawdown stabilized in a short period of time (specific capacity test). Hydraulic recovery (residual drawdown) was monitored after pumping was terminated. The general procedure for this type of testing was as follows:

- Install sampling pump in the monitoring well (if pump was not previously installed).
- Measure the water level with an electric probe and place an electric pressure transducer (connected to a data logger) in the well. If a pressure transducer and data logger were unavailable, hand measurements from a water level probe were used.
- Monitor water level long enough to verify that static conditions existed in the well.
- Begin pumping and quickly establish a constant pumping rate by either:
    - Adjusting a valve on the pump discharge line.

- Adjusting the pump power supply.
- Recirculating some of the pumped water back into the well (re-circulation tank method).

- Maintain pumping for 2 to 4 hours. Monitor the water level drawdown in the well.
- Shut off the pump and measure recovery for the next 2 to 4 hours or until 95 percent recovery was achieved (whichever comes first).
- Download the data from a data logger or field notebook (if measurements were performed by hand) into an electronic spreadsheet for later evaluation.

The above procedure was applied to the majority of monitoring wells. However, seven wells (Table A-7) had low yields and significant well-bore storage, which required a modification of the above procedure to produce a rising-head slug test. Instead of pumping for 2 to 4 hours, the pumping duration was reduced to quickly purge the well-bore storage. After a sufficient well-bore storage volume was removed, the pump was shut off and recovery measured. The procedure was modified for longer pumping times at monitoring well MW-1A (12 hrs) and water test hole TH-98-5 (24 hrs).

2.2 Work Performed

Using the above general procedures, 20 monitoring wells were tested for hydraulic conductivity. Pumping of each well was accomplished with either a dedicated pump or a portable, variable speed, 2-inch-diameter pump (manufactured by Grundfos, Inc.). The speed control on the Grundfos pump controlled the flow rate from the well. On the wells with dedicated pumps, a valve on the discharge line controlled flow rates. Flow rates were measured periodically using a calibrated bucket and stop watch, and necessary adjustments were made. On wells with adequate access, both a recording pressure transducer and hand-operated water level probe were used to monitor the depth to water over time. Figure A-2 displays a typical field setup for a well with a dedicated pump.

Figures A-3 through A-12 display drawdown hydrographs and pumping rates versus time for the tests performed. Table A-1 reports the pumping start and stop times and the time-weighted-average pumping rates. Table A-2 provides completion information for each monitoring well. A summary of each test is provided below:

- MW-1. This aquifer test consisted of 251 minutes (4.2 hours) of pumping and 137 minutes (2.3 hours) of recovery. The discharge rate during the pumping period varied from 0.13 to 0.48 gallons per minute (gpm) with a time-weighted average of 0.36 gpm. Flow from well-bore storage (described in section) decreased to less than 10 percent of the total flow rate after 230 minutes (3.8 hours) and to less than 5 percent after 238 minutes (4.0 hours). The pumping rate varied due to the large pumping head, low flow rates, and worn pump parts (that is, the pump operated sporadically).

- MW-1A. Three tests were performed in MW-1A. The first test was conducted in July 1997. Due to a broken transducer cable, only hand measurements were available for this aquifer test. The test consisted of 98 minutes (1.6 hours) of pumping and 1,382 minutes (23 hours) of recovery. The pumping rate varied between 0.82 and 1.02 gpm, with a time-weighted average of 0.89 gpm. Well-bore storage accounted for less than 10 percent of the total flow rate after approximately 25 minutes of pumping and less than 1 percent after 90 minutes.

  The second test in MW-1A was conducted in January 1999. This aquifer test consisted of 236 minutes (3.9 hours) of pumping and 1,180 minutes (19.7 hours) of recovery. The discharge rate during the pumping period averaged 1.2 gpm. Well-bore storage accounted for only 7% of the flow during the time period analyzed.

  The third test in MW-1A was conducted in March 1999. This test consisted of 724 minutes (12.1 hours) of pumping and 2,280 minutes (38 hours) of recovery. The discharge rate averaged 0.79 gpm. The long-term nature of this test minimized the effects of wellbore storage.

- MW-2. This well contained a dedicated pump. The test consisted of 210 minutes (3.5 hours) of pumping and 1,480 minutes (24.7 hours) of recovery. The flow rate from the well was controlled by a ball valve installed on the outlet of the piping (see Figure A-2). The flow varied between 0.65 and 0.98 gpm, with a time-weighted average of 0.72 gpm. Well-bore storage accounted for less than 10 percent of the flow after 135 minutes of pumping and less than 5 percent after 200 minutes.

- MW-3. SMI previously estimated the hydraulic conductivity at this well based on recovery during a previous sampling event at Cobre. Therefore, the purpose of this test was to corroborate the previous results. The test had a pumping period of 6 minutes at a rate of 13 gpm, and a recovery time of 62 minutes. This test was essentially, a rising-head slug test.

- MW-4. Difficulties in water level probe measurements were encountered during testing of this monitoring well. Only early pumping time data were collected for this test and during this period, drawdown was dominated by well-bore storage. Therefore, no analyzable data exist from this test.

- MW-4A. A rising-head slug test was conducted in February 1999. Using a 2-inch Grunfos Readiflo2 submersible pump, the well-bore storage was rapidly pumped to maximize aquifer hydraulic stress. Maximum drawdown during this test was 1.8 feet. The well covered for 350 minutes after pumping termination.

- MW-5. SMI performed a recovery test on this well during a 1996 sampling event. The purpose of this test (1997) was to corroborate the 1996 results. The test consisted of 120 minutes of pumping at flow rates between 0.82 and 1.3 gpm, with a time-weighted average of 1.19 gpm. The subsequent recovery period was not monitored. After 105 minutes of pumping, well-bore storage accounted for less than 5 percent of the total flow.

- MW-5A. A rising-head slug test was conducted during February 1999. Using a 2-inch Grunfos Readiflo2 submersible pump, the well-bore storage was rapidly pumped to maximize the hydraulic stress to the aquifer. Maximum drawdown during this test was 3.3 feet. Recovery data were recorded for 1,275 minutes (21.3 hours) after pumping termination.

- MW-8. The pumping period for MW-8 was approximately 149 minutes (2.5 hours), with a decreasing step in the flow rate approximately 70 minutes (1.2 hours) after pumping began. Water level recovery was monitored for approximately 140 minutes. The first pumping period had:

    - A duration of 70 minutes

    - A time-weighted-average pumping rate of 0.59 gpm

    - A maximum pumping rate of 1.0 gpm

    - A minimum pumping rate of 0.45 gpm

    - 26 percent of flow was derived from well-bore storage.

The second pumping period is defined by:

- A duration of 79 minutes
- A time-weighted-average pumping rate of 0.22 gpm
- A maximum pumping rate of 0.29 gpm
- A minimum pumping rate of 0.19 gpm
- No well-bore storage effects for most of the period.

- MW-10. The pumping period of this test (17 minutes) was relatively short compared to the 255 minutes of recovery time. Also, well-bore storage accounted for more than 14 percent of the flow rate at the end of pumping. Therefore, this test was essentially a rising-head slug test.

- MW-12. This aquifer test lasted for approximately 242 minutes (4.0 hours). A ball valve regulated the flow rate from the dedicated pump and the flow rates ranged between 0.18 and 2.4 gpm, with a time-weighted average of 0.35 gpm. Well-bore storage accounted for approximately 15 to 20 percent of the total flow rate at the end of the 81 minute pumping period.

- MW-14. This single borehole pumping test was performed during January 1999. The test lasted for 1,366 minutes (22.8 hours). An initial pumping rate of 2.5 gpm was used to remove most well-bore storage. After 10 minutes, the average pumping rate was reduced to 1.11 gpm. Well-bore storage accounted for less than 8% of the flow for the time period analyzed.

- MW-16. A rising-head test was performed in March 1999. The well-bore storage volume was quickly purged using a 2-inch Grunfos submersible pump for a total drawdown of 27 feet. The recovery data were recorded for 945 minutes (15.8 hours).

- MW-17. This single borehole pumping test was performed during January 1999. The test lasted for approximately 284 minutes (4.7 hours). The average pumping rate was 2.1 gpm. Well-bore storage accounted for less than 2% of the flow for the time period analyzed. Maximum drawdown was 7.15 feet. Recovery data were recorded for 95 minutes following pump shut off.

- MW-19. This aquifer test consisted of a pumping period of only 50 minutes because additional time was not required for water quality sampling purposes. The pumping rate ranged from 1.71 to 1.98 gpm with a time-weighted average of 1.89 gpm. After 3 minutes of pumping, well-bore storage accounted for less than 10 percent of the total flow. Recovery was not monitored because the check valve in the pump failed, causing water in the discharge pipe to siphon back into the well.

- MW-20. The pumping period for this aquifer test was 56 minutes and recovery was monitored for 160 minutes (2.7 hours). The pumping rate ranged from 0.24 to 1.89 gpm with a time-weighted average of 0.67 gpm. Well-bore storage accounted for most of the flow throughout the pumping period. Therefore, this test is treated as a rising-head slug test.

- MW-21. This aquifer test consisted of bailing the well dry over a short period of time and then measuring the recovery. It is considered to be a rising-head slug test.

- MW-22. A single borehole pumping test was performed during January 1999. The average pumping rate was 4.83 gpm over a duration of 324 minutes (5.4 hours). Maximum drawdown was 1.19 feet. Recovery data were recorded for 90 minutes. A residual drawdown of 0.27 feet remained after the recovery period. However, sufficient formation response was recorded to allow for test analysis.

- MW-24. This aquifer test consisted of several flow rate steps. The first step lasted approximately 40 minutes and had a time-weighted average pumping rate of 1.35 gpm. In the second step, the pumping rate was increased to 2.40 gpm for a duration of approximately 20 minutes. For the following 16 minutes, the time-weighted-average pumping rate was 3.32 gpm. The aquifer test ended after the final pumping rate was stepped up to 3.91 gpm for approximately 26 minutes. Throughout this test, well-bore storage did not constitute significant portion of the flow rate. Note that spikes in the measured drawdown curve (see Figure A-12) seem to correlate to the passage of a large dump truck on a nearby road during the test.

- MW-25. This well was pumped dry after 7 minutes. The pump was shut off and recovery was monitored for approximately 110 minutes. Therefore, it was treated as a rising-head slug test.

In addition to the aquifer tests performed, SMI also collected water quality samples and measured field parameters for the Cobre third-quarter 1997 sampling event. Table A-3 summarizes the field measurements obtained during this sampling event

3.0 DATA ANALYSIS OF SHORT-TERM AQUIFER TESTS

3.1 Assumptions and Approach

The main objective of the short-term aquifer testing program was to obtain reasonable estimates of the hydraulic conductivity of water-bearing formations at the Continental Mine site. Given this objective, several simplifying assumptions were used in analyzing the aquifer test data:

1. Ground water flow to the wells is horizontal and vertical components of flow are negligible

2. The bottom of the well screen represents the bottom of the aquifer

3. Flow to the well is radial and the aquifer is of "seemingly" infinite lateral extent

4. The aquifer is homogeneous and isotropic

5. The drainable porosity of the well sandpack material is 0.25

6. Well losses are negligible

7. Due to water table drawdown near the well, the appropriate aquifer thickness is given by:

$$b = \frac{h_w + h_i}{2}$$

where:

b = The representative aquifer thickness

h_w = The height of water in the well at the end of the test

h_i = The initial height of water in the well.

Assumptions 1 and 2 are valid because the screen length is very large compared to the well diameter. Assumptions 2 and 3 are appropriate due to the short-term nature of the aquifer tests performed at Cobre. Assumption 5 is based on porosity values cited in the literature for a clean sand (McWhorter and Sunada [1977], Freeze and Cherry [1979], and Spitz and Moreno [1996]). The well loss assumption applies only to slug test analyses and storage coefficient estimates (multiple-hole tests only); it does not affect transmissivity estimates made with the Jacob or Theis-recovery method of analysis. Assumption 7 is based on the Dupuit-Forcheimer assumption and is explained in McWhorter and Sunada (1977).

Calculations indicate the well-bore storage effects were minimal at later times during the pumping tests. Analytical equations, which neglect well bore storage, were applied only to this late-time data.

3.2 Analysis

Based on the assumptions above, SMI used methods to analyze aquifer tests that were based, on the Theis solution of radial flow to a well in an infinite aquifer:

$$s = \frac{Q}{4\pi T} W(u) \tag{1}$$

where:

s = drawdown at an observation point (L)

Q = pumping rate of the well (L^3/T)

T = aquifer transmissivity (L^2/T)

W(u) = Theis well function

u = variable defined by:

$$u = \frac{r^2 S}{4Tt} \tag{2}$$

where:

r = radius of interest (L)

S = storage coefficient of the aquifer

t = time (T)

3.2.1 Pumping Drawdown Analysis

For small values of u (from a practical standpoint $u \leq 0.1$), the well function can be approximated by:

$$W(u) = \ln\left(\frac{2.246Tt}{Sr^2}\right) \quad (3)$$

Thus for $t > \frac{Sr^2}{0.4T}$, the Theis solution can be written as:

$$s = \frac{2.303Q}{4\pi T}\log\left(\frac{2.246Tt}{Sr^2}\right) \quad (4)$$

This late-time approximation of the Theis equation plots as a straight line on a semi-log plot of log (t) versus s.

Thus, if drawdown (s) data are plotted against log time (t) on semi-log paper, and the pumping test has been performed for an adequate amount of time, the data should approximate a straight line. Through either a linear regression analysis or visual fitting of a straight line to this data, the aquifer transmissivity can then be calculated from the following equation:

$$T = \frac{2.303\ Q}{4\pi\ \Delta s} \quad (5)$$

where:

Δs is the change in drawdown over 1 log cycle of time. Figure A-13 shows an example of this method.

By definition, the transmissivity is a product of the aquifer thickness (b) and the hydraulic conductivity (K). Thus, the hydraulic conductivity can be estimated by:

$$K = \frac{T}{b} \quad (6)$$

McWhorter and Sunada (1977) and Dawson and Istok (1991) describe this procedure, called the Jacob method, in more detail. This type of analysis was applicable to seven tests performed at Cobre. Figures A-13 through A-24 and Table A-4 display the semilog plots and results of this method used on the Cobre wells.

3.2.2 Drawdown-Recovery Analysis

Using superposition and the semi-log approximation, the Theis solution may also be used to analyze the residual drawdown during the recovery portion of a pumping-drawdown test. The late-time approximation for a well recovering from pumping can be written as (McWhorter and Sunada, 1977):

$$s_r = \frac{2.303}{4\pi T} \log\left(\frac{t}{t'}\right) \tag{7}$$

where:

t is the time since pumping began and t' is the time after pumping stopped.

Similar to the Jacob Method, a plot of later time residual drawdown (s_r) data versus $\log\left(\frac{t}{t'}\right)$ on semi-log paper should produce a straight line. For an ideal confined aquifer without boundaries, the semi-log line should project to residual drawdown equals 0 at $\log\left(\frac{t}{t'}\right)$ equals 1 (which represents infinite recovery time). Transmissivity can be computed using Equation 5, where Δs is the change in residual drawdown per log cycle of $\left(\frac{t}{t'}\right)$ on the semi-log recovery plot. This procedure is commonly referred to as the Theis Recovery Method. Figure A-25 contains an example of this method. Table A-5 summarizes the results obtained from the analyses shown on Figures A-25 through A-33.

3.2.3 Wellbore Storage Effects

To estimate the effects of wellbore storage, SMI calculated the flow rate attributable to the volumetric rate change of water stored in the well bore and compared it to the total flow (pumping) rate. The volumetric rate change of well bore storage was calculated from:

$$Q = A\frac{d_{sw}}{dt} \qquad (8)$$

where:

Q_w= flowrate associated with drawdown in the well (decrease in wellbore storage)

A= area of the wellbore (defined in equations 12 and 13 below)

3.2.4 Specific Capacity Analysis

McWhorter and Sunada (1977) define specific capacity as "...the discharge per unit drawdown in an aquifer." Using specific capacity to estimate aquifer transmissivity is most applicable in an aquifer test where drawdowns have approximately stabilized. Well MW-24 reached a approximate-steady state at four different pumping rates. Well MW-8 also reached a approximate-steady state in the latter portion of the drawdown period. For horizontal, steady state flow, the discharge rate from a well is given by:

$$Q = \frac{2\pi T s_w}{F} \qquad (9)$$

where:

s_w = drawdown at the well face

F = shape factor (typical values range between 5.5 and 6.5)

Assuming as a first approximation $F \cong 2\pi$, then:

$$T \cong \frac{Q}{s_w} \tag{10}$$

The results of the specific-capacity analyses for monitoring wells MW-24 and MW-8, are shown in Table A-6.

3.2.5 Slug Test Analysis

For a rising-head slug test, water is "rapidly" removed from the well. Water level recovery is then monitored over time. Some of the wells at Cobre exhibited low hydraulic conductivities and purging the well with a pump, even at a low flow rate, was similar to a slug test. Hvorslev (1952) proposed the following equation for guasi-steady-state recovery in a well (see Dawson and Istok [1991] for a full derivation):

$$Q = \frac{2\pi T\, s_w}{F} = -A\frac{ds_w}{dt} \tag{11}$$

where:

L = screened interval

s_w = drawdown in the well

F = dimensionless shape factor

A = horizontal cross-sectional area of the well through which the free water surface is rising.

If the free water surface is within the well casing, area (A) is the cross-sectional area of the casing with diameter, d:

$$A = \frac{\pi}{4} d^2 \tag{12}$$

If the free water surface is within the screen/sandpack, A is the cross-sectional area of the screen and the surrounding sand is:

$$A = \frac{\pi}{4} d^2 + \phi \frac{\pi}{4}\left(D^2 - d^2\right) \tag{13}$$

where:

D is the borehole diameter

ϕ= drainable sandpack porosity.

Integrating over time, and solving for hydraulic conductivity (K) yields:

$$K = \frac{AF}{2\pi L\left(t_2 - t_1\right)} \ln\left(\frac{s_1}{s_2}\right) \tag{14}$$

Hydraulic conductivity (K) is calculated from

$$K = \frac{T}{L}$$

where:

L= the saturated length of the screened an/or sand packed interval

The shape factor is a dimensionless parameter that accounts for the geometry of the well and surrounding flow system. According to Dawson and Istok (1991), Bower and Rice developed an empirical relationship to estimate the shape factor. For the assumptions applied at Cobre, the relationship for the shape factor is:

$$F = \left\{ \frac{1.1}{\ln\left(l/r_w\right)} + \frac{C}{(l-d)/r_w} \right\}^{-1} \quad (15)$$

where:

C = a dimensionless coefficient (defined in Dawson and Istok, 1991)

l = distance from the initial water table elevation to the bottom of the screened interval

To analyze data from a slug test, the procedure is to plot the natural log of s_W as a function of time and fit straight line to the data. The hydraulic conductivity can be estimated from Equation 13, where (s_1, t_1) and (s_2, t_2) are any two points on a straight line fit to the data. An example is shown on Figure A-21. Table A-7 and Figures A-34 through A-43 show the results of ten slug test analyses at Cobre.

4.0 OTHER ESTIMATES OF HYDRAULIC PROPERTIES

4.1 Discussion of Alternative Methods to Estimating Aquifer Properties

During February 1996, SMI collected water quality samples at all of the Cobre existing wells. After well purging, recovery data were recorded for monitoring wells MW-3 and MW-5. SMI applied the simplifying assumptions stated earlier to generate Table A-8 and also Figures A-34 and A-42. The estimated hydraulic conductivities for monitoring wells MW-3 and MW-5 are 0.045 and 0.31 feet/day (1.6×10^{-5} and 1.1×10^{-4} cm/s), respectively.

During the summer of 1996, SMI drilled a borehole (Borehole 22) into a syenodiorite sill upgradient of the reclaim pond (see Figure A-1, upper left corner). Drilling to a depth of 85 feet initially indicated no water; however, after the borehole had set open overnight (21 hours), approximately 5 feet of water were measured in the borehole. The depth to water in the borehole 12 days later was measured at 36.2 feet. Assuming this is the static water level, and using depth to water measurements at 1, 2, 3, and 8 days, slug test analysis indicates that the permeability of the igneous sill is 7.7×10^{-4} feet/day (2.7×10^{-7}cm/s). Figure A-43 displays the results of this analysis.

During the drilling of boreholes for the pneumatic piezometer installation around Hanover Mountain (November 1996), SMI recorded depth to water and flow rates as a function of depth. Using the specific-capacity analysis procedure described previously, the estimated hydraulic conductivity ranges from 0.002 to 0.043 feet/day (7×10^{-7} to 1.5×10^{-5} cm/s) for piezometers completed in the Colorado Formation. The high end of the range was calculated from sandstone units in the Colorado Formation, while the low end of the range was associated with igneous intrusives and shale units in the Colorado Formation (SMI, 1997). PP-05 was drilled into the Beartooth Quartzite Formation beneath the Colorado Formation. Borehole flow rates and hydraulic heads encountered indicated that the transmissivity of the Beartooth Formation is on the order of 0.11 feet/day (4×10^{-5} cm/s).

4.2 Other Aquifer Testing

4.2.1 Pumping Well PW 1

Cobre contracted with Schafer and Associates (Schafer) in 1995 to investigate an on-site source of ground water for the Cobre expanding operations. Schafer (1995a) drilled six strategically spaced test holes around the mine site. During drilling, Schafer routinely performed airlift recovery tests to estimate the water-bearing capacity of the different formations encountered. As a result of their ground water investigation, Schafer (1995b) installed a 1,200-foot-deep well south and east of Humbolt Mountain (see well PW-1 on Figure A-1). Schafer performed a 72-hour step drawdown test on this well. They estimated the hydraulic conductivity of the Lake Valley Formation to range between 0.02 and 0.25 feet/day (7.1×10^{-6} and 8.8×10^{-5} cm/s). Note that these values correspond quite closely to results from the short-term tests on MW-5, which is completed in the same formation.

4.2.2 Cron Ranch Water Supply Wells

As a part of a water supply investigation for the Continental Mine Expansion, Hydro-Search (1996) performed an aquifer evaluation and summarized previous analysis of the Cron Ranch wells. The range of transmissivity values estimated for this area is 93.6 to 214 ft^2/day. Assuming a thickness of 375 feet, this range of transmissivity corresponds to an estimated hydraulic conductivity range of 0.25 to 0.57 feet/day (8.8×10^{-5} to 2.0×10^{-4} cm/s). Appendix B describes these and SMI's alternate interpretations of the testing data.

4.2.3 Water Test Hole TH-98-5

In 1998, Cobre initiated a study to develop a nearby water supply for the mine facilities (John Shomaker & Associates, 1999). During their investigation, John Shomaker & Associates performed a short-term aquifer test on well TH-98-5 to assess the water producing potential northeast of Hanover Mountain, near the Barringer Fault. At approximately 120 minutes into the test, a change in the slope of the time versus drawdown plot was encountered. This was attributed to a low permeability feature.

To test the possibility that the Barringer Fault is a low permeability feature, Cobre subsequently pumped and monitored drawdown in this test hole for 24 hours. The pump was shut off and recovery was monitored for approximately 38 hours. This test indicated that TH-98-5 was surrounded by low permeability features. Detailed discussion of this test is provided in Attachment A-1.

4.2.4 Estimates from Exploration Drillholes

During 1998 and the first part of 1999, Cobre drilled 117 exploration holes at the site. The drillers collected the following information: collar elevation, depth to first water encountered, total borehole depth, water production rates, and rock type. Ninety-six of the 117 holes drilled produced measurable amounts of water. Forty-five of these measurements were suitable for aquifer transmissivity estimation.

SMI used the specific-capacity analysis procedure described previously to estimate hydraulic conductivity for each borehole. To perform the specific capacity analysis, SMI assumed the following:

- A constant discharge rate from the borehole
- Drawdown in the borehole is static
- Drawdown is equal to pumping depth minus the depth to first water,
- The aquifer thickness is equal to the drill hole saturated thickness (that is, the total borehole depth minus depth to first water).

These specific capacity calculations resulted in a hydraulic conductivity range from $9.47x10^{-7}$ cm/sec to $2.79x10^{-4}$ cm/sec with a geometric mean of $2.11x10^{-5}$ cm/sec.

Table A-10 summarizes the specific capacity results from the exploration borehole data.

Figure A-44 shows the distributions of measured hydraulic conductivities (natural log-transformed) from the more conventional tests and the specific capacity analysis from the exploration borehole information. Statistical analyses (F-test and t-test) show that the variances and means of these natural-log-transformed populations are statistically identical at a confidence interval of 10%. Thus, a higher than normal degree of confidence can be placed in hydraulic conductivities calculated from the specific capacity analyses performed on the exploration borehole data.

5.0 SUMMARY

One objective of the work plan was to obtain site-specific hydrogeologic information on each of the geologic formations present at the Continental Mine site. The short-term aquifer tests provided a quick and acceptably accurate method to gain insight into these hydraulic properties. Table A-9 and A-10 display the estimated hydraulic conductivity for the various geologic units.

This document met the objective set forth in the work plan by providing:

- An estimate of the hydraulic properties of the geologic units associated with the Continental Mine and the planned expansion
- A guide to short-term aquifer testing that Cobre personnel may use in the future to estimate aquifer properties.

The estimates are consistent with those found in Trauger (1972). In addition, the testing results reaffirm the conceptual model presented in the 1997 Continental Mine Environmental Assessment (Bureau of Land Management, 1997). Cobre will use these aquifer properties to estimate the ground water inflow component of the water balances for the possible Continental and Hanover pit lakes.

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