MBMG OPEN-FILE REPORT 265

RESULTS OF FLOWING WELL TESTS IN THE EAGLE SANDSTONE, CENTRAL MONTANA: POTENTIAL IMPACTS OF WITHDRAWALS ON ARTESIAN PRESSURE

by

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ABSTRACT

The Eagle Sandstone forms an extensive aquifer underlying much of central Montana. The aquifer contains large quantities of good quality water under flowing artesian conditions. Constant head aquifer tests were conducted on three wells owned by the Bureau of Land Management (BLM). Aquifer characteristics for the Eagle Sandstone calculated from these tests include transmissivities ranging from 19.2 to 78 ft^2/day and storage coefficients ranging from 1 X 10^{-4} to 1 X 10^{-5}.

Measured losses of artesian pressure range from 42 feet at the Elevator Ridge well up to 74 feet at the Haines Ridge well over a period of continuous flows between 1981 and 1992. Significant additional declines of flow rate and head are predicted by projecting test results into the future. Data plots of time-drawdown and distance-drawdown were constructed based on aquifer characteristics calculated from the three tests. The plots clearly demonstrate the long-term advantages of adjusting flow rates at the wells. Reducing flow rates will significantly reduce drawdown in the vicinity of a flowing well. By simply partially shutting in flowing wells significant water pressures and water storage in the aquifer will be conserved. Eliminating excess flows by restricting water use to demonstrated beneficial uses will help maintain long-term artesian pressures and increase aquifer life.

Although well interference was not detected at the three tested wells, the potential for interference is strong, based on long-term predictions. Well interference will increase head losses, resulting in decreased production. It can be avoided or reduced by adequately separating water wells.

INTRODUCTION

Wells in the Eagle Sandstone provide a dependable supply of good quality water for a large area in central Montana (Figure 1). Reported Eagle Sandstone wells are plotted on Plate 1 and hydrogeologic data from these wells are listed in Table 1. The Bureau of Land Management (BLM) is particularly interested in wells located on federal land within this area. Many of the BLM wells are under flowing artesian conditions and supply water to stock and wildlife over large areas. Because of the remote location, several miles from electrical service, the artesian head is necessary to bring water to the surface and to move the water through extensive systems of pipelines to watering tanks and reservoirs. Losing flowing artesian conditions would greatly reduce the economic viability of current land uses in this part of Montana.

Purpose

Three flowing-well aquifer tests were conducted to determine the aquifer characteristics of the Eagle Sandstone in this area. Aquifer characteristics determined from aquifer tests were the transmissivity, storage coefficient, and boundary conditions. Transmissivity is the ability of an aquifer to transmit water and is defined as the rate of flow under a unit hydraulic gradient through a cross-section of unit width over the whole thickness of the aquifer (Kruseman and De Ridder, 1970). The storage coefficient is a dimensionless unit that is defined as the volume of water

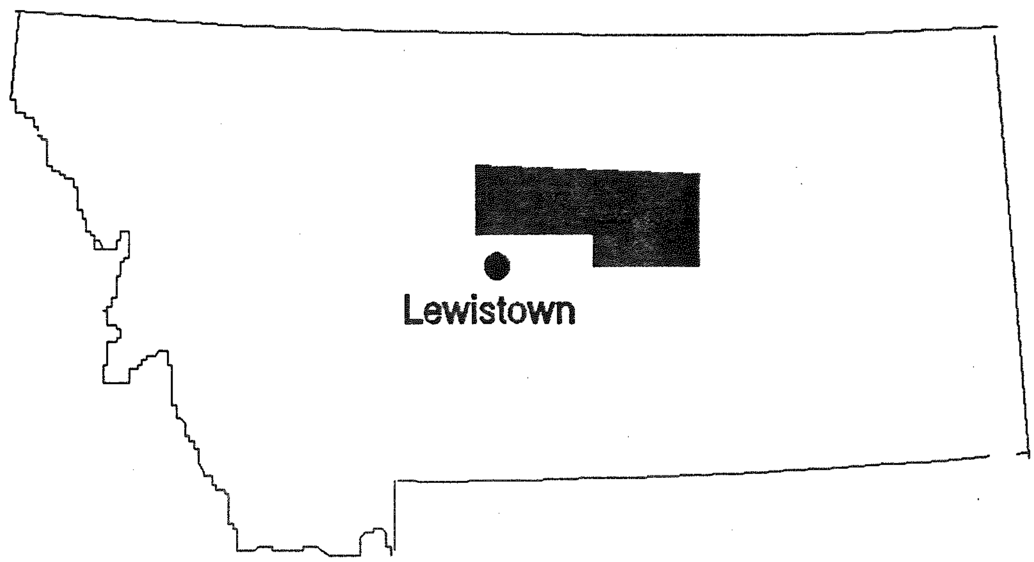


Figure 1. Location of the study area.

TABLE 1. REPORTED WELL DATA IN BLM EAGLE AQUIFER STUDY AREA CENTRAL MONTANA
(from MT.Bureau of Mines Ground-Water Information Center and USGS files)

WELL NUMBER	LOCATION		WELL OWNER	WELL DEPTH FT	STATIC WATER LEVEL FT *	WELL HEAD PRESSURE PSI	YEAR DRILLED	WELL YIELD GPM	LAND SURFACE ALTITUDE FEET	WATER USE	WATER LEVEL ELEVATION FEET
M:24491	12N 26E 02 BD		NEBRASKA FEEDING CO.	65			1961	10		STOCKWATER	3340.0
M:1798	12N 26E 11 AA	01	MLEKUSH TONY	200	110		1958		3450	S	
M:24501	12N 26E 12 CC		MLEKUSH TONY	130	55		1967	4		STOCKWATER	
M:24504	12N 26E 13 AAB		NEBRASKA FEEDING C.	140	20		1950	8		STOCKWATER	
M:24505	12N 26E 14 C		NEBRASKA FEEDING C.	185	104		1966	12		STOCKWATER	
M:24509	12N 26E 17 BC		NEBRASKA FEEDING CO.	175	30		1949	8		STOCKWATER	
M:24511	12N 26E 23 CD		NEBRASKA FEEDING CO.	145	40		1951	8		STOCKWATER	
M:1799	12N 27E 03 BBD	01	WIGGENS STANLEY	260	30		1970		3150	S	
M:24520	12N 27E 06 B		REDD MABEL	90			1914	25		STOCKWATER	
M:24521	12N 27E 06 C		REDD MABEL	100			1914	30		STOCKWATER	
M:24522	12N 27E 06 DCC		JOHNKE OTTO	102	30		1937	30		STOCKWATER	
M:24523	12N 27E 06 DCC		JOHNKE OTTO	103	30		1914	40		STOCKWATER	
M:24524	12N 27E 07 ABA		JOHNKE OTTO	103	30		1916	20		STOCKWATER	
M:24525	12N 27E 07 BDD		JOHNKE OTTO	56	30		1950	50		STOCKWATER	
M:24526	12N 27E 18 A		DINWIDDIE HORACE	129			1915	50		STOCKWATER	
M:24527	12N 27E 34 BDB	01	NEBRASKA FEEDING CO.	737	35		1952	15	3245	STOCKWATER	3210.0
M:24527A	12N 27E 34 BDB	01	NEB FEED CO	737	139		1952		3245	S	3106.0
M:24528	12N 28E 06 DADA	01	WIGGENS S E	670	90		1977		3390	S	3300.0
M:24529	12N 28E 09 AABC	01	HILL FLOYD	600	40		1949	20	3180	H	3140.0
M:1800	12N 28E 13 DB	01	HILL FLOYD	816	-42		1975	3	2970	S	3012.0
M:24534	12N 28E 28 DC	01	MUSSELSHELL RANCH CO	731	-28	12	1984	6		STOCKWATER	
M:1801	12N 28E 29 CCD	01	GOFFENA RANCH	627	-41		1961	10	3120	STOCKWATER	3215.0
M:25219	13N 27E 11 ABC		MT LAND COMMISSIONER	177	122		1988	6		STOCKWATER	
M:25220	13N 27E 11 BD		FRASER LAND & LIVEST	201	146		1969	4		STOCKWATER	
M:25221A	13N 27E 14 ACC	01	FRASER	300	122		1969	4	3150	STOCKWATER	3028.0
M:25222	13N 27E 18 AC		FRASER LAND AND LIVE				0	35		STOCKWATER	
M:125178	13N 27E 33	01	WIGGINS STANLEY	50	20		1961	10		STOCKWATER	
M:25223	13N 27E 33 BBB		WIGGINS STANLEY	120	50		1964	75		DOMESTIC	
M:25224	13N 28E 03 CDDC	01	KIEHL W J	600	360		1979		3120		2760.0
M:25225	13N 28E 17 BA		BETHEL COLLEGE				1983		3050	UNKNOWN	
M:25226	13N 28E 31 CCD	01	FRASER	765	159		1970		3290	S	3131.0
M:25977	14N 27E 02 BC		GERSHMEL GARY	198	154		1966	7		STOCKWATER	
M:25978	14N 27E 02 CCB		ALLEN CLAUDE	100	40		1958	50		STOCKWATER	
M:25979	14N 27E 03 CA		BRATTEN WAYNE	97	40		1975	10		STOCKWATER	
M:25980	14N 27E 03 DA		ALLEN CHARLES	112	44		1965	21		STOCKWATER	
M:25981	14N 27E 04 AB		RIGGS OLEO	115	70		1965	10		STOCKWATER	
M:25994	14N 27E 06		BOLSTAD HAROLD	29	22		1979	10		DOMESTIC	

* Static water level: minus sign means feet above ground surface (flowing wells).

Table 1. (continued)

WELL NUMBER	LOCATION	WELL OWNER	WELL DEPTH FT	STATIC WATER LEVEL FT *	WELL HEAD PRESSURE PSI	YEAR DRILLED	WELL YIELD GPM	LAND SURFACE ALTITUDE FEET	WATER USE	WATER LEVEL ELEVATION FEET
M:26000	14N 27E 08 AC	ST OF MT CONS BOARD	95			1935	10		PUBLIC WATER SUPPLY	
M:26001	14N 27E 11 A	GERSHMEL MERLIN	61	15		1957	10		STOCKWATER	
M:26002	14N 27E 11 D	GERSHMEL MERLIN	305	15		1961	3		STOCKWATER	
M:26003	14N 27E 12 B	BOHN RAY	72	40		1957	100		STOCKWATER	
M:26004	14N 27E 14 CD	BOHN RAY	287	164		1958	3		STOCKWATER	
M:26005	14N 27E 17 BD	BRATTEN WAYNE	122	68		1958	4		STOCKWATER	
M:26007	14N 27E 23 AC	PETAJA GORDON	225	150		1958	6		STOCKWATER	
M:26011	14N 28E 02 CCA	SOLF LEO	125			1973	5		STOCKWATER	
M:26012	14N 28E 03	SAYLOR C.R.	125		25	1960	110		STOCKWATER	
M:26013	14N 28E 03 BA	GERSHMEL GARY	152		4	1966	25		STOCKWATER	
M:26015	14N 28E 03 DD	SOLF JOSEPH	140			1956	4		STOCKWATER	
M:26014	14N 28E 03 DD	SOLF JOSEPH	182		2	1958	75		DOMESTIC	
M:26016	14N 28E 04 BB	KINDT RAYMOND	180			1961	35		STOCKWATER	
M:26017	14N 28E 05 BB	SUNDAKER T.N.	151		1	1961	60		STOCKWATER	
M:26018	14N 28E 05 CB	SUNDAKER T.N.	145			1961	60		STOCKWATER	
M:26020	14N 28E 06	BOHN JERRY	125	2		1973	35		STOCKWATER	
M:26019	14N 28E 06	POULTON J AND BOHN A	53	4		1957	45		STOCKWATER	
M:26021	14N 28E 08 B	POULTON JIM	260	50		1961	20		STOCKWATER	
M:26022	14N 28E 10 ADA	SOLF WILLIAM	190	20		1973	7		STOCKWATER	
M:26023	14N 28E 11 B	SOLF ANNA	97		30	1972	150		STOCKWATER	
M:26024	14N 28E 11 BD	SOLF JOSEPH/ANNA	165		2	1965	45		STOCKWATER	
M:26025	14N 28E 12 CC	RANCH	157			1988			STOCKWATER	
M:125182	14N 28E 18 01	CORNUE HARVEY	120	40		1961	10		STOCKWATER	
M:26026	14N 28E 18 AD	CORNUE HARVEY	326			1948	5		DOMESTIC	
M:26027	14N 28E 19 BC	GERSHMEL M.N.	95	17		1958	10		STOCKWATER	
M:26031	14N 28E 25 A	WELTER KENNETH #1	150			1958	10		STOCKWATER	
M:26033	14N 28E 28	DAMSHIEN WARREN	220	70		1981	8		UNKNOWN	
M:26034	14N 28E 28 BA	HANSEN ERNEST	138		3	1960	15		STOCKWATER	
M:123365	14N 28E 28 DC 01	KIEHL JACK	110	8		1990	90		DOMESTIC	
M:26035	14N 28E 28 DCA	KICHL W.J.	105			1956	15		DOMESTIC	
M:26036	14N 28E 29 CC	HASSETT CLINTON	22	17		1915	5		STOCKWATER	
M:26037	14N 28E 29 CD	HASSETT CLINTON	92			1973	15		STOCKWATER	
M:26038	14N 28E 29 DD	HASSETT CLINTON	101		22	1973	100		STOCKWATER	
M:26039	14N 28E 30 AD	PETAJA GORDON	135	70		1963	15		STOCKWATER	
M:26040	14N 29E 01 DB	MOSBY EVERETT	111	20		1961	1		STOCKWATER	
M:26041	14N 29E 06 CB	EIKE LARRY	200	80		1973	10		STOCKWATER	
M:26042	14N 29E 07 DB	EIKE LARRY (BLM)	277	20		1988	30		STOCKWATER	
M:26043	14N 29E 18 BA	AASRUD ALDEN	110			1955	55		STOCKWATER	
M:26044	14N 29E 18 DAA	EIKE LARRY	130			1974	15		STOCKWATER	
M:26045	14N 29E 20	DAMSCHEN KENNETH	157		2	1969	20		STOCKWATER	
M:26046	14N 29E 20 BB	HANSEN ERNEST				1957	8		STOCKWATER	

* Static water level: minus sign means feet above ground surface (flowing wells).

Table 1. (continued)

WELL NUMBER	LOCATION		WELL OWNER	WELL DEPTH FT	STATIC WATER LEVEL FT *	WELL HEAD PRESSURE PSI	YEAR DRILLED	WELL YIELD GPM	LAND SURFACE ALTITUDE FEET	WATER USE	WATER LEVEL ELEVATION FEET
M:26047	14N 29E 20 CCA		DAMSCHEN KENNETH	120			1974	4			
M:26048	14N 29E 21		DAMSCHEN KENNETH	260			1969	5		STOCKWATER	
M:26049	14N 29E 21 DDC		DAMSCHEN KENNETH	140		1	1969	40		STOCKWATER	
M:26051	14N 29E 28 BA		HANSEN EARNEST			3	1960	15		STOCKWATER	
M:26052	14N 29E 30		THOMPSON LES/VERN	153			1960	6		STOCKWATER	
M:26053	14N 29E 30 DB		THOMPSON BROS. #2	140			1973	6		STOCKWATER	
M:26054	14N 29E 30 DB		THOMPSON BROS #1	140			1973			STOCKWATER	
M:26055	14N 29E 34		DAMSCHEN KENNETH	170		2	1969	25		STOCKWATER	
M:26056	14N 29E 36 AC		DAMSCHEN KENNETH	290			1969	2		STOCKWATER	
M:26058	14N 30E 04 DA		RANKIN RANCH	300	75		1973	2		STOCKWATER	
M:27233	15N 27E 10 AC		STUART GENE	115	18		1967	10		STOCKWATER	
M:27234	15N 27E 11 CA		BRATTON WAYNE	200	125		1958	30		STOCKWATER	
M:27235	15N 27E 14 AD		STUART GENE	233	28		1967			STOCKWATER	
M:27237	15N 27E 23		BRATTEN WAYNE	60		1	1964	50		STOCKWATER	
M:27238	15N 27E 24 AB		BRATTEN WAYNE	100			1954	40		STOCKWATER	
M:27240	15N 27E 33 CD		RIGG OLE	120	105		1969	5		DOMESTIC	
M:27243	15N 27E 33 DC		RIGG OLE	130	80		1967	5		STOCKWATER	
M:27244	15N 27E 35 B		GERSHMEL M.N.	235	165		1957	100		STOCKWATER	
M:27247	15N 28E 11 C		LANDHEIM GUNVALD	201	80		1961	11		STOCKWATER	
M:27248	15N 28E 12 C		LANDHEIM GUNVALD	201	105		1961	3		STOCKWATER	
M:27249	15N 28E 15 CB		BRATTEN WAYNE	100	40		1975	4		STOCKWATER	
M:27250	15N 28E 20 BB		BRATTON WAYNE	185	140		1918	12		STOCKWATER	
M:27252	15N 28E 25 C		THOMPSON BROS.	303			1961	6		STOCKWATER	
M:27253	15N 28E 32 BC		SANDMAN CARL	263	45		1977	13		STOCKWATER	
M:125185	15N 28E 33	01	WHISONANT D.W.	258	15		1961	10		STOCKWATER	
M:27254	15N 28E 33 DC		WHISONANT D.W.	189		3	1962	10		STOCKWATER	
M:27255	15N 28E 34 CD		GERSHMEL GARY	175			1966	60		STOCKWATER	
M:27306	15N 29E 18 CD		THORSEN L.C.	29			1913	5		STOCKWATER	
M:29908	17N 24E 14 CB		DELANEY M.R.	150			1961	10		STOCKWATER	
M:29916	17N 25E 08 BBB	01	DELANEY M R	2080			1959	40	3050	S	
M:29921	17N 25E 27 CA		FUHS RANCH	150			1945	11		STOCKWATER	
M:29922	17N 25E 27 DD		FUHS RANCH	150			1930	11		DOMESTIC	
M:29924	17N 25E 28 ADB		FUHS RANCH	150			1945	3		STOCKWATER	
M:2117A	17N 27E 30 CAC	01	BRADY RONDELL	2390	-8		1967		3010	S	3018.0
M:2118	17N 27E 34 AAD	01	BLM	2190	-116	50	1973	1	2980	STOCKWATER	3096.0
M:2119	17N 28E 09 DB	01	MILLER	1979	-5		1951	2	2590	S	2595.0
M:29931	17N 28E 11 CA	01	WAYNE BRATTEN	1995			0	5	2485	S	
M:30750	18N 18E 12 ACA	01	ARNTZEN K	376			1953	6	3780	H	
M:30751	18N 18E 15 BDA	01	ROYCE C	285	60		1968	8	3980	H	3920.0
M:2184	18N 19E 08 ABB	01	ROYCE CURTIS	660	-31		1968	6	3800	S	3831.0
M:30789	18N 19E 08 BCD	01	BENES W	606			1948	8	3800	H	

* Static water level: minus sign means feet above ground surface (flowing wells).

Table 1. (continued)

WELL NUMBER	LOCATION		WELL OWNER	WELL DEPTH FT	STATIC WATER LEVEL FT	WELL HEAD PRESSURE PSI	YEAR DRILLED	WELL YIELD GPM	LAND SURFACE ALTITUDE FEET	WATER USE	WATER LEVEL ELEVATION FEET
	18N 19E 19 BBB	01	SWINDELL C	358			1961		3820	H	
M:30812	18N 19E 31 CCCD	01	GILSKEY BERNARD	700	150		1975	7	4175	STOCK	4025.0
	18N 19E 33 AAA	01	BRECKNRDGE M	547			1968		4000	H	
M:2185	18N 20E 16 BBB	01	YAEGAR RUDOLPH	848	-3		1962	6	3750	STOCK	3747.0
M:30826	18N 20E 17 BBAA	01	YEAGER CHARLES	610			1962	10	3795	S	
M:2188	18N 21E 05 ABD	01	SATTERFIELD NO. 1*	6408			0		3806	UNUSED	
M:2189	18N 22E 01 AAC	01	HORYNA JAMES	2005	120		1974	55	3420	DOMESTIC	3300.0
M:2190	18N 22E 27 BBD	01	BOWSER JIM	690	-12		1965	20	3475	S	3463.0
M:30923	18N 23E 09 BB		KALINA DON	2075	60		1980	25		UNKNOWN	
M:2191	18N 23E 10 ABA	01	SIROKY FRANK	2088	-26		1960	7	3260	DOMESTIC	3234.0
	18N 23E 11 DD	01		1815			0		3250	S	
M:30926	18N 23E 11 DDD		PETERS ROY	2052		4	1962	60	3250	STOCKWATER	3259.0
M:30926A	18N 23E 12 CBC	01	PETERS ROY	2052	-92		1962		3150	STOCK	3242.0
M:30945	18N 24E 03 CDA		DELANEY GEORGIA	1970			1988	35		STOCKWATER	
M:30946A	18N 24E 14 BAB	01	BAUMAN HAROLD	2318	15		1962	30	3200	S	3185.0
M:30952	18N 25E 02 DCCC	01	BLOOD CR	2009	-231		1961	50	2980	S	3211.0
M:30953	18N 25E 07 CADB	01	WOLFF F	2142			1964	13	3150	H	
M:30954	18N 25E 13 CD		SLUGGETT LESTER	2108		4	1981	12	2800	UNKNOWN	
M:2192	18N 26E 29 AAA	01	BUSENBARK, MERLIN	2092	-150	65	1969	18	2960	STOCKWATER	3110.0
M:2194	18N 27E 11 BAC	01	WEINGART, ROBERT * 8	2173	-300	130	1969	2	2790	STOCKWATER	3090.0
M:32198	19N 22E 05 AC		PETRANEK CHARLES	1750			1975			STOCKWATER	
M:32199	19N 22E 06 CCD	01	RINDAL OLAF	970	-23		1966	3	2880	S	2903.0
M:32200	19N 22E 22 ABB		MACHLER JOHN	1917		3	1981	10	2800	UNKNOWN	2809.0
M:127322	19N 22E 34	01	FINK ROBERT	1685			1981	60			
M:32204	19N 23E 02 D		ZAHN ERNEST	1634			1980			STOCKWATER	
M:32205	19N 23E 06		CIMRHAKL FRANK	1956			1962	70		DOMESTIC	
M:32206	19N 23E 25 AB		JORDON LARRY	1884			1961	60		STOCKWATER	
M:32221	19N 24E 06 CBB	01	ZAAN WILBERT	1700	-231		1966	100	2940	STOCK	3171.0
	20N 20E 17 DCBB	01	BUTCHER MILTON	1652	1		1967		3450	H	3451.0
M:33765	20N 21E 21 DC		PETRANEK CHARLES	2000		5	1969	35		STOCKWATER	
M:33774	20N 22E 11 ABB	01	MURRAY RUSSELL	2110	-138		1967	60	3150	STOCK	3288.0
M:33775	20N 22E 14 CCC	01	FINK ROBERT	1971			1965	120	3135	STOCK	
M:33776	20N 22E 14 DCB		FINK ROBERT	1966			1965	120		STOCKWATER	
M:124139	20N 22E 15 BCC	01	HYEM EDWNA & LINDA	1945		43	1991			STOCKWATER	
M:33778	20N 22E 23 CAC	01	VANSTEAD ROY	1980	-88		1969	75	3125	S	3213.0
M:33781	20N 23E 03 ADCC		KOMAREK JOE	1892			1965			STOCKWATER	
M:33781A	20N 23E 03 ADCC	01	KOMAREK JOSEPH D	1982			1965		3025	H	
M:33782	20N 23E 04 CC		JORDAN LARRY	1968			1961	20		STOCKWATER	
M:33783	20N 23E 18		CIMRHAKL FRANK	1827		8	1964	90		STOCKWATER	
M:33784	20N 23E 21 BBD	01	KOMAREK JOSEPH	2070	-55		1961	70	3090	STOCK	3145.0
M:33785	20N 23E 23		WILLMORE WARREN	1888			1981	22		UNKNOWN	

* Static water level: minus sign means feet above ground surface (flowing wells).

Table 1. (continued)

WELL NUMBER	LOCATION	WELL OWNER	WELL DEPTH FT	STATIC WATER LEVEL FT *	WELL HEAD PRESSURE PSI	YEAR DRILLED	WELL YIELD GPM	LAND SURFACE ALTITUDE FEET	WATER USE	WATER LEVEL ELEVATION FEET
M:33786	20N 24E 04 D	INDIAN BUTTE GRAZING	1840			1981	50	3500	UNKNOWN	
	20N 24E 25 AAB 01	JORDAN LARRY	1884			1961		2900	S	
M:33787	20N 24E 29	ZAHN RANCH	1906		5	1981	30		STOCKWATER	
M:127844	20N 26E 09 CDAB 01	MARCOTT WELL (BLM)	2102	-264		1992	16	2885	STOCKWATER,WILD	3149.0
M:33788	20N 26E 18 DC	YAEGER CHARLES	1901			1980	30		UNKNOWN	
M:34868	21N 21E 19 BCAC 01	BAYCE MARJORIE	1168	289		1964	1	3110	STOCK	
M:2608	21N 22E 07 BDD 01	MURRAY-HOAG NO. 1*	1459			0		2927	UNUSED	
M:34874	21N 22E 34 DAD	FINK ROBERT	1793			1981	60		UNKNOWN	
M:2609	21N 23E 13 CBBB 01	INTERIOR DEPT. OF	1630	-233		1979		2915		3148.0
	21N 23E 22 CDCC 01	PEARCE JAMES	1868	-208		1967		3100	STOCK	3308.0
	21N 24E 26 CCBC	BLM(ELEVATOR RIDGE WELL)	1902	216	90	0	25	2940	STOCK	3156.0
	21N 25E 03 CA 01	STAN GAR	980			0		2280	STOCK	
	21N 25E 28 CACA	BLM (HAINES RIDGE WELL)	1975	-239	100	0	65	2960	STOCK	3199.0
	21N 27E 34 ACCC 01	MCARTHUR FRANK	2025	-146		1962		2840	STOCK	2986.0
M:35421	22N 19E 08 CCAA	BERGUM T M	1800			1969	8	3180	DOMESTIC	
M:2741	22N 19E 08 CCAA 01	BERGUM, GERALD * 10	1600			0		3175	STOCK	
M:2743	22N 19E 32 ABBC 01	OLSEN EDWIN	1624			1975	2	3250	STOCK	
M:2747	22N 20E 22 CABD 01	LAND CO EAGLE	1407	210		1966	18	3290	DOMESTIC	3080.0
M:36075	23N 15E 20 01	MOES ED	1040	700		1973	2		STOCK	
M:36083	23N 15E 23 CBA 01	LIDSTONE ELMER	663	363		1916	4		STOCK	
M:2890	23N 23E 15 ABDD01	WEB RESOURCES	1860			0			UNUSED	
M:36100	23N 24E 09 CB 01	BLM	1853			0	36		STOCKWATER	
M:2891	23N 25E 17 AD 01	GOVERNMENT 17-1 DST NO. 1	3030			0			UNUSED	
M:36973	24N 25E 02 DCA 01	PHILLIPS B.M.	151	70		0	12		STOCKWATER	
M:36976	24N 25E 18 ABC 01	PHILLIPS B.M.	198	40		0	9		STOCKWATER	

* Static water level: minus sign means feet above ground surface (flowing wells).

released or stored per unit surface area of the aquifer per unit change in the component of head normal to that surface. Aquifer boundaries can be either barrier boundaries caused by low permeability zones greatly restricting lateral flow or recharge boundaries that allow more water to infiltrate into the aquifer than would normally be expected. Examples of barrier boundaries include an alluvial aquifer occupying channels incised into impermeable bedrock, a stratigraphic pinchout of a sandstone aquifer surrounded by shale, and a low permeability shale faulted to a position adjacent to a sandstone aquifer. Examples of recharge boundaries include outcrops of aquifers intersecting lakes, rivers, and alluvial aquifers. By understanding the aquifer characteristics and aquifer boundary conditions, responses to water use can be predicted. These include head losses through time, reduced well yield through time, and interference caused by discharging water from a number of wells. Consequently, aquifer management plans can be established that optimize the available water resources by spacing wells adequately, and by regulating ground-water discharge rates and duration.

HYDROGEOLOGY OF THE EAGLE SANDSTONE

The Upper Cretaceous Eagle Sandstone is an eastward-pointing wedge of nonmarine shoreline sandstone and marine shallow-water sandstone and shale. It underlies an area covering thousands of square miles in central Montana. The extent of Eagle Sandstone outcrops, and contours drawn on the top of the Eagle Sandstone are depicted on Plate 1. Other structural features and the generalized direction of ground water flow are also shown on Plate 1. The geologic information was compiled from several published sources including Noble and others, 1982; Johnson and Smith, 1964; Knechtel, 1959; Ostercamp, 1968; Porter, 1990; Porter, 1991; Feltis, 1982a; Feltis, 1982b; and Reeves, 1927. Most of the study area occupies a northwest to southeast trending structural depression named the Blood Creek syncline. The Eagle Sandstone forms a widely used aquifer that extends from outcrops along the Cat Creek anticline and Judith Mountains in the south to the Little Rockies and Bearpaw Mountains to the north. Extensive exposures of Eagle Sandstone occur west of the map coverage on Plate 1. Faulting south of the Bearpaw Mountains and north of the Judith and Moccasin Mountains interrupts the continuity of the Eagle aquifer between potential recharge areas west of the map and areas east of this zone of faulting (Ostercamp,1968). The eastern extent of the Eagle Sandstone as an aquifer is in the vicinity of the Musselshell River where the sandstone grades into sandy shale.

Lithology and Stratigraphy

The Eagle Sandstone generally consists of a basal sandstone unit (equivalent to the Virgelle Sandstone Member west of the study area), a middle shale unit, and an upper sandstone unit. The underlying Upper Cretaceous Telegraph Creek Formation is a sequence of shallow water marine shale, siltstone, and fine-grained sandstone. The Telegraph Creek Formation forms a transitional zone between shale of the Colorado Group and the Eagle. Overlying the Eagle Sandstone is a westward-pointing wedge of Clagett Shale. The low permeability shales overlying and underlying the Eagle Sandstone form confining beds restricting vertical ground-water flow.

A generalized cross-section (Figure 2), based on lithologic data from outcrops and drill holes along the Cat Creek anticline and related structures, shows the stratigraphic relationships in this area. The sandstones, shales, and siltstones of the Eagle and Telegraph Creek Formations grade into the offshore marine shales of the Gammon Formation over a distance of several tens of miles (Rice and Shurr, 1983). The west to east facies change in this interval probably continues over much of the eastern margin of the study area. The Musselshell River roughly marks the easternmost edge of significant sandstone occurrence in the Eagle interval (Figure 2).

Ground-water flow

Ground-water recharge to the Eagle Sandstone aquifer occurs in areas of surface exposure and at subcrops underlying alluvium. The volume of recharge water infiltrating into the aquifer is directly related to the areas of surface exposure and subcrops. Based on the outcrop pattern shown on Plate 1, significant quantities of

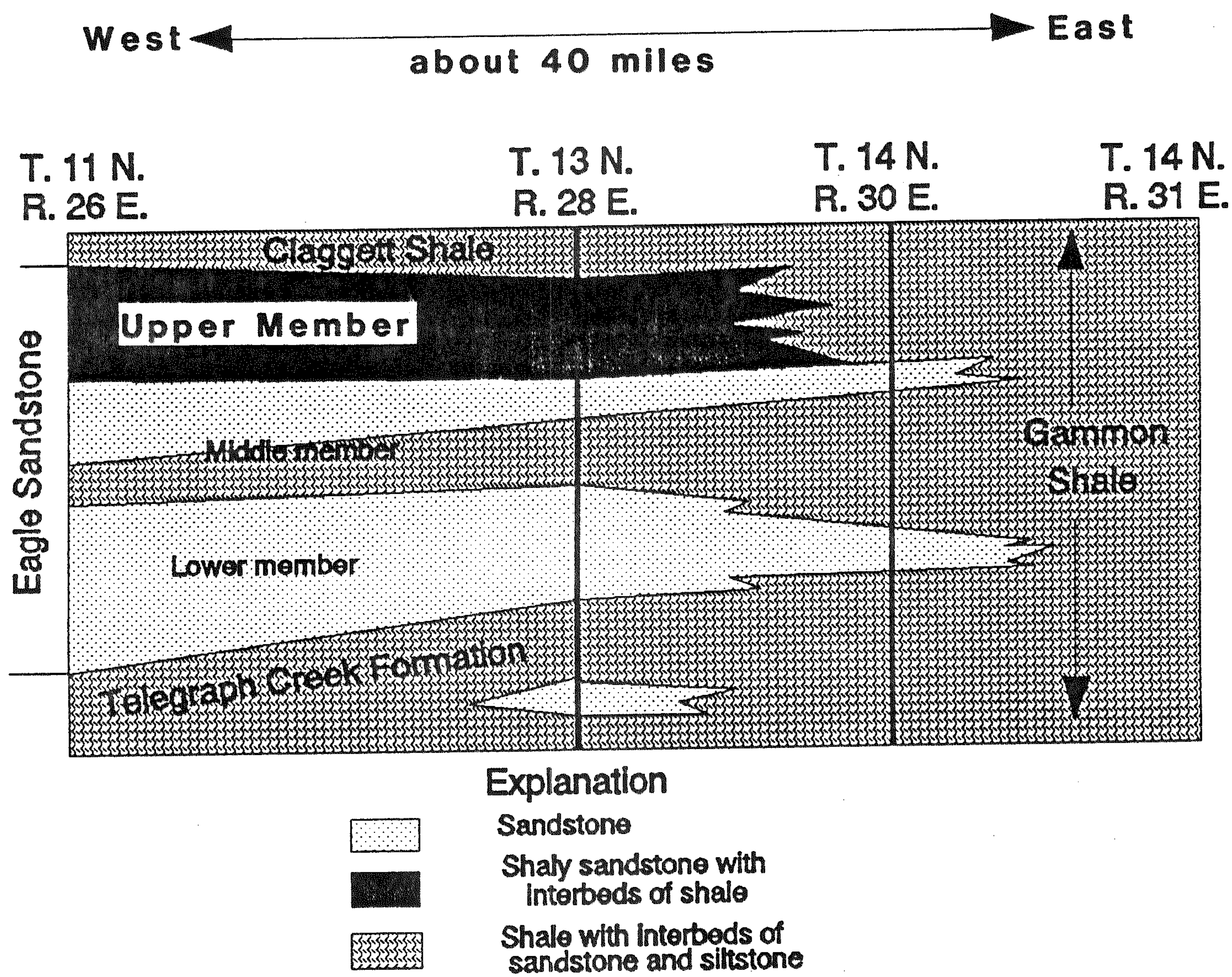


Figure 2. West to east cross-section through Upper Cretaceous rocks aong the central Montana uplift shows sandstones, shales, and siltstones of the Eagle Sandstone and Telegraph Creek Formation grading into offshore marine shales of the Gammon Formation (after Rice and Shurr, 1983).

recharge water probably enter the aquifer around the Little Rocky Mountains to the north, the Judith and Moccasin mountains to the southwest, with lesser quantities of recharge occurring along the edge of the Cat Creek anticline. Another area of significant recharge is near Winnett where Eagle Sandstone covers large areas of the land surface.

West of the area mapped on Plate 1, there are large areas of the land surface having Eagle Sandstone cropping out at the land surface. Ground-water flow from these areas is disrupted, however, in the region mapped as the area of major faulting (Ostercamp, 1968).

The elevation at which aquifer materials are exposed at the land surface, particularly under watercourses, provides the potential hydraulic head to drive flow in the aquifer system. Ground water flows away from these areas towards areas of discharge. Natural discharge from the Eagle aquifer probably occurs as seepage into laterally equivalent finer-grained formations and possibly into overlying or underlying confining beds. Much of this discharge probably occurs along a north-south line near the Musselshell River where the Eagle Sandstone grades into finer-grained units of the Gammon Shale. Additional discharge occurs from wells tapping the Eagle aquifer. Available data are not sufficient nor accurate enough to construct a potentiometric surface map of the system, but generalized flow is depicted by arrows on Plate 1.

Water Quality

Water from the Eagle aquifer typically has relatively low dissolved-solids concentrations making it suitable for most uses. Water analyses from the Haines Ridge, Marcott, and Elevator Ridge wells are summarized in Appendix A. The average calculated dissolved-solids concentration from these analyses is 1081 mg/L. The water is dominated by sodium and bicarbonate ions.

Aquifer Characteristics

Aquifer characteristics determine how an aquifer will respond to development, and this knowledge can be used to optimize water use. Constant-head variable discharge aquifer tests were conducted at three wells tapping the Eagle aquifer to determine the aquifer characteristics. The aquifer tests were evaluated using the straight-line solution of the Theis equation derived by Jacob and Lohman (1952). This solution is designed to determine transmissivity (T) and storage coefficient (S) from tests in which the drawdown is constant and the discharge varies with time (Lohman,1979). The S-value may be determined by this method where the radius of the flowing well is known. If the radius is questionable because of caving, well construction, or well development, this method will not compute a realistic storage coefficient. In addition, small changes in slope of the line used to calculate T will cause minor changes in the value of T but can cause large changes in the S-value. Although storage coefficients may be questionable, a minimum S can be determined by using the

Theis equation combined with observations of the maximum extent of drawdown surrounding the production well. Another method of estimating storage coefficient is described by Lohman (1979, p. 53), based upon thickness of confined aquifers, and is fairly reliable for most purposes. While aquifer tests and other methods can provide valuable insight into estimating the aquifer characteristics, the results are not necessarily unique; and other combinations of transmissivity, storage coefficient, boundaries, and leakage may show similar responses during a test.

Haines Ridge Well Flow Test

The Haines Ridge well was the first of the three BLM wells tested (Figure 3 and Plate 1). It is located in Township 21N, Range 25E, Section 28 CACA at an elevation of 2960 feet above sea level. The well was drilled to a depth of 1975 feet in 1981. Geologic formations encountered during drilling included: Bearpaw Shale (0 to 800 ft), Judith River Formation (800 to 1260 ft), Clagett Formation (1260 to 1780 ft), and Eagle Sandstone (1780 to 1920 ft). The Telegraph Creek Formation, and Colorado Shale were not differentiated. These geologic units are interpreted for this report from descriptions on the driller's lithologic log. The Haines Ridge well log report containing the driller's lithologic log and well construction details are included in Appendix B. The well was drilled using a 6.25-inch drill bit through the Eagle Sandstone interval. Fifty feet of #20 slot 2.5-inch stainless steel screen was set between depths of 1799 to 1912 feet below land surface. Perforations are assumed to have been set adjacent to

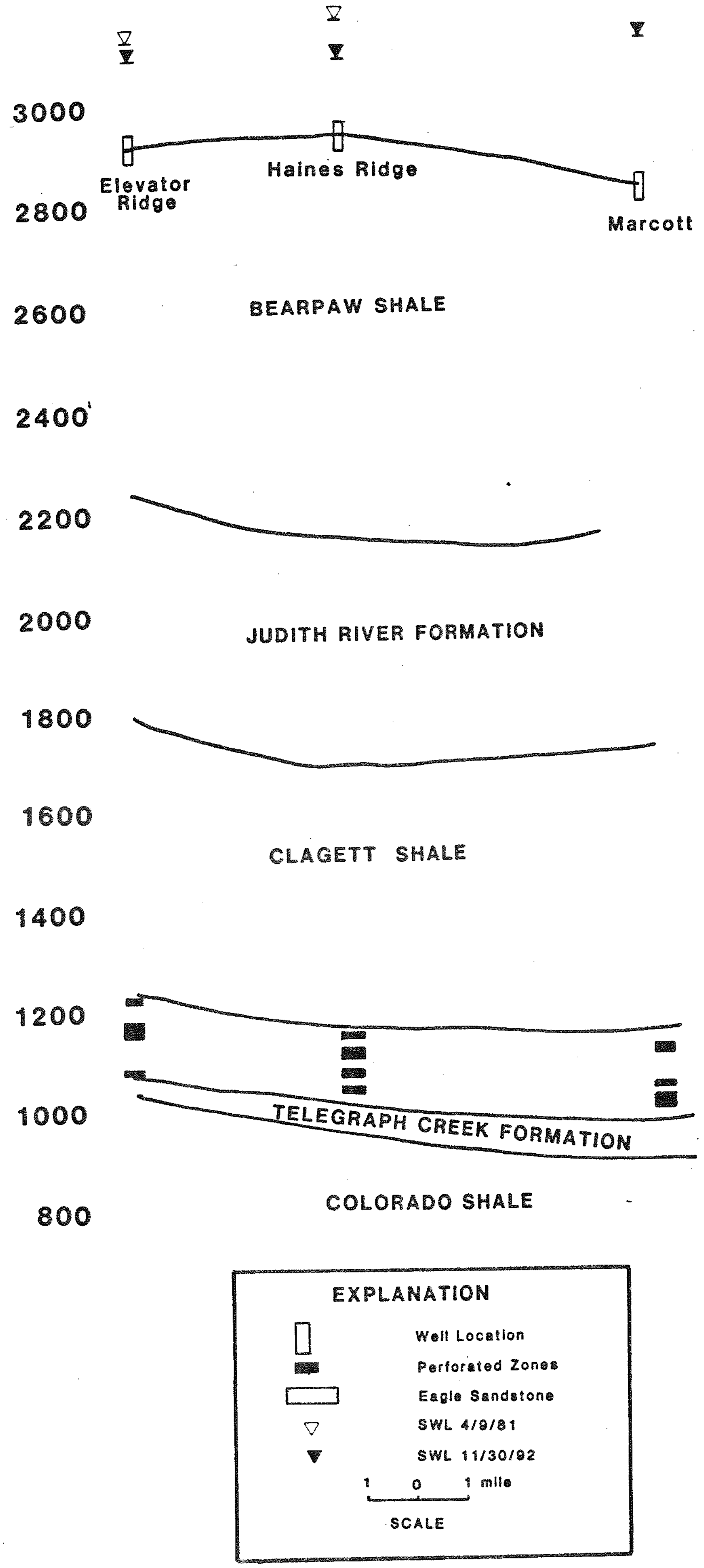


Figure 3. Cross-section summarizing hydrologic conditions at the three BLM wells tested.

the most permeable beds in the Eagle Sandstone. The well was sealed with cement from the base of the well pit to 1779 feet below land surface. The control valves and other flow controls are contained in a well pit to prevent freezing.

The closed-in pressure was 100 psi (pounds per square inch) immediately following drilling in 1981, and was equivalent to a water level elevation of 3182.7 feet, about 231 feet above the pressure gauge (Appendix C). Unrestricted flow in 1981 was reported at 65 gpm. Water from this well is used for stock and wildlife watering. The well is connected to a pipeline that supplies water to several stock tanks from April through mid-November. Fritzner reservoir, located a few hundred yards downslope from the well has been refilled with well water during the winter months for the past two years. During previous winters the well had been allowed to flow into stock tanks not equipped with float valves, thereby wasting large volumes of water to overland flow. A hydrograph depicting reported water-level measurements (Figure 4) shows about an 74-foot drop in head since the well was drilled. The water use prior to 1992 is not reflected by the hydrograph. This well has probably been heavily used since 1981 with the use pattern alternating between stock watering in the summer to overland flow and reservoir filling in the winter. Minor fluctuations in reported well-head pressures are the result of calibration differences between pressure gauges.

A 26-hour constant-head aquifer test was conducted at the Haines Ridge well from 11:30 A.M. on December 2 to 1:28 P.M. on

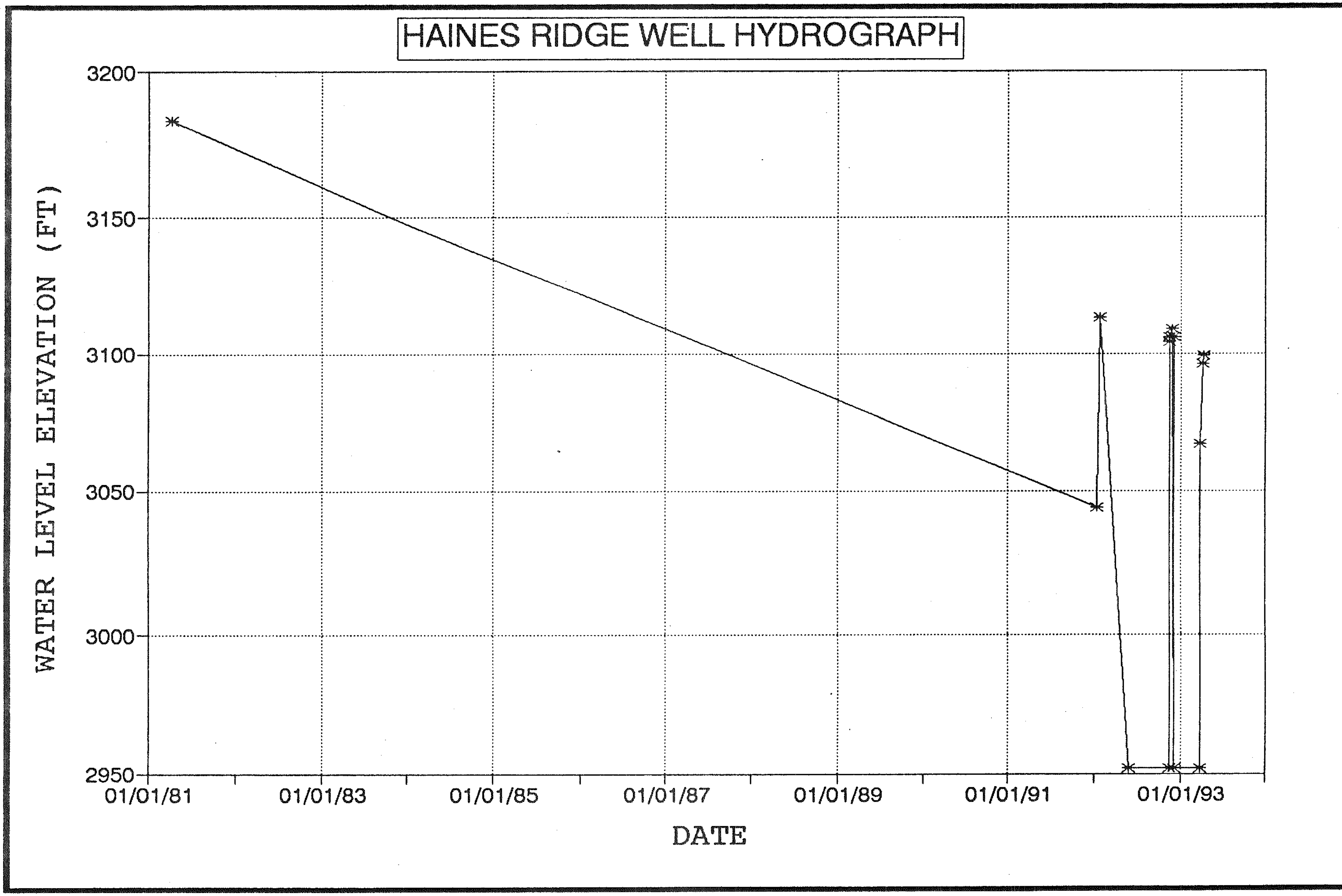
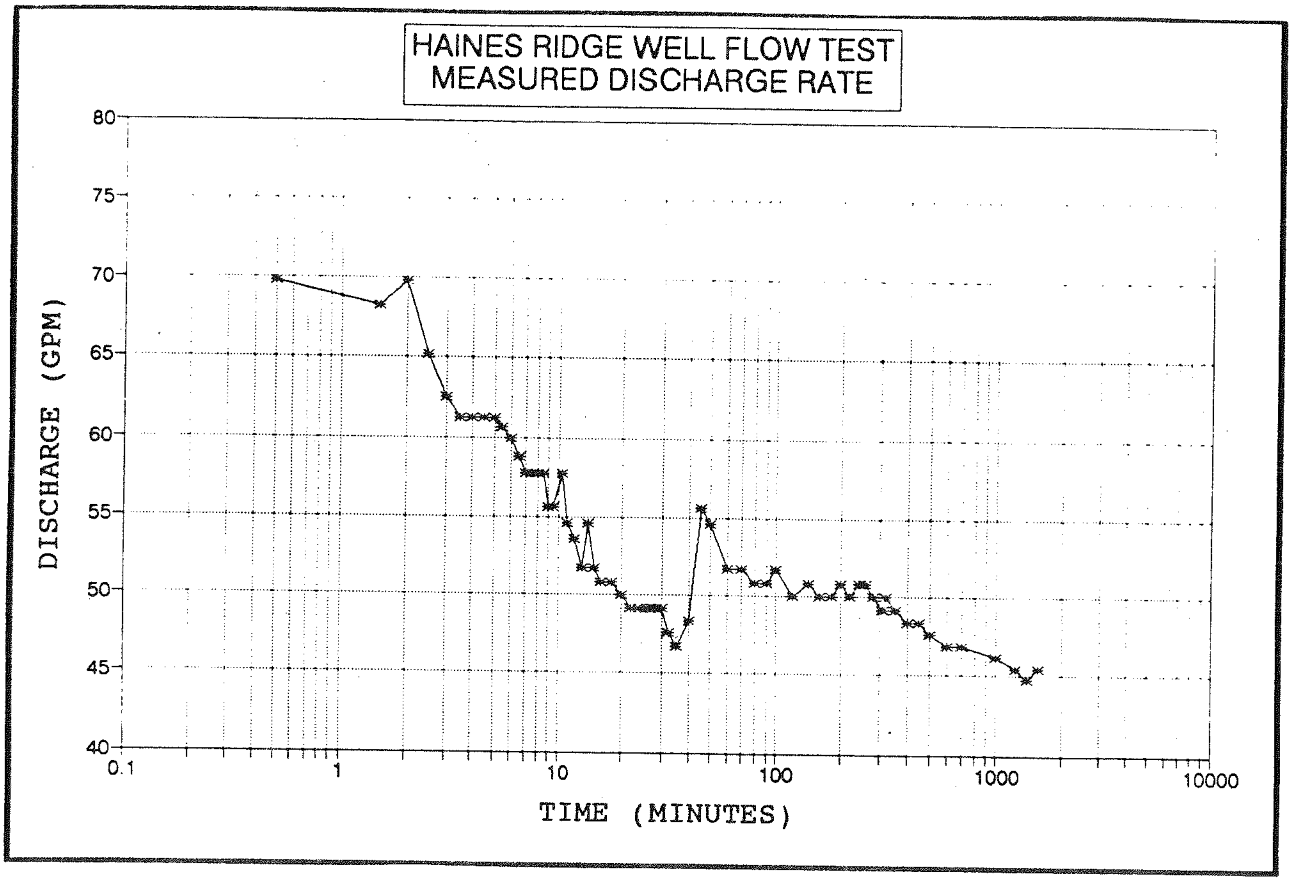


Figure 4. Hydrograph of reported water level measurement at the Haines Ridge well.

December 3, 1992. Recovery was monitored for about 24-hours following the discharge period. Water was discharged through a 6-inch pipe that emptied into a small tributary feeding Fritzner Reservoir. A plastic irrigation dam fitted with a short piece of 4-inch PVC pipe was used to block flow in the channel and restrict discharge through the 4-inch PVC pipe. The flow rate was monitored using a 5-gallon bucket and stopwatch. Water flowed at about 70 gpm when the test was started. The flow rate declined to about 52 gpm one hour into the test, and to about 45 gpm after 26 hours of testing. The overall average flow rate (based on hourly values) was about 48 gpm. Total discharge during the test period (26 hours) was about 75,000 gallons. Pressure readings were monitored at the well head before the test to determine the static water level, and during the test to determine constant drawdown. Wellhead pressure readings were periodically monitored at the Marcott well (30,500 feet east of the Haines Ridge well) and the Elevator Ridge well (23,000 feet west of the Haines Ridge well). No response was observed at either well during the test. Results of monitoring during the test and corrections applied to the raw data are listed in Appendix D.

Semilog plots of time versus flow rate (Figure 5a) depict erratic flow rates caused by a minor breach in the plastic dam during the early part of the test. The dam was repaired at about 40 minutes into the test and correction factors applied to the early time data (Figure 5b). Semilog plots of t/r^2 (time/well radius squared in minutes per square foot) versus dd/Q

(a)



(b)

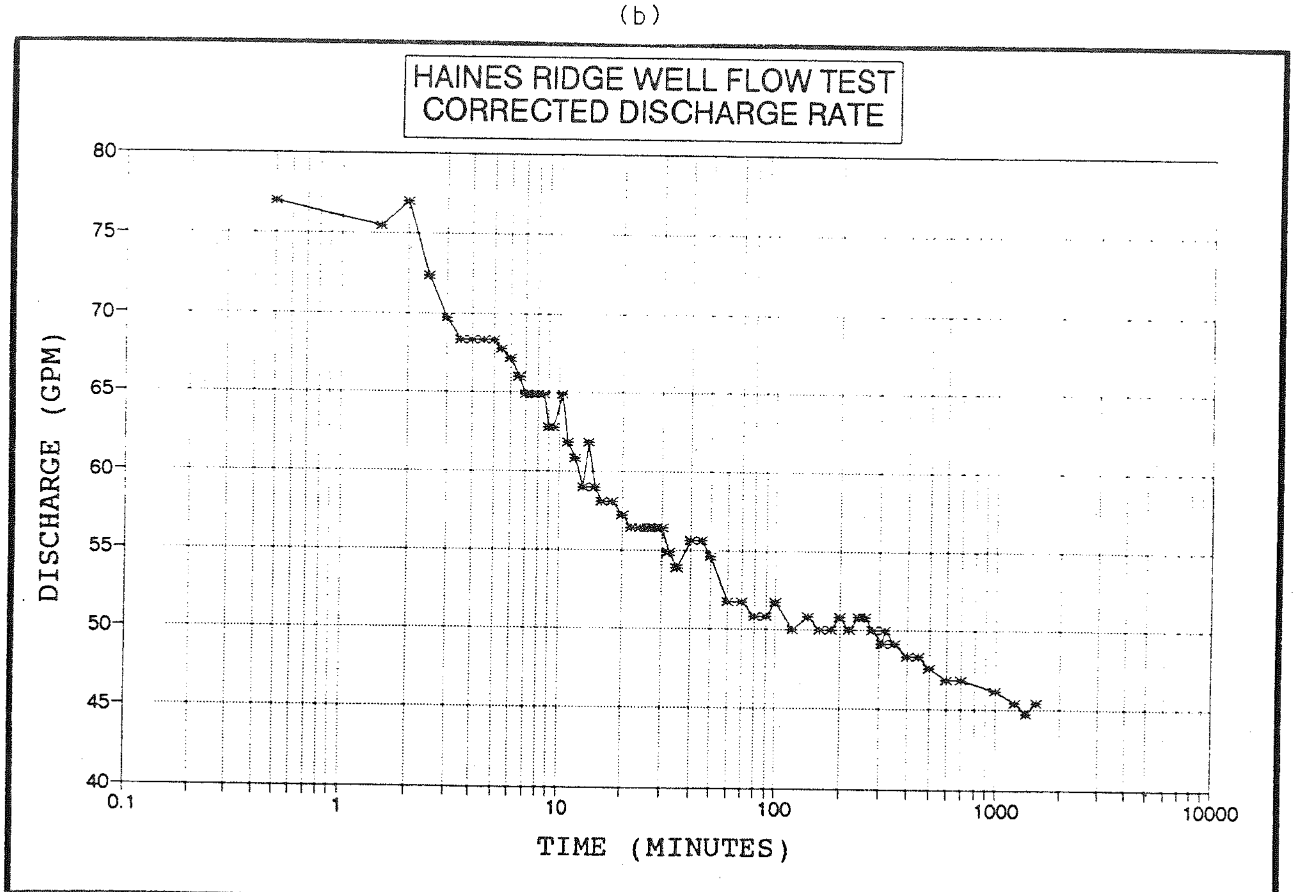


Figure 5. Plot of time versus flow rate at the Haines Ridge well. Uncorrected flow rate (5a) and flow rate corrected for erratic measurements caused by a breach in the plastic dam (5b).

(drawdown/corrected discharge rate in feet per gallon per minute) were constructed using the test data (Figure 6). Based on a best-fit line through the data points a transmissivity of 73 ft^2/day was calculated. A transmissivity of 82 ft^2/day was calculated based on the recovery of wellhead pressure after shutting in the well and using the overall average discharge rate of 48 gpm (Figure 7). The average transmissivity is 78 ft^2/day based on flow and recovery parts of the test. No evidence of either barrier or recharge boundaries were indicated by the test. A storage coefficient of 1.4 x 10^{-4} was calculated by replotting the t/r^2 versus dd/Q semilog plot at a scale allowing the zero dd/Q or t_0 value to be determined and applying the known values to the Theis equation (Figure 8). Lohman's (1979, p. 53) method of estimating storage coefficient also gives a value of 1.4 X 10^{-4}, utilizing an aquifer thickness of 140 feet from the well log in Appendix B.

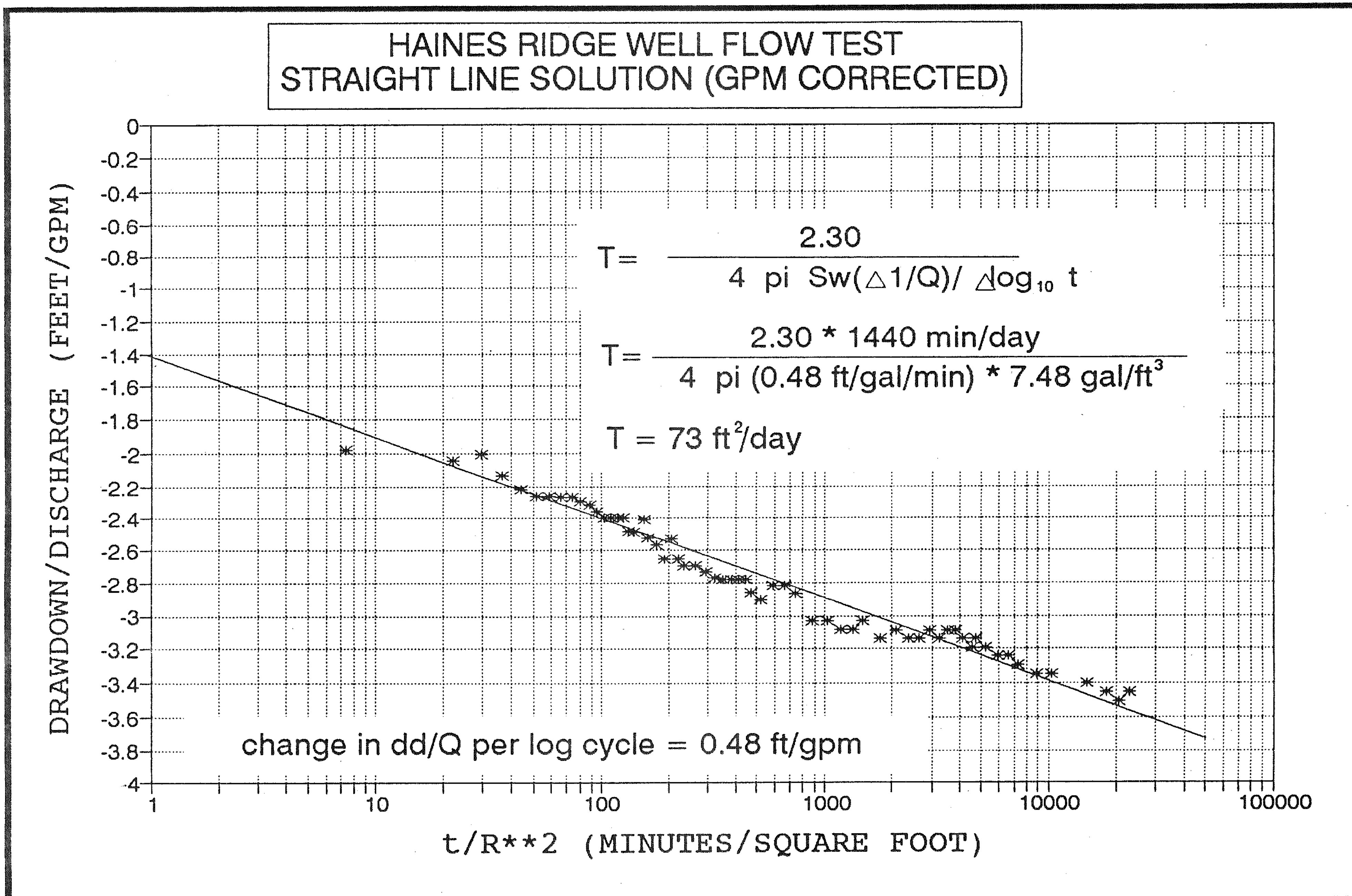


Figure 6. Semilog plot t/r^2 (time of measurement/well radius squared) versus dd/Q (drawdown/corrected discharge rate) during the discharge period of the Haines Ridge well aquifer test.

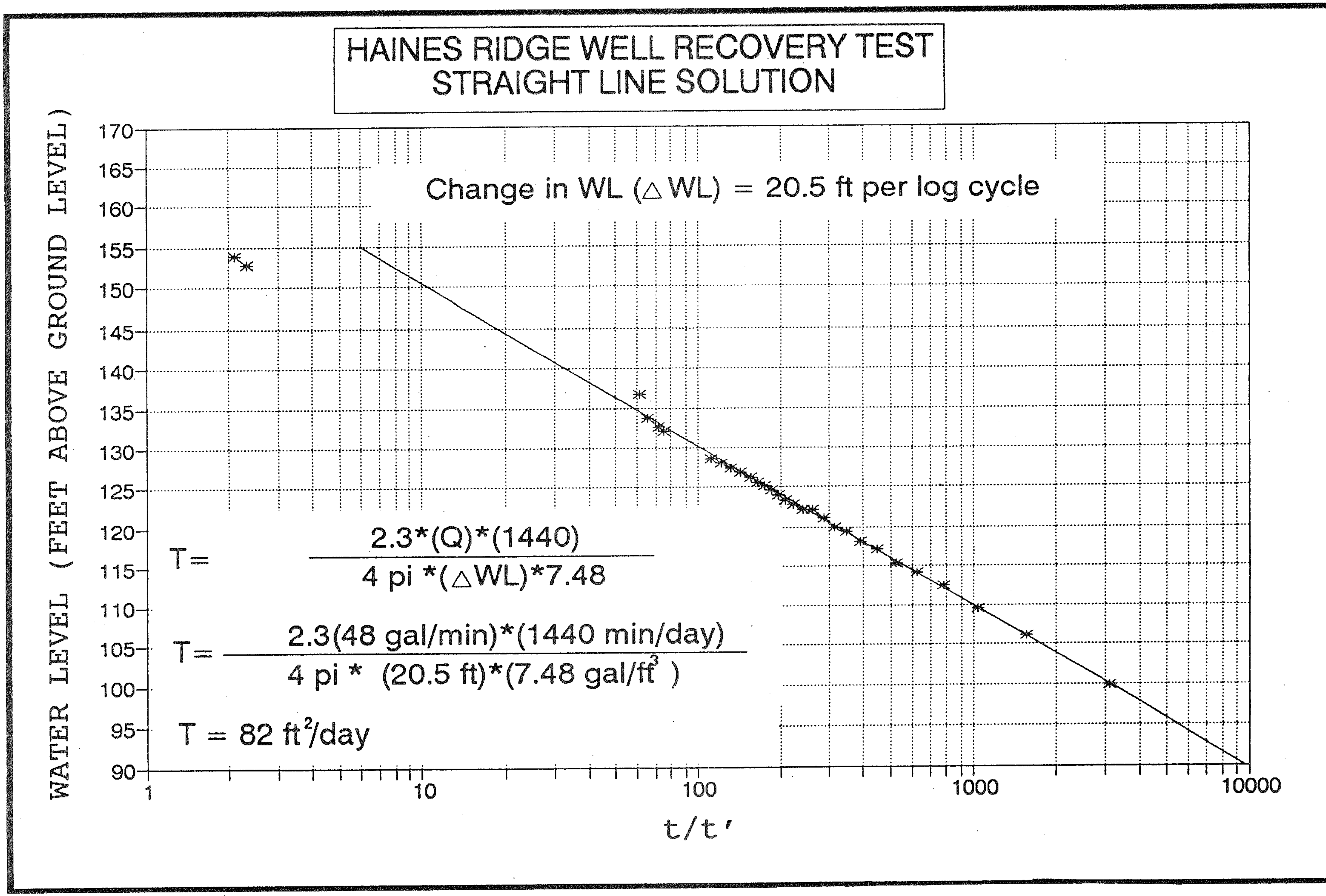


Figure 7. Semilog plot of the ratio of t/t′ versus water level during the recovery period of the Haines Ridge well aquifer test.

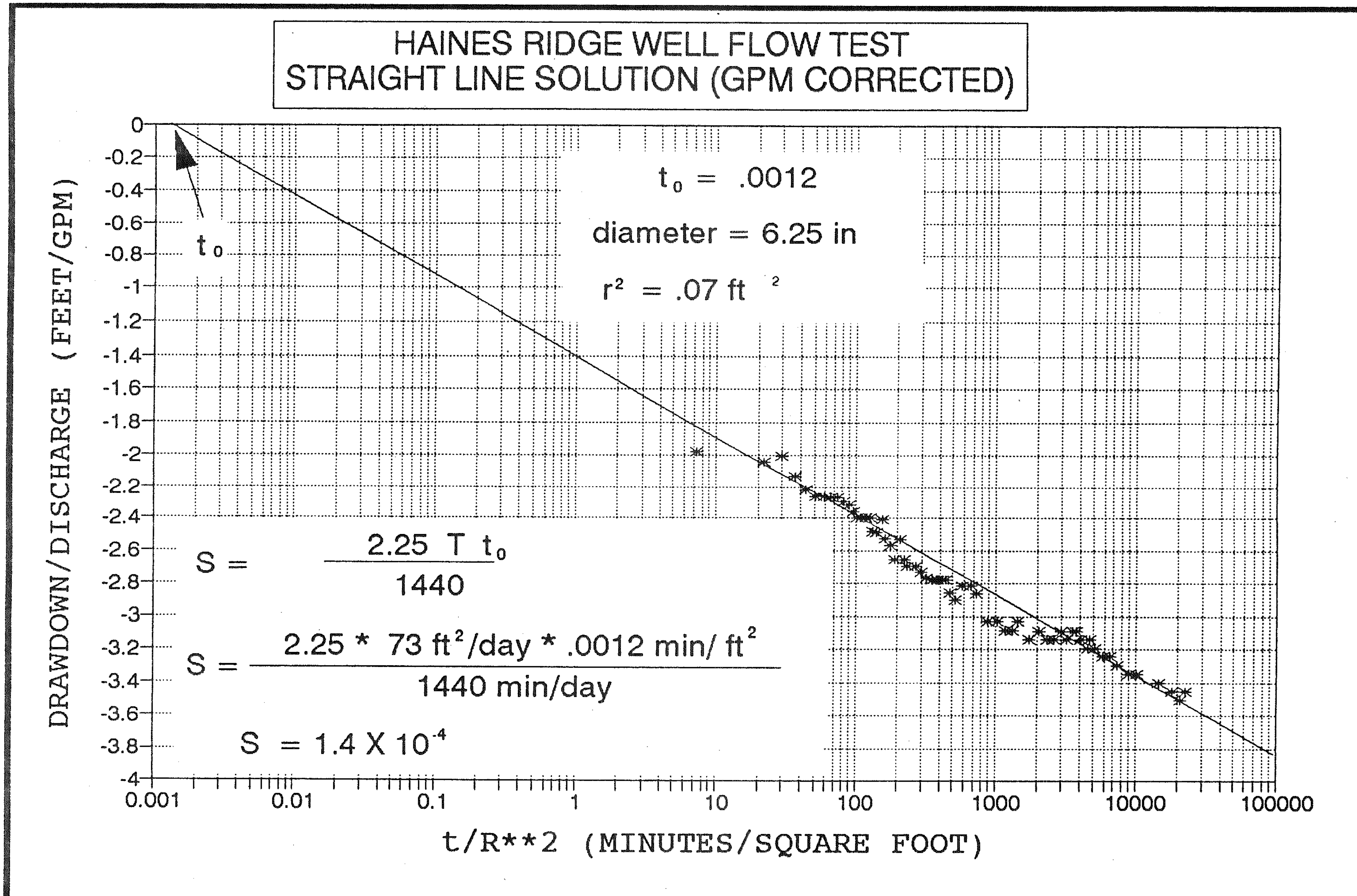


Figure 8. Semilog plot of t/r^2 (time of measurement/well radius squared) versus dd/Q (drawdown/corrected discharge rate) during the discharge period of the Haines Ridge well aquifer test. Scale is changed from Figure 6 to allow the zero dd/Q or t_o to be picked.

Marcott well flow test

The Marcott well is located in Township 20 N, Range 26 E, Section 09 CDAB at an elevation of 2885 feet above sea level. The well was drilled to a depth of 2102 feet in 1992. Geologic formations encountered during drilling included: Bearpaw Shale (0 to 735 ft), Judith River Formation (735 to 1160 ft), Clagett Formation (1160 to 1714 ft), Eagle Sandstone (1714 to 1990 ft), and Colorado Shale (1990 to 2102 ft). The Telegraph Creek Formation was not picked by the driller but probably is within the basal Eagle Sandstone interval between 1880 to 1990 ft (Figure 3). These geologic units are interpreted for this report from descriptions on the driller's lithologic log (Appendix B). The well was drilled using a 5.875-inch drill bit through the Eagle Sandstone interval. Forty feet of #20 slot 2.5-inch stainless steel screen were set between depths of 1757 to 1880 feet below land surface. Perforations are assumed to have been set adjacent to the most permeable beds in the Eagle Sandstone. The well was sealed with cement from the base of the well pit to 1209 feet below land surface. The control valves and other flow controls are contained in a well pit to prevent freezing.

The closed-in pressure was 115 psi (pounds per square inch) immediately following drilling in April 1991. A slightly lower pressure of 111 psi was measured when the well was inspected on November 11, 1992. This pressure is equivalent to a water level elevation of 3133.1 feet, about 256 feet above the pressure gauge. Unrestricted flow was reported at 16 gpm when the well was completed. Well development increased the initial flow rate to 22 gpm on 06/01/92, 27 gpm on 06/11/92, 30 gpm on 06/25/92, and 36 gpm on 12/03/92. Water from this well is planned to be used for stock and wildlife watering. The well will be connected to a pipeline supplying water to several stock tanks. A hydrograph depicting reported water-level measurements (Figure 9) shows little change in head since the well was drilled. Minor fluctuations in reported well-head pressures are probably the result of calibration differences between pressure gauges.

A 20-hour constant-head aquifer test was conducted at the Marcott well from 14:55 P.M. on December 3 to 10:55 A.M. on December 4, 1992. Recovery was monitored for about 2 hours following the discharge period. Water was discharged through a 2-inch fire hose that emptied into a small tributary sloping away from the well. The flow rate was monitored using a 5-gallon bucket and stopwatch. Water flowed at about 36 gpm when the test was started. The flow rate declined to about 24 gpm one hour into the test, and the final flow rate was about 18 gpm after 20 hours of testing. The overall average flow rate (based on hourly values) was 20.6 gpm. Total discharge during the test period (20 hours) was about 25,000 gallons. The well appears to have been developing during the test as indicated by noticeable quantities of black silt and very fine sand produced during the test. Pressure readings were monitored at the well head before the test to determine the static water level and during the test to determine constant drawdown. Wellhead pressure readings were periodically monitored

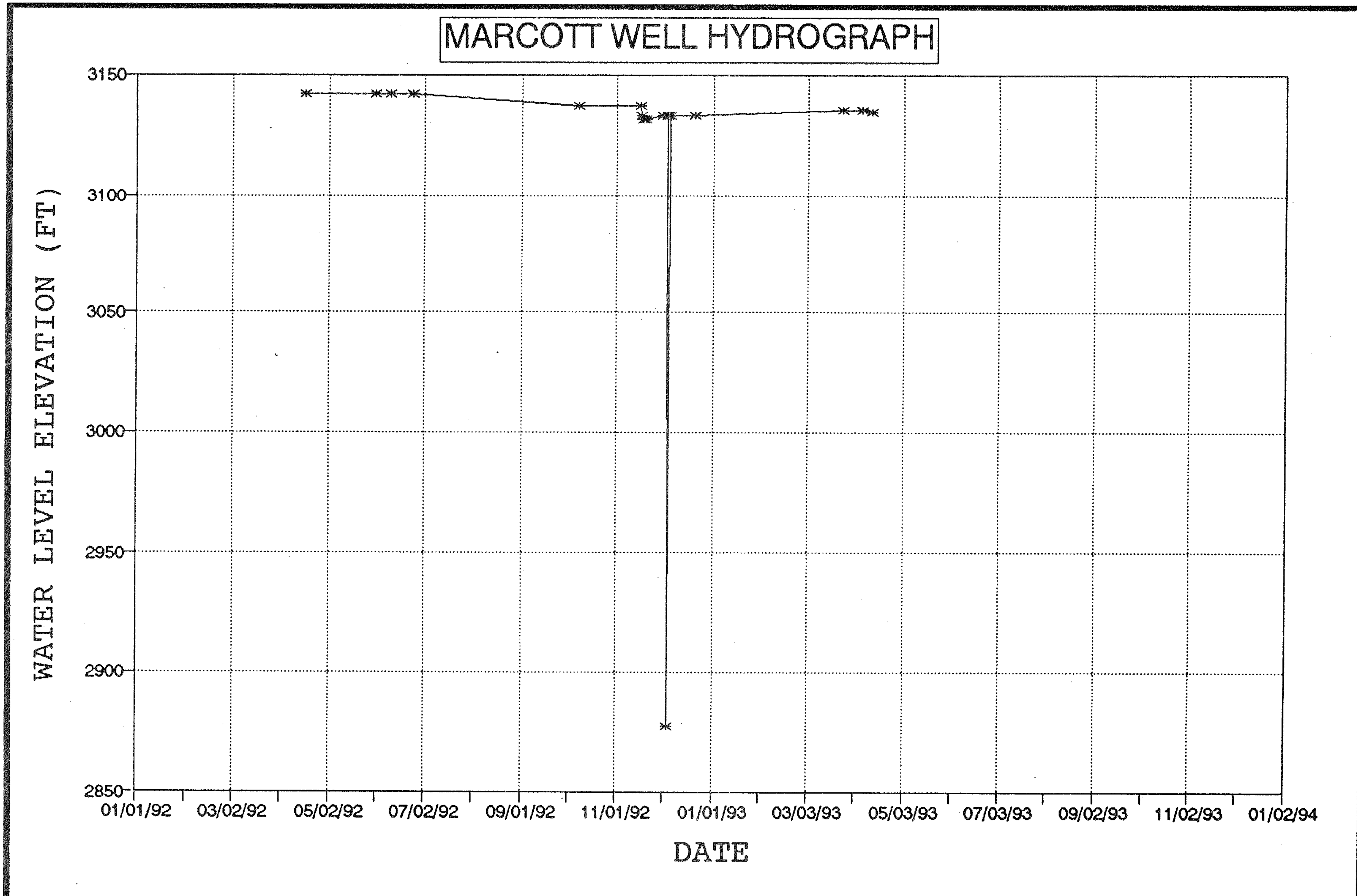


Figure 9. Hydrograph of reported water level measurement at the Marcott well.

at the Haines Ridge well (30,500 feet west of the Marcott well) and the Elevator Ridge well (51,000 feet west of the Marcott well). No response was observed at either well during the test. Results of monitoring during the test and corrections applied to the raw data are listed in Appendix B.

Semilog plots of t/r^2 (time/well-radius squared in minutes per square foot) versus dd/Q (drawdown/discharge rate in feet per gallon per minute) were constructed using the test data (Figure 10). Based on a best-fit line through the data points a transmissivity of 18.4 ft^2/day was calculated. A transmissivity of 19.9 ft^2/day was calculated based on the recovery of wellhead pressure after shutting in the well and using the overall average discharge rate of 20.6 gpm (Figure 11). The average transmissivity is 19.2 ft^2/day based on flow and recovery parts of the test. No evidence of either barrier or recharge boundaries were indicated by the test. A storage coefficient of 1.1×10^{-4} was calculated by replotting the t/r^2 versus dd/Q semilog plot at a scale allowing the zero dd/Q or t_0 value to be determined and applying the known values to the Theis equation (Figure 12). Lohman's (1979, p. 53) method of estimating storage coefficient gives a value of 2.8×10^{-4}, utilizing the aquifer thickness of 276 feet indicated on the driller's log (Appendix B).

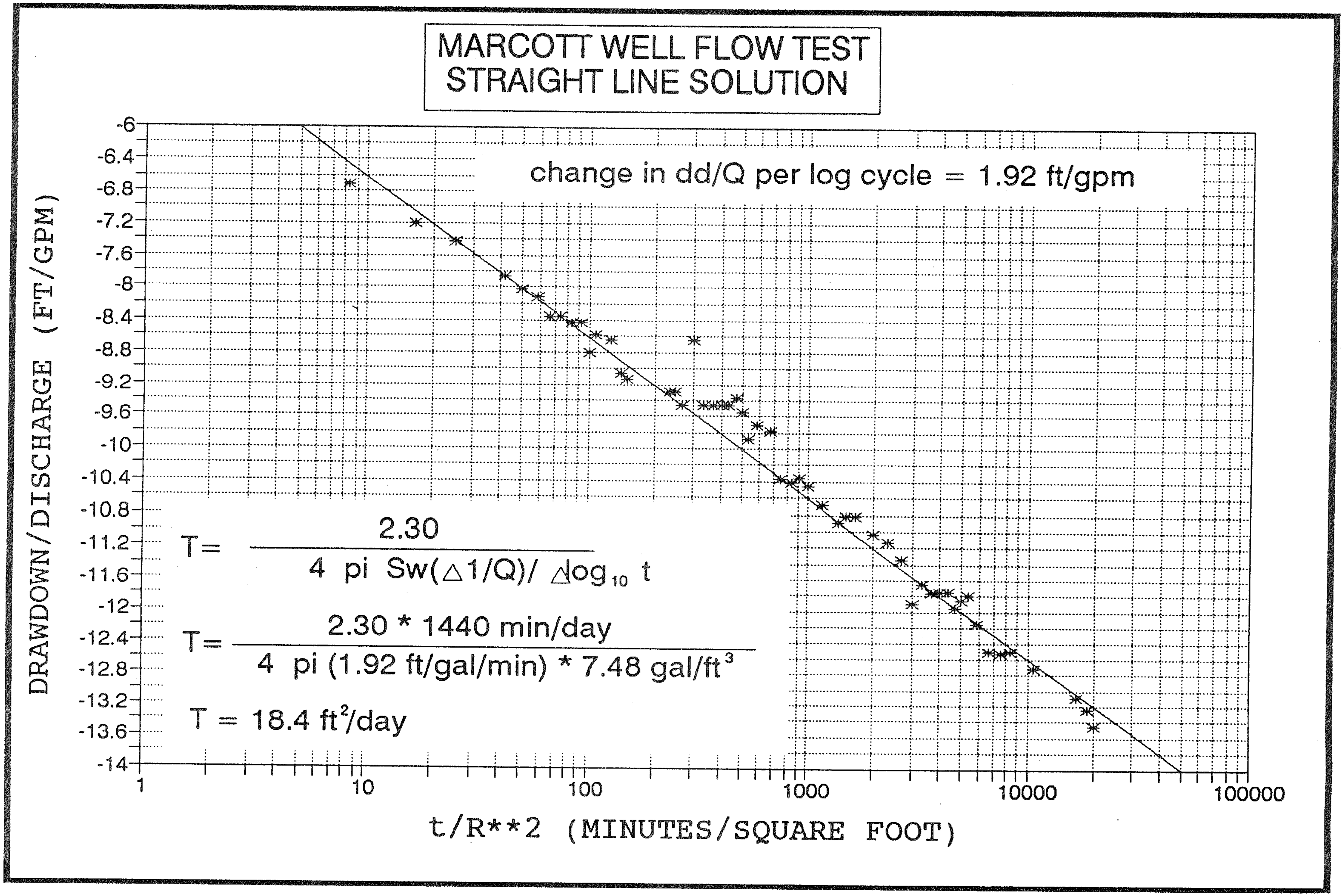


Figure 10. Semilog plot t/r^2 (time of measurement/well radius squared) versus dd/Q (drawdown/corrected discharge rate) during the discharge period of the Marcott well aquifer test.

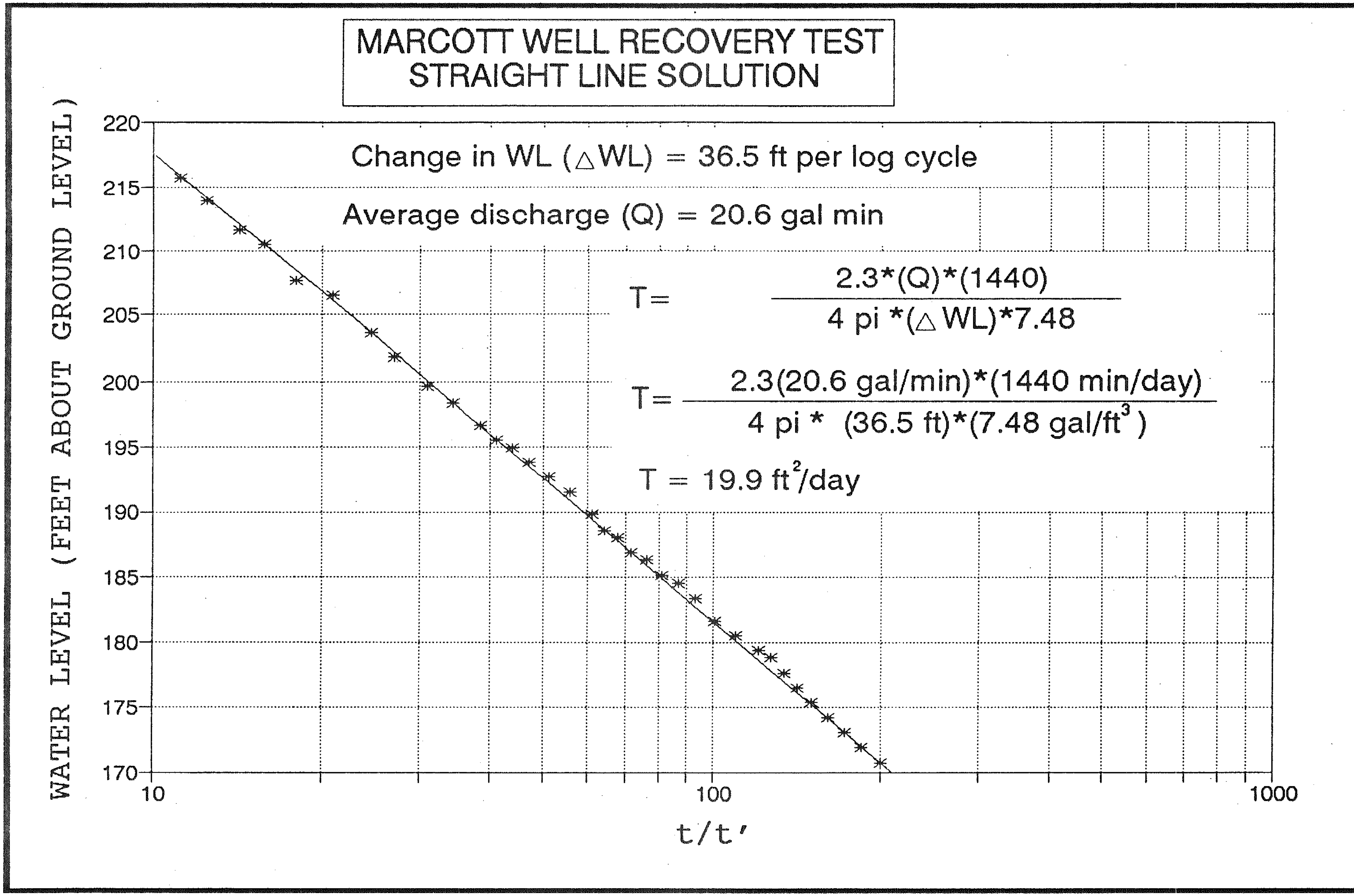


Figure 11. Semilog plot of the ratio of t/t′ versus water level during the recovery period of the Marcott well aquifer test.

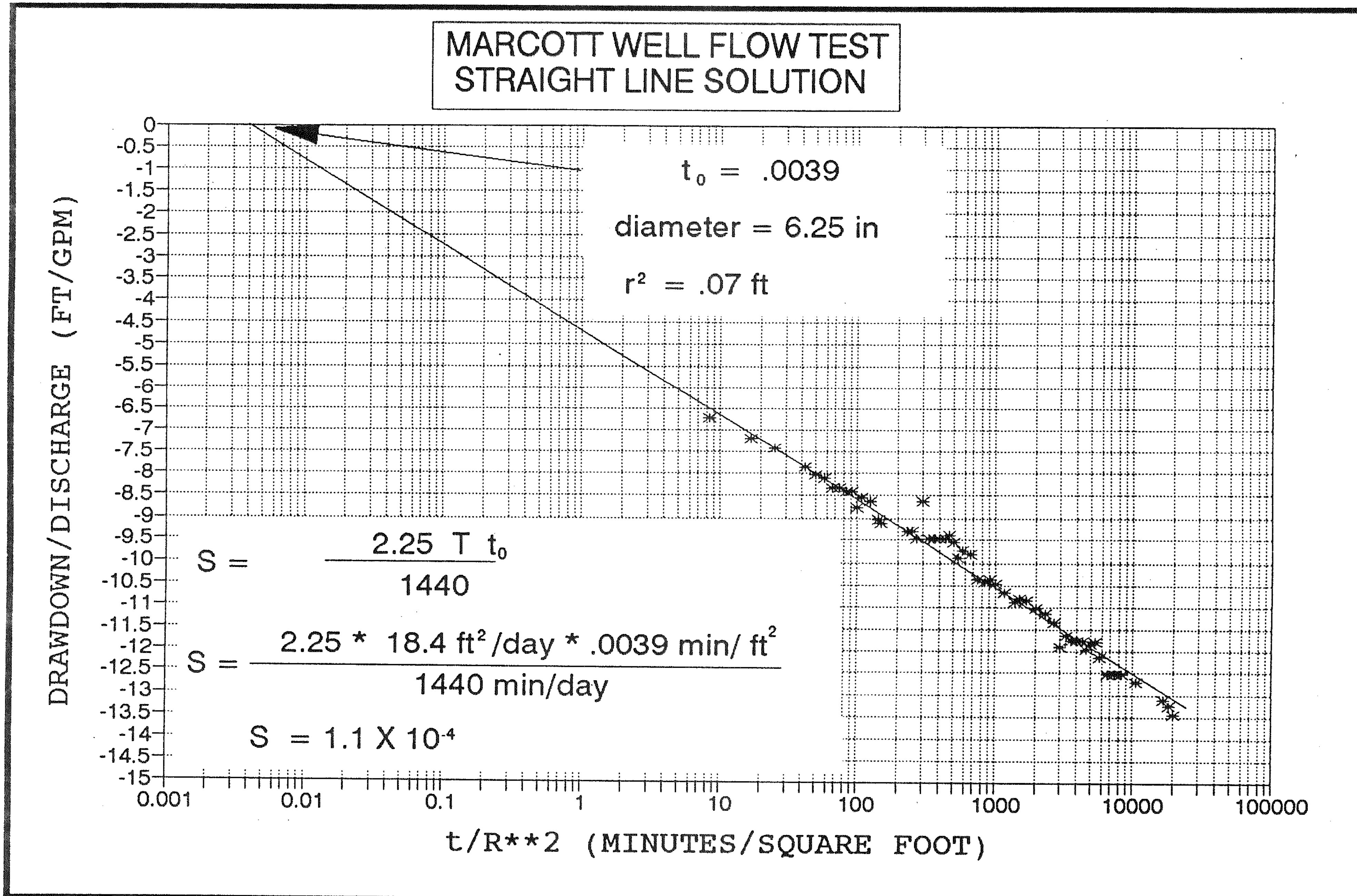


Figure 12. Semilog plot of t/r^2 (time of measurement/well radius squared) versus dd/Q (drawdown/corrected discharge rate) during the discharge period of the Marcott well aquifer test. Scale is changed from Figure 6 to allow the zero dd/Q or t_o to be picked.

Elevator Ridge Well Flow Test

The Elevator Ridge well is located in Township 21 N, Range 24 E, Section 26 CCBC at an elevation of 2940 feet above sea level. The well was drilled to a depth of 1902 feet in 1991. As interpretted from the driller's log (Appendix B), geologic formations encountered during drilling included: Bearpaw Shale (0 to 703 ft), Judith River Formation (703 to 1150 ft), Clagett Formation (1150 to 1700 ft), Eagle Sandstone (1700 to 1876 ft), and Colorado Shale (1876 to 1902 ft). The Telegraph Creek Formation/Colorado Shale undifferentiated is within the interval between 1876 to 1902 ft (Figure 3). The well log report containing the drillers lithologic log and well construction details are included in Appendix B. The well was drilled using a 6.25-inch drill bit through the Eagle Sandstone interval. Fifty feet of #20 slot 2.5-inch stainless steel screen were set between depths of 1705 to 1860 feet below land surface. Perforations are assumed to have been set adjacent to the most permeable beds in the Eagle Sandstone. The well was sealed with cement from the base of the well pit to 1655 feet below land surface. The control valves and other flow controls are contained in a well pit to prevent freezing.

The closed-in pressure was 90 psi (pounds per square inch) immediately following drilling in 1981, and is equivalent to a water-level elevation of 3139.6 feet, about 208 feet above the pressure gauge. Unrestricted flow was reported at 25 gpm when the well was completed.

The well is used for stock and wildlife watering, and is connected to a pipeline supplying water to several stock tanks. A hydrograph depicting reported water-level measurements (Figure 13) shows a 42 ft drop in head since the well was drilled. Minor fluctuations in reported well-head pressures are the result of calibration differences between pressure gauges.

A 22-hour constant-head aquifer test was conducted at the Elevator Ridge well from 11:20 P.M. on April 7, 1993 to 9:26 A.M. on April 8, 1993. Recovery was monitored for about 2 hours following the discharge period. Water was discharged through a 2-inch fire hose that emptied into a small tributary sloping away from the well. The flow rate was monitored using a 5-gallon bucket and stopwatch. Water flowed at about 52 gpm when the test was started. The flow rate declined to about 42 gpm one hour into the test and was about 36 gpm after 22 hours of testing. The overall average flow rate (based on hourly values) was 38 gpm. Total discharge during the test period (22 hours) was about 42,400 gallons. Pressure readings were monitored at the well head before the test to determine the static water level and during the test to determine constant drawdown. Results of monitoring during the test and corrections applied to the raw data are listed in Appendix B.

Semilog plots of t/r^2 (time/well radius squared in minutes per square foot) versus dd/Q (drawdown/discharge rate in feet per gallon per minute) were constructed using the test data (Figure 14). Based on a best-fit line through the data points a transmissivity of 63 ft^2/day was calculated. A transmissivity of

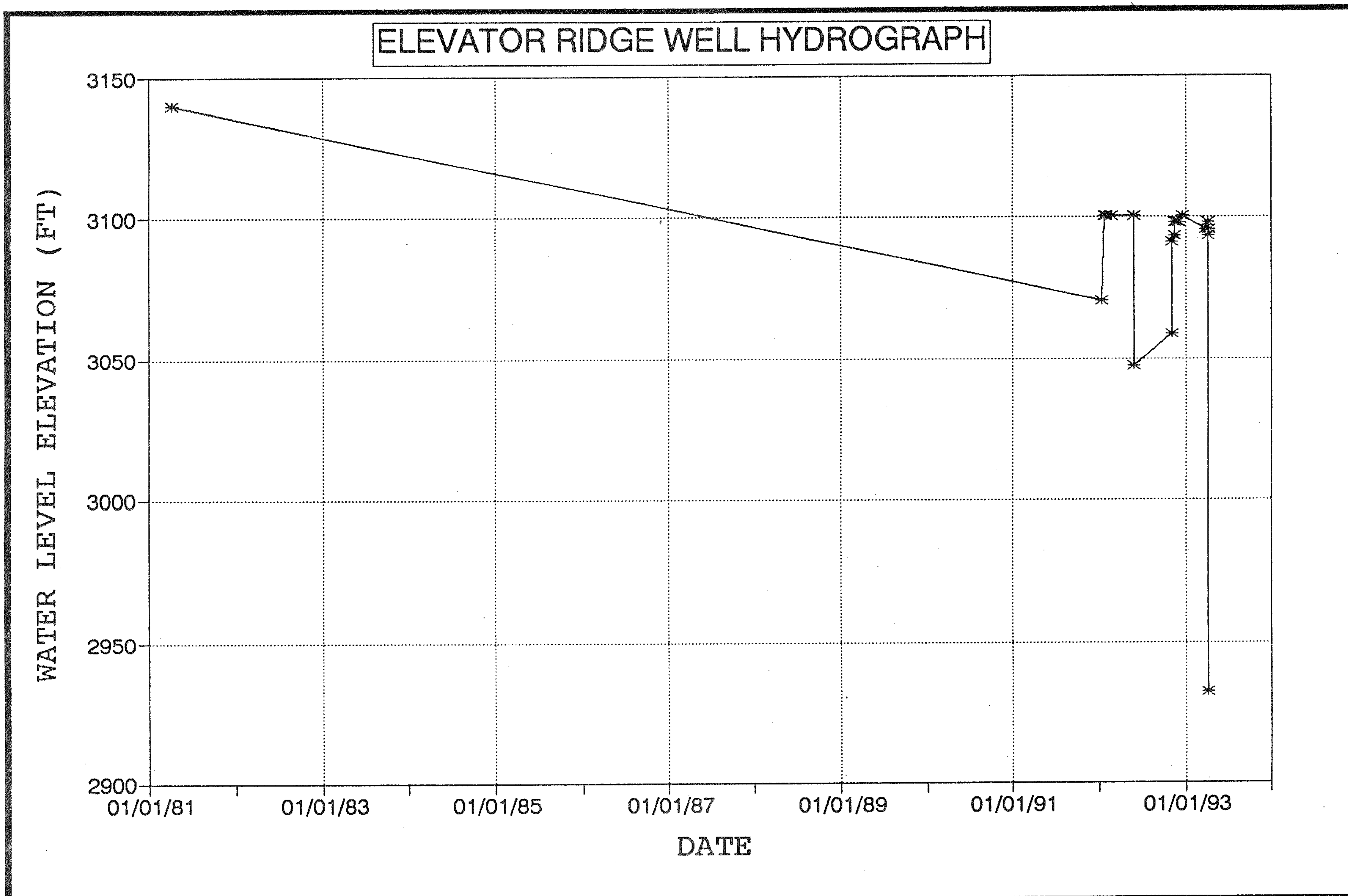


Figure 13. Hydrograph of reported water level measurement at the Elevator Ridge well.

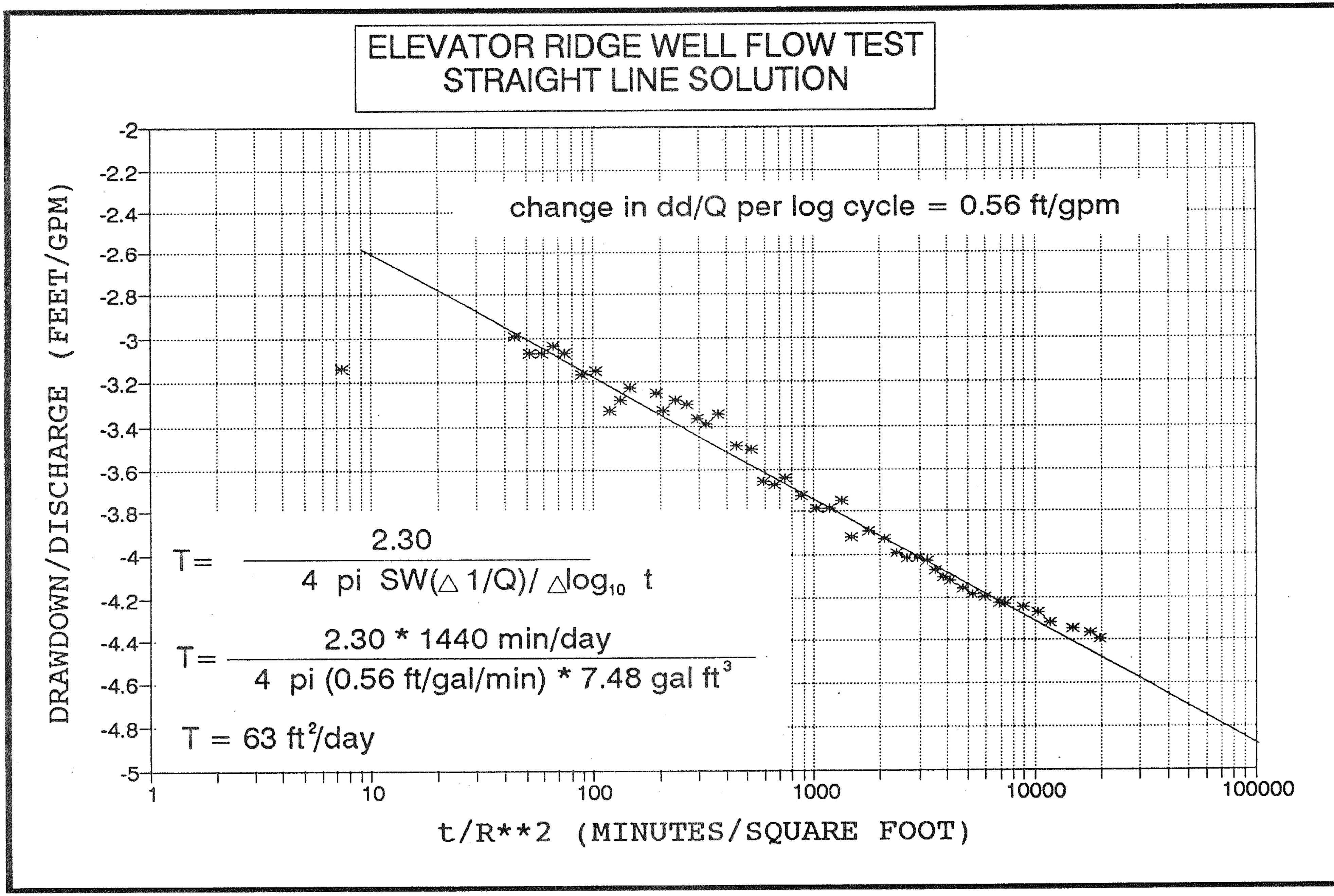


Figure 14. Semilog plot t/r^2 (time of measurement/well radius squared) versus dd/Q (drawdown/corrected discharge rate) during the discharge period of the Elevator Ridge well aquifer test.

76 ft^2/day was calculated based on the recovery of wellhead pressure after shutting in the well and using the overall average discharge rate of 38 gpm (Figure 15). The average transmissivity is 70 ft^2/day based on flow and recovery parts of the test. No evidence of either barrier or recharge boundaries were indicated by the test. A storage coefficient of 1.9×10^{-5} was calculated by replotting the t/r^2 versus dd/Q semilog plot at a scale allowing the zero dd/Q or t_0 value to be determined and applying the known values to the Theis equation (Figure 16). Lohman's (1979, p. 53) estimation method gives a storage coefficient of 1.8×10^{-4}, based on an aquifer thickness of 176 feet (Appendix B).

IMPACTS OF WATER DEVELOPMENT ON FLOWING WELLS

The aquifer tests have provided a better understanding of Eagle aquifer characteristics. Consequently, more accurate impacts to water supplies can be predicted under current and future uses. The most significant impact to water supplies would be the loss of flowing well conditions. Significant declines have already been observed. For example, static water levels are currently 18 psi (42 ft) lower at the Elevator Ridge well and 32 psi (74 ft) lower at the Haines Ridge well than in 1981 when these wells were constructed. These declines appear to be permanent losses (mined) from storage in the aquifer that will not be recovered unless water use is drastically reduced for many years. Additional wells and water usage will undoubtedly result in more head losses. In the vicinity of the wells tested, significant available head remains

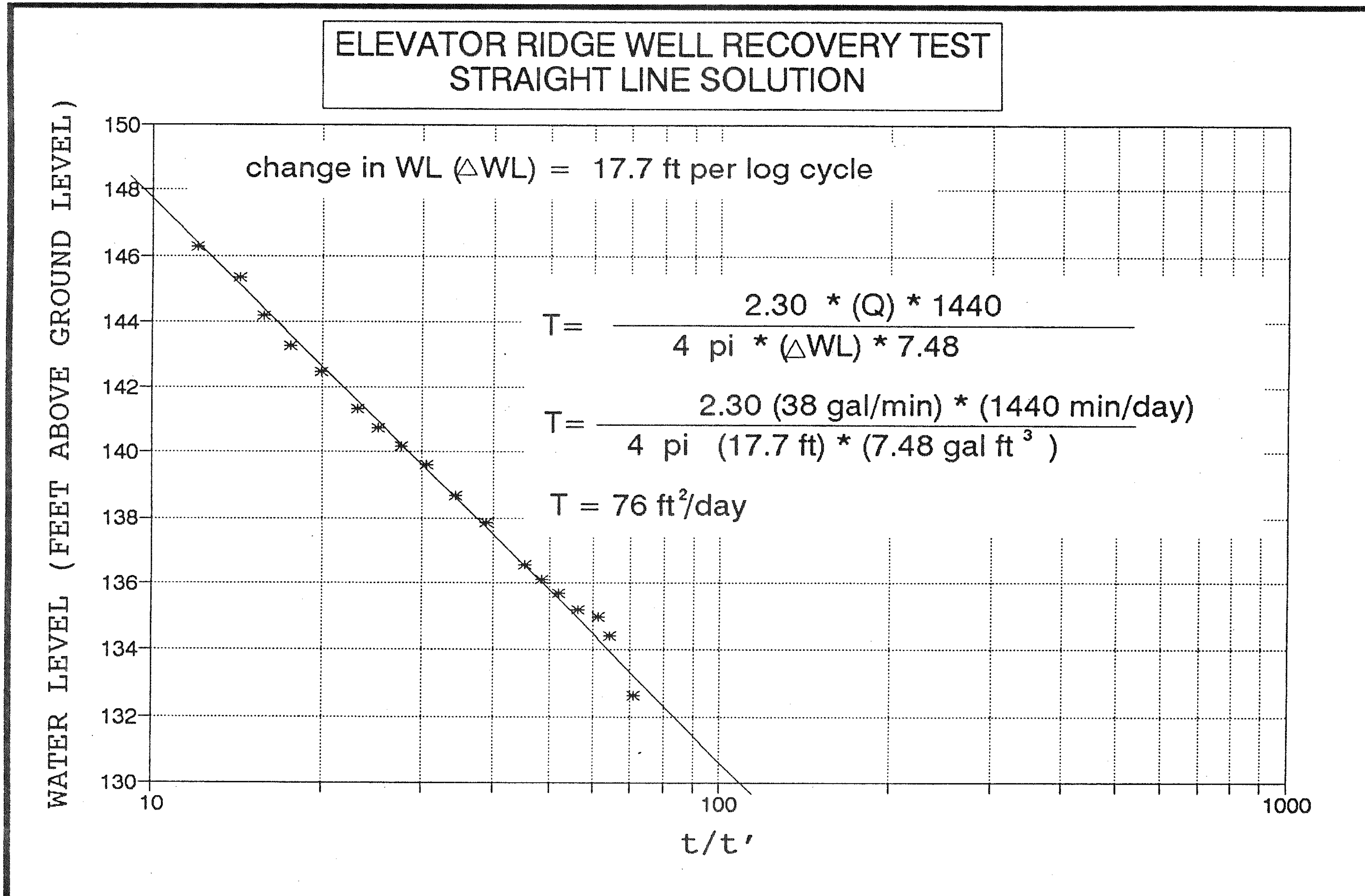


Figure 15. Semilog plot of the ratio of t/t' versus water level during the recovery period of the Elevator Ridge well aquifer test.

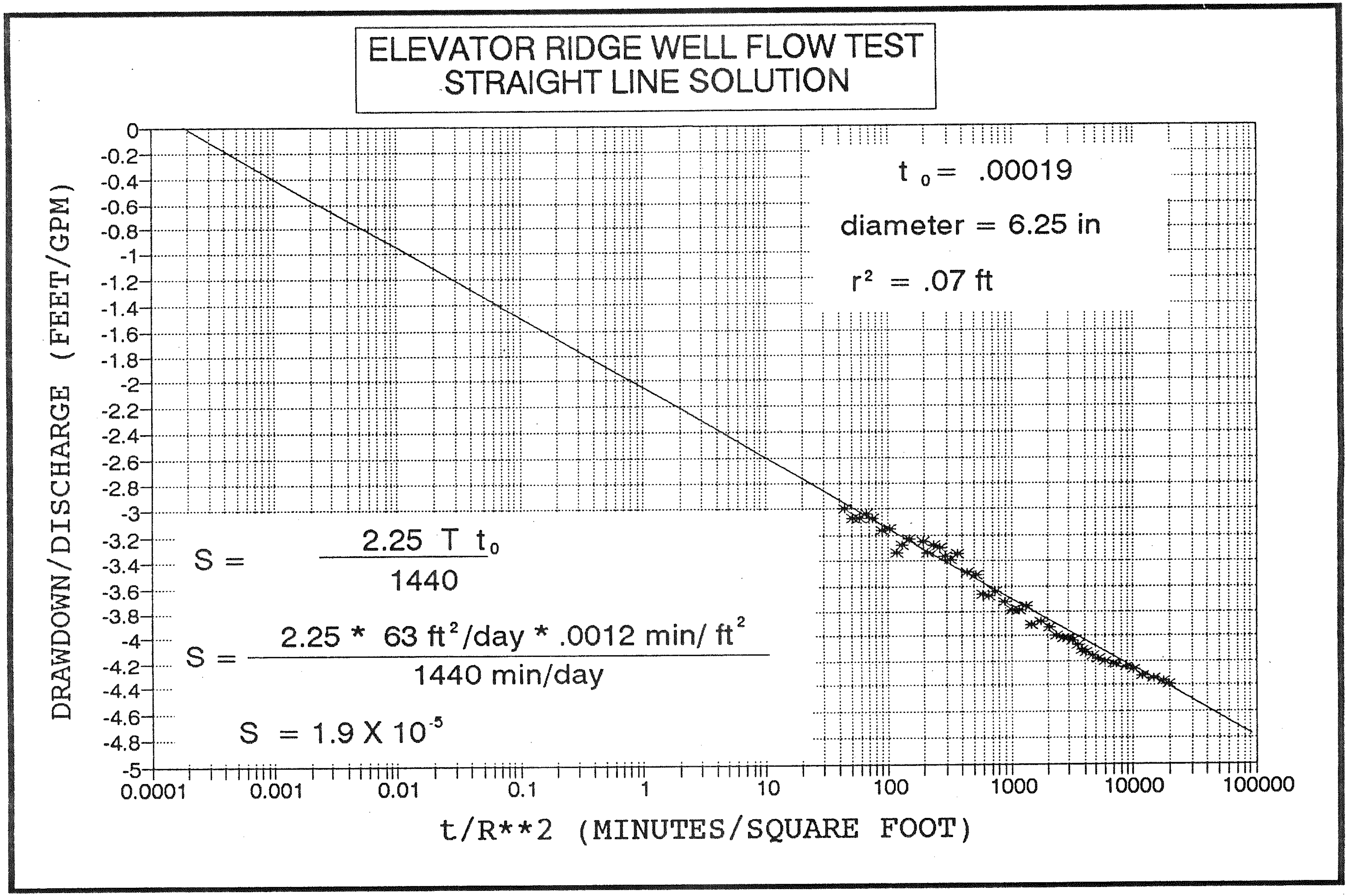


Figure 16. Semilog plot of t/r^2 (time of measurement/well radius squared) versus dd/Q (drawdown/corrected discharge rate) during the discharge period of the Elevator Ridge well aquifer test. Scale is changed from Figure 6 to allow the zero dd/Q or t_o to be picked.

with artesian pressures ranging from 68 psi at the Haines Ridge well to 112 psi at the Marcott well. Decisions must be made as to what are acceptable minimum target head levels. A logical minimum head level is the land surface at each well. When monitoring shows these targets are being approached, further development may need to be restricted contingent upon periodic monitoring to verify anticipated impacts.

Estimates of potential impacts to artesian pressure caused by water use can be developed in several different ways, including assessing impacts at individual wells and assessing interference between wells. The decline in flow rate at each well tested can be projected into the future assuming the trends will remain uniform through time. If the Haines Ridge well was allowed to flow unrestricted the predicted discharge would decline to 28 gpm after one year, 24 gpm after 5 years, 22 gpm after 10 years , 19 gpm after 25 years, 18 gpm after 50 years and 16 gpm after 100 years (Figure 17). Unrestricted flow at the Marcott well is predicted to decline to 8 gpm after 1 year, 6 gpm after 5 years, 5 gpm after 10 years, 3 gpm after 25 years, 2.5 gpm after 50 years, and 1.5 gpm after 100 years (Figure 18). Based on the early time trend, unrestricted flow at the Elevator Ridge well is predicted to decline to 9 gpm after 1 year, 4 gpm after 5 years, and 2 gpm after 10 years. Flow would have stopped after about 15 years of continuous discharge (Figure 19). Late time trends indicate flow rates declining to 28 gpm after 1 year, 26 gpm after 5 years, 25 gpm after 10 years, 24 gpm after 25 years, 23 gpm after 50 years,

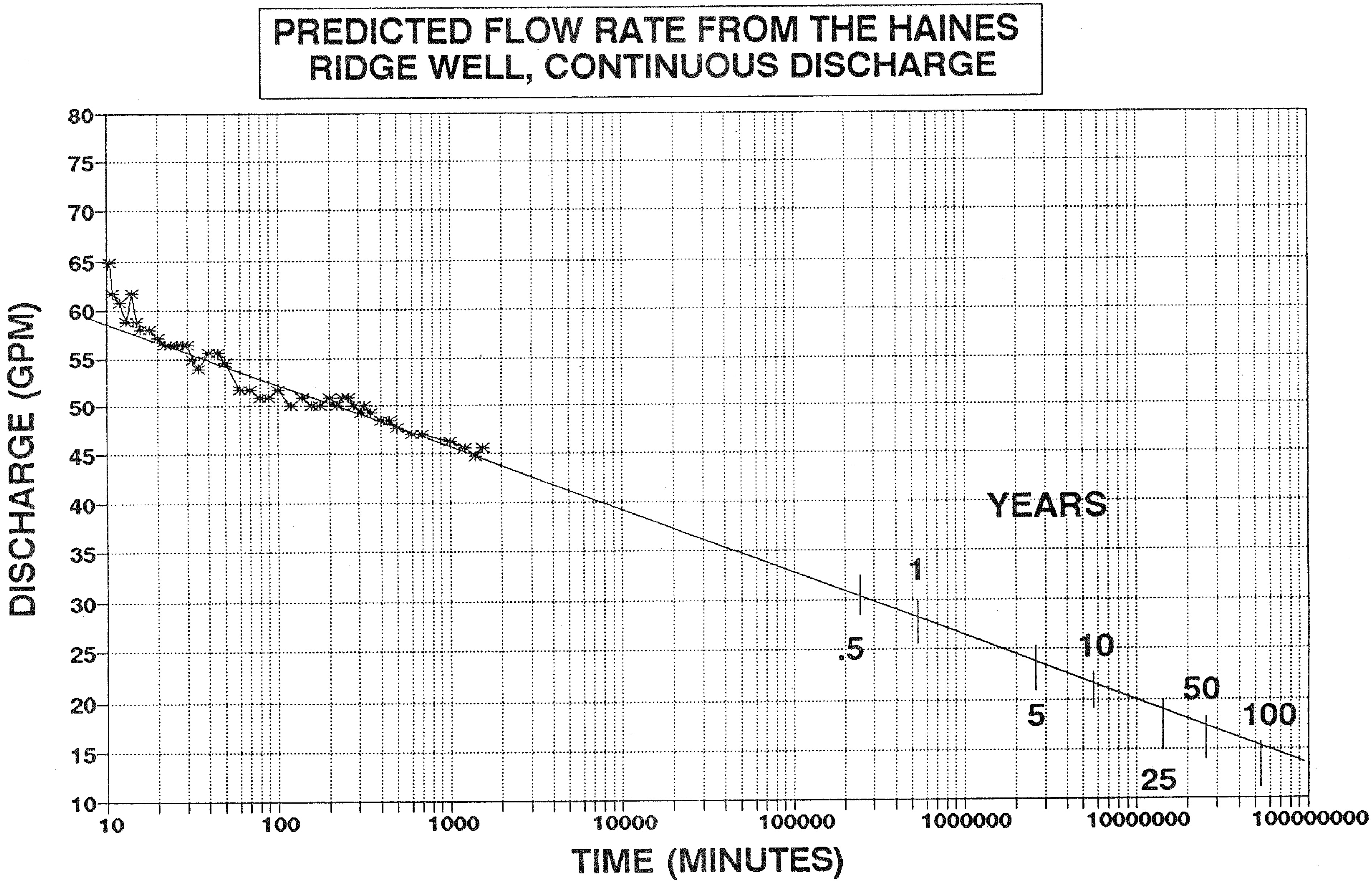


Figure 17. Projected flow rate for the Haines Ridge Well based on continuous discharge.

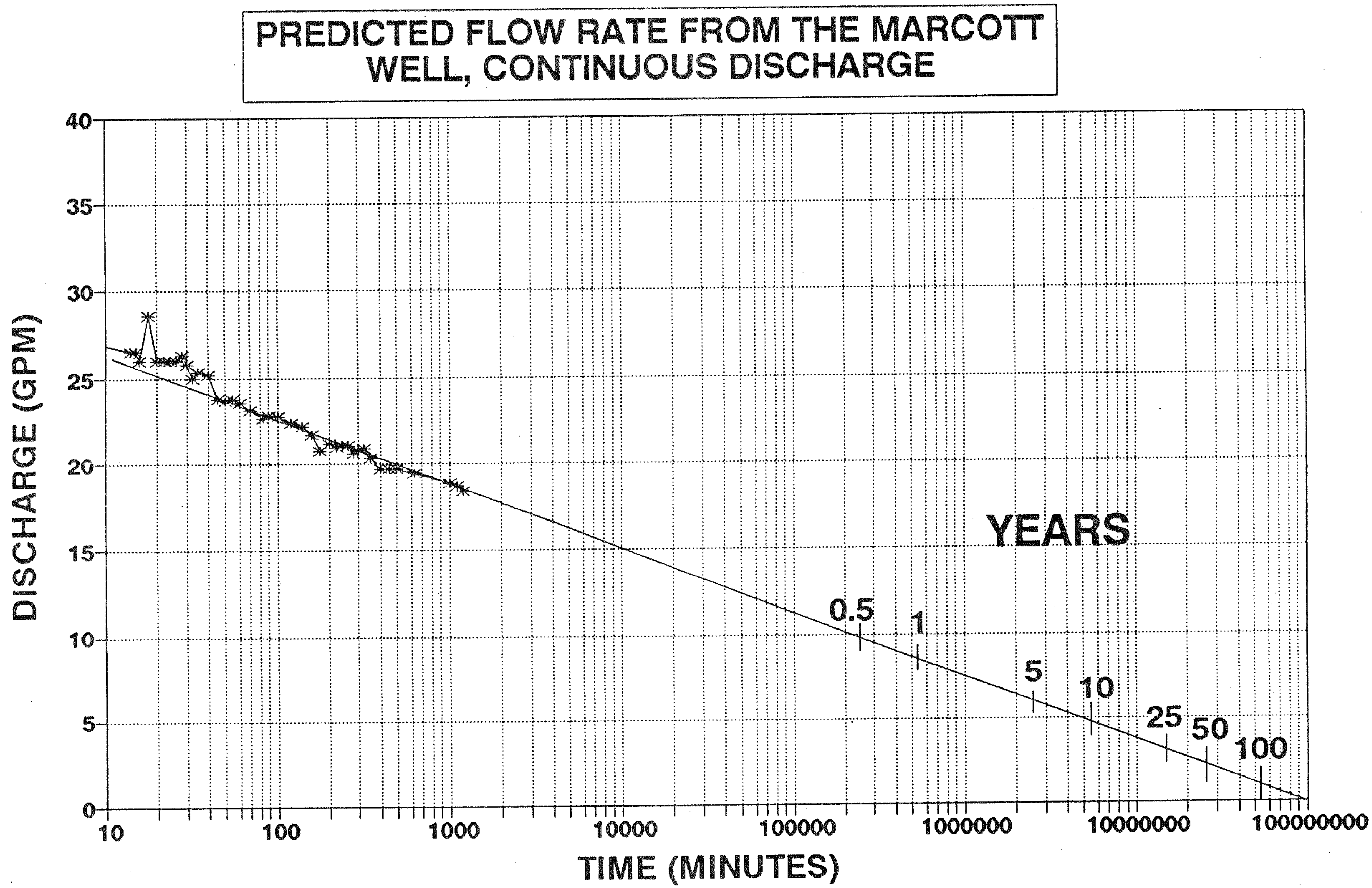


Figure 18. Projected flow rate for the Marcott Well based on continuous discharge.

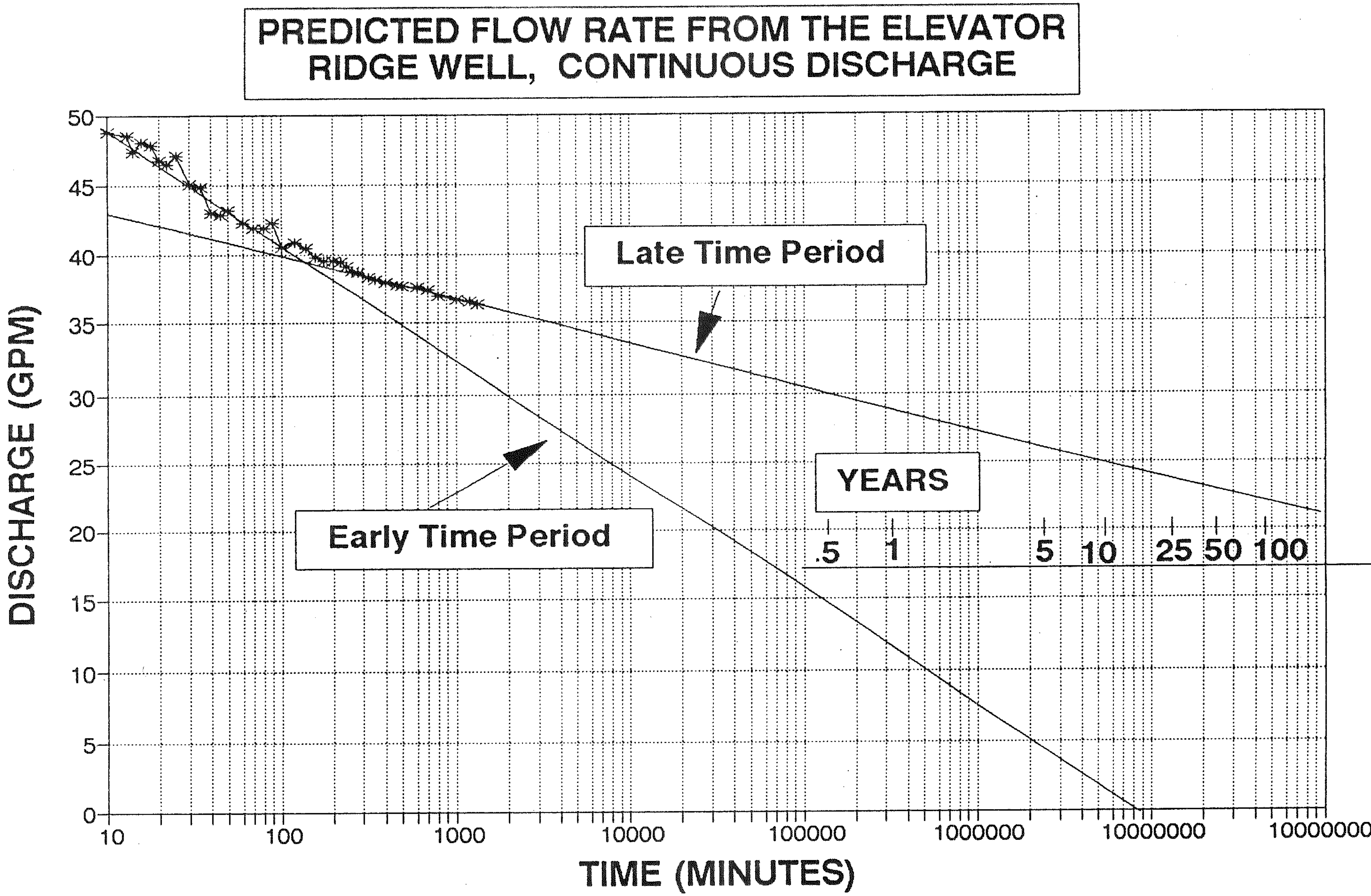


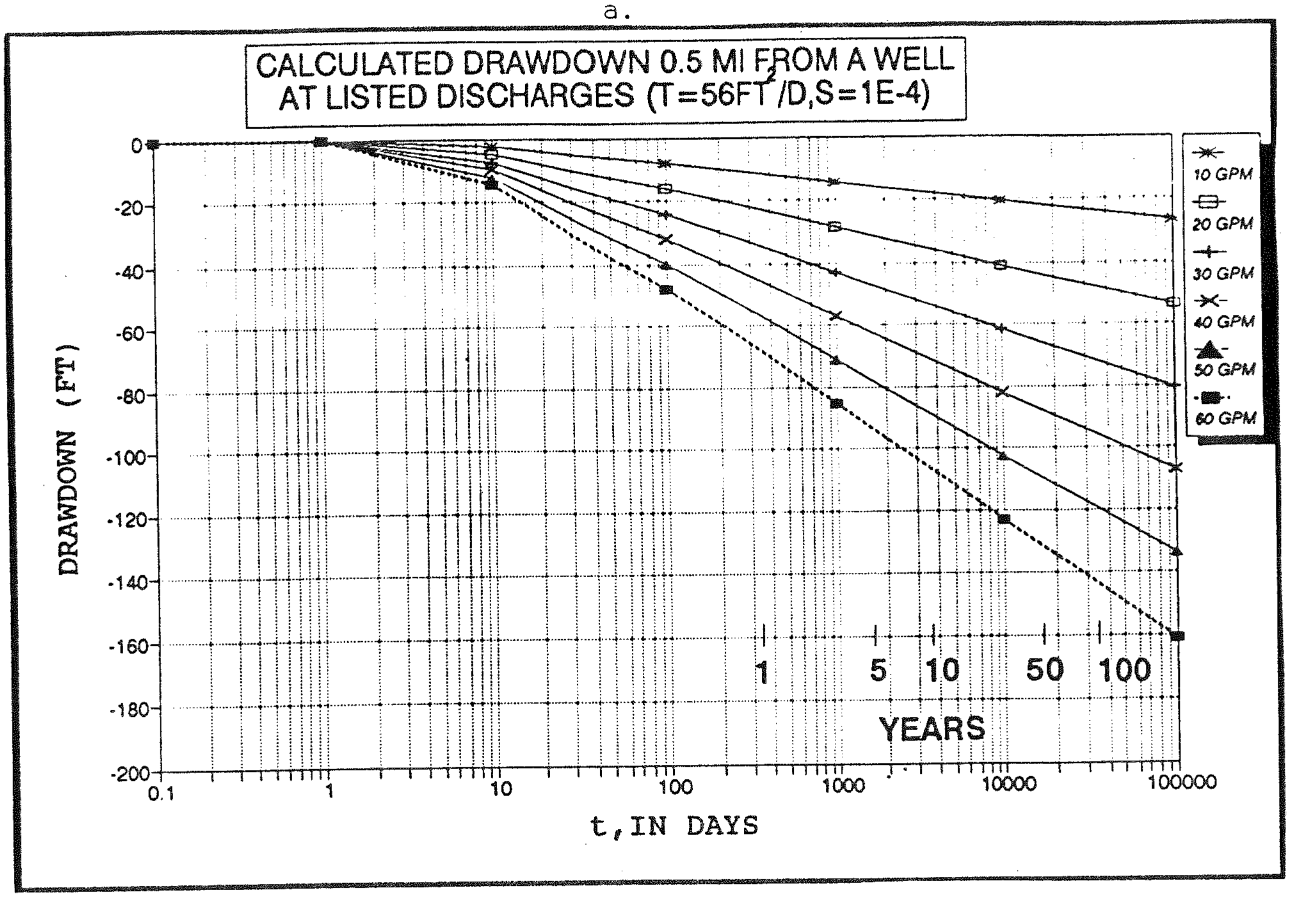
Figure 19. Projected flow rate for the Elevator Ridge Well based on continuous discharge. Projected flow based on the late time trend is significantly more optimistic than projected flow based on the early time trend.

and 22 gpm after 100 years. The significantly more optimistic flow-rate declines predicted by the late time trend line are probably the most realistic. The break in slope between the two trends is probably caused by either induced flow (leakage) from confining beds or flow from a recharge boundary.

A case for leakage could be made from the results of both the Haines Ridge flow test and the Marcott well flow test. As a result, the predicted flow rates are probably conservative at these sites. Meaning that if these wells were actually allowed to flow, the decline of flow rate would likely be less than predicted. Longer duration flow tests would be required to evaluate the late time trends of declining flow rates and would produce more accurate predictions.

Predicted interference between wells refers to the decline in pressure head caused by discharge from a nearby well tapping the same aquifer. Interference can be evaluated as either a time dependent variable or a distance dependent variable. To illustrate the effect of time on interference between wells, time-drawdown plots were constructed (Figures 20, 21). Drawdown values are predicted at times ranging from less than a day up to 100 years. The aquifer characteristics used to develop this prediction are T= 56 ft^2/day (average of three tests) and S= 1×10^{-4} (from Haines Ridge and Marcott tests). The predictions apply to a hypothetical well tapping the Eagle aquifer located 1/2 mile and 1 mile from a producing well (Figure 20) and 23,000 feet (horizontal distance between Haines Ridge and Marcott wells) and 10 miles from a well (Figure 21). Average discharge rates used in this prediction

a.



b.

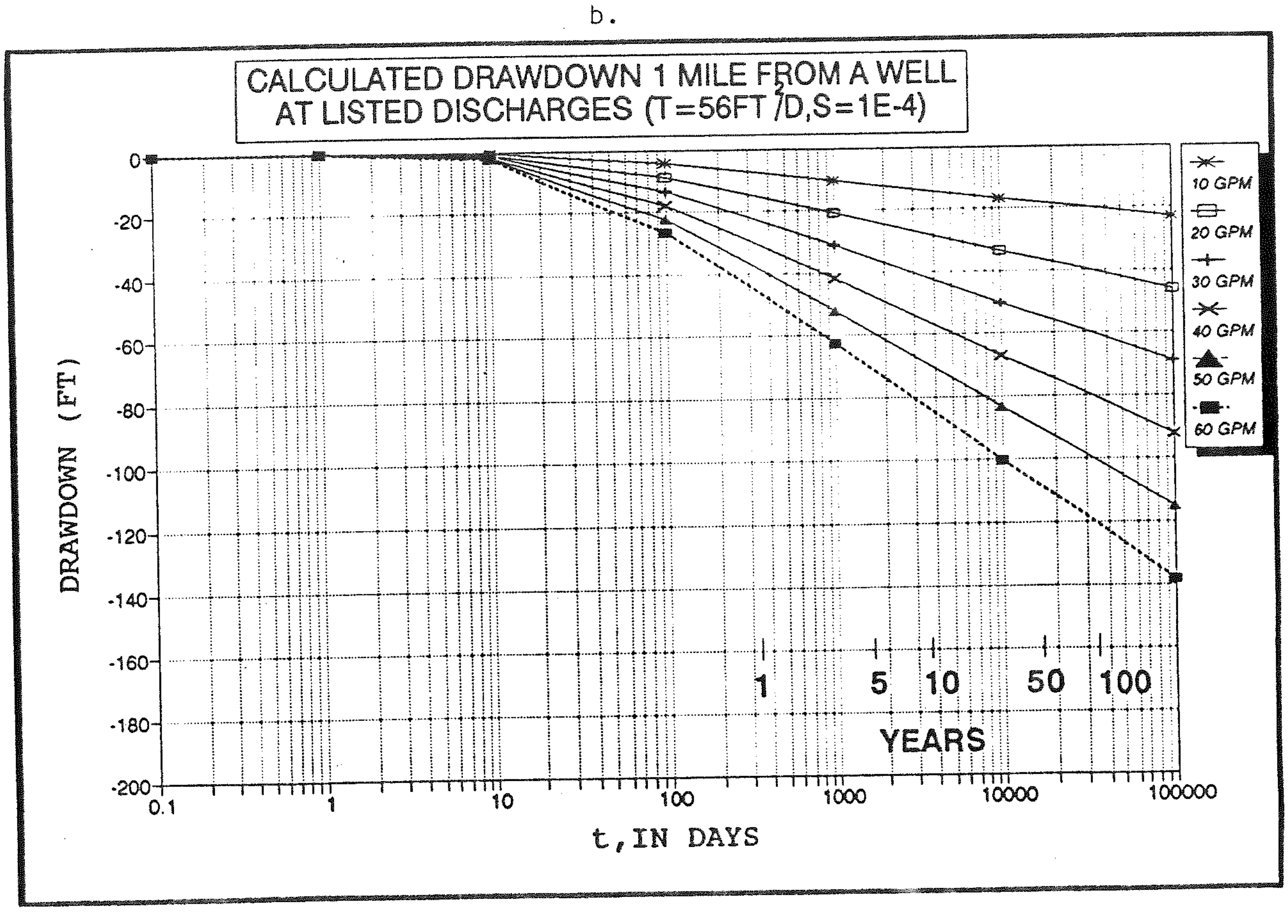
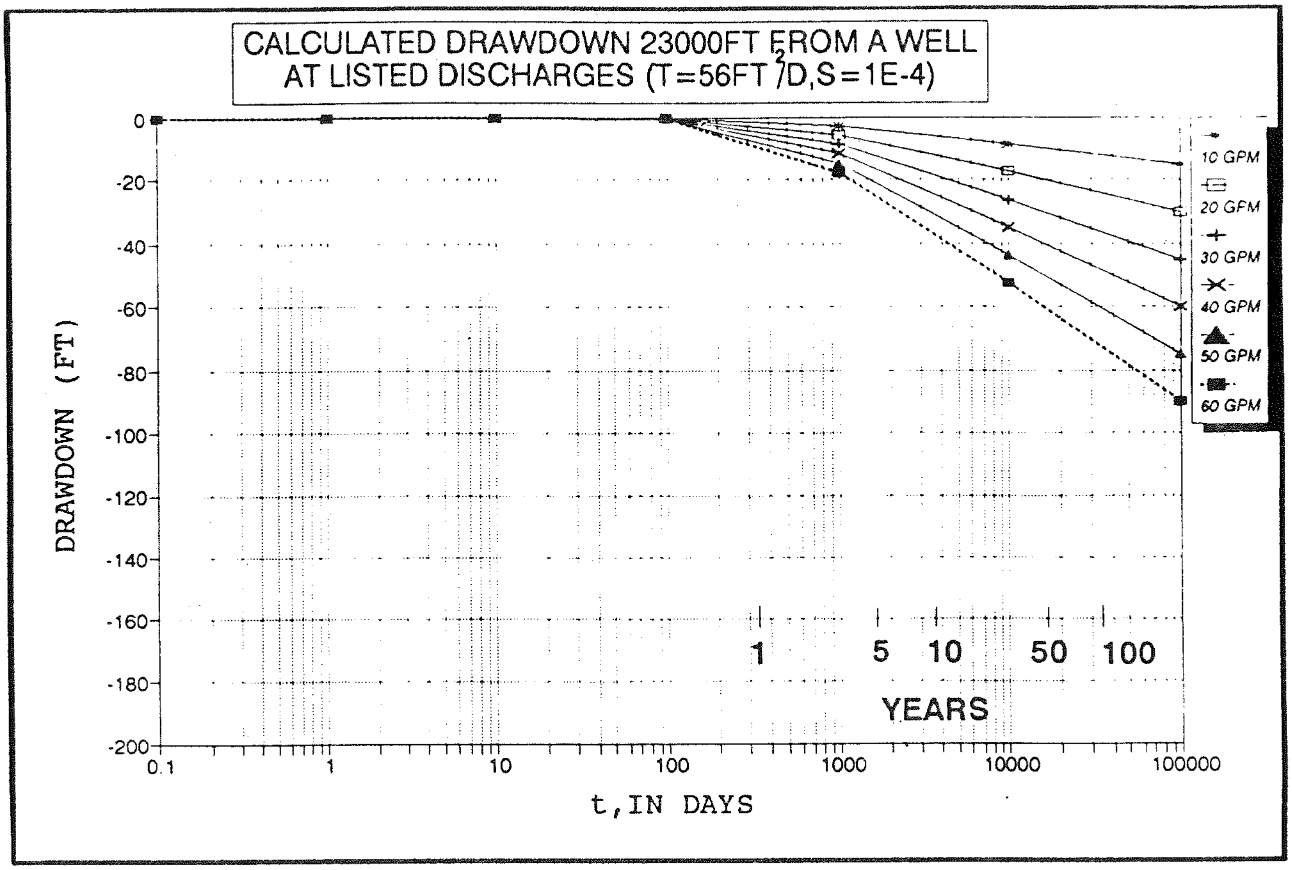


Figure 20. Predicted well interference through time at wells located (a) 0.5 miles and (b) 1 mile from a producing well. Predicted interference is based on T = 56 ft^2, S = 1 X 10^{-4} with continuous discharge at listed flow rates.

a.



b.

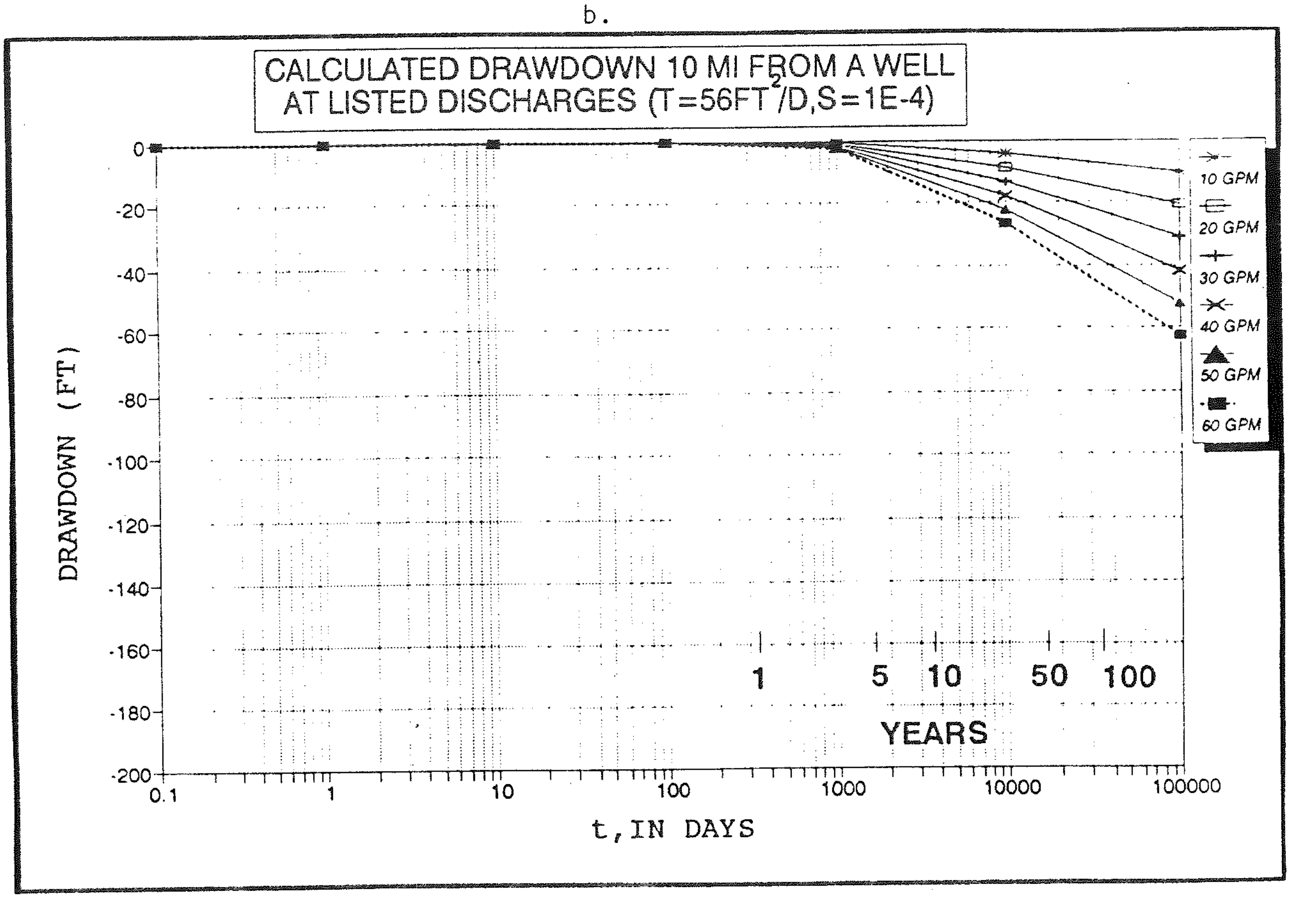


Figure 21. Predicted well interference through time at wells located (a) 23,000 feet and (b) 10 miles from a producing well. Predicted interference is based on T = 56 ft^2, S = 1 X 10^{-4} with continuous discharge at listed flow rates.

ranged from 10 to 60 gpm. The results predict increasing well interference with time, depending on the discharge rate and proximity of the wells. The initial time measurable drawdown occurs ranges from 1 day of discharge at a point 1/2 mile from a production well, increasing to after nearly 3 years of discharge at a point 10 miles from a production well. All of the time-drawdown diagrams on Figures 20-21 depict the impact of varying flow rates. Significant reductions in drawdown can be realized by simply reducing the flow rate. For example, at a distance 23,000 feet from a producing well , total drawdown or pressure head loss could be reduced from 38 feet to 7 feet by reducing the flow rate from 60 gpm to 10 gpm (Figure 21a). Shutting in the well completely would allow pressure increases up to an equilibrium point at which the aquifer pressure would stabilize.

The effect of distance on drawdown is shown on a series of distance-drawdown plots developed for specific time intervals (Figures 22 and 23). This analysis was based on the same aquifer characteristics (T =56 ft^2/day and S = 1 X 10-4) that were used in the time-drawdown assessment. Average discharge rates ranged from 10 to 60 gpm. Drawdowns are predicted at the various distances after 1 year, 5 years, 10 years, 50 years, and 100 years.

The radial distance over which measurable drawdown can be observed (radius of influence) ranges from less than 19 miles after 1 year of discharge (Figure 22a) to more than 45 miles after 100 years of discharge (Figure 23). Again, simply decreasing flow

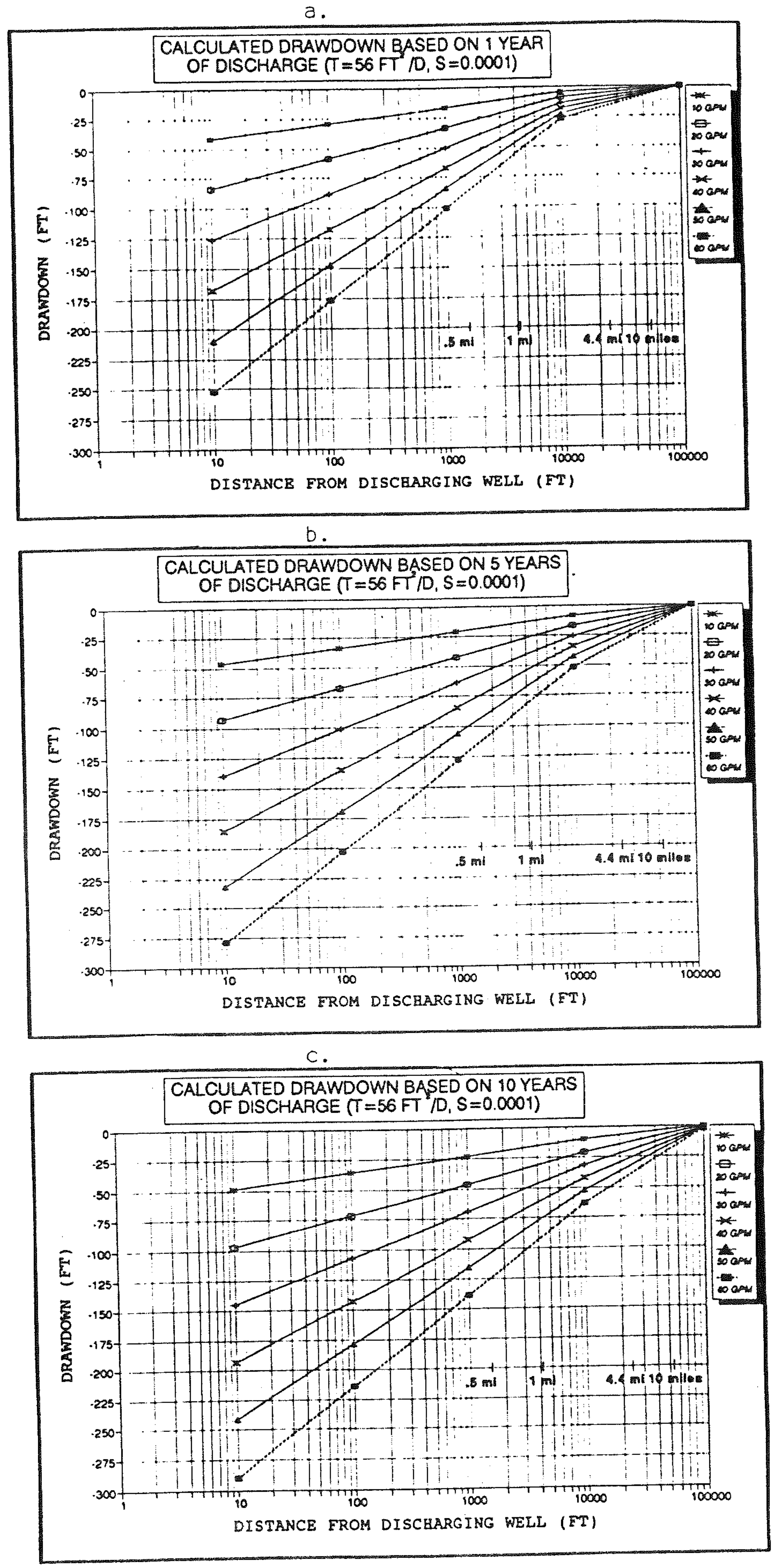
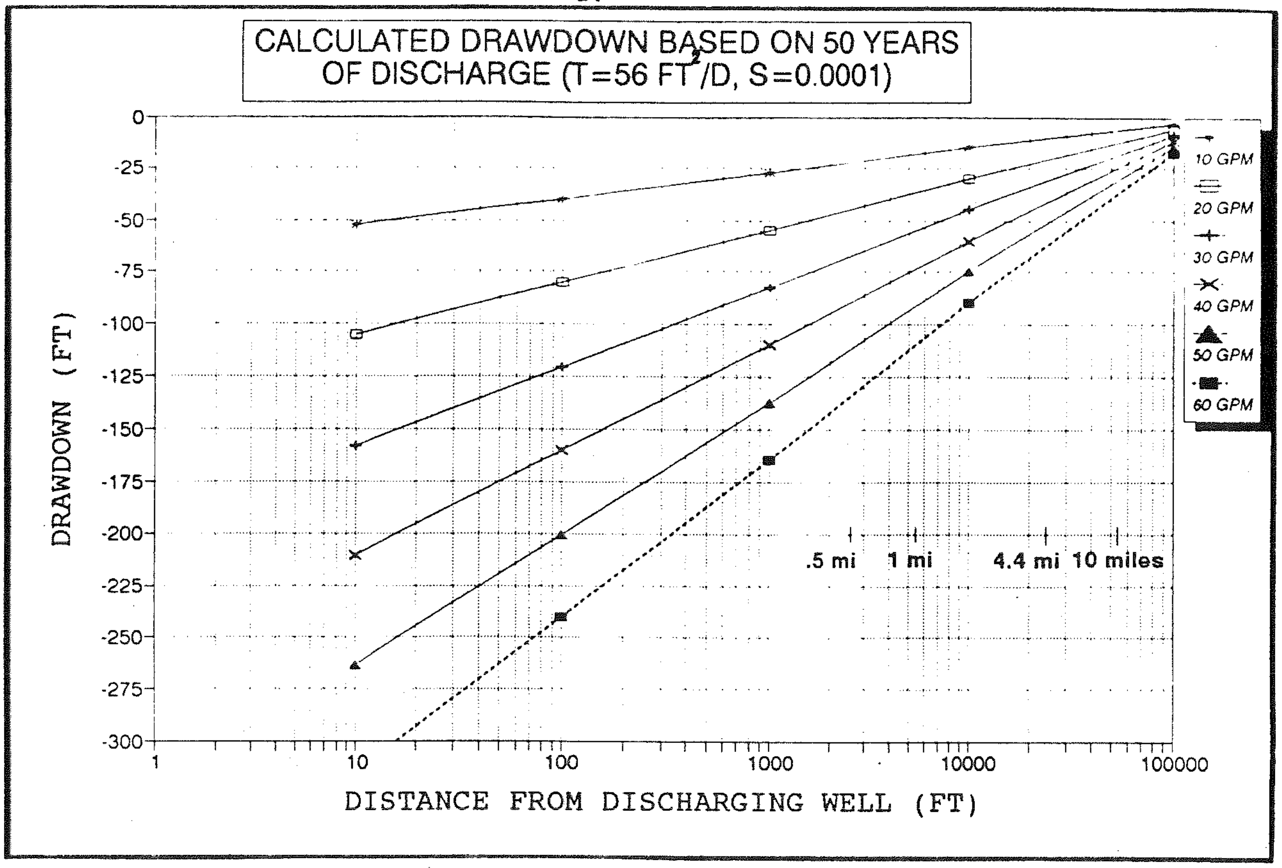


Figure 22. Predicted drawdown at distances ranging from 10 to 100,000 feet from a well producing for (a) 1, (b) 5, and (c) 10 years. Predicted values are based on T = 56 ft^2, S = 1 X 10^{-4} with continuous discharge at listed flow rates.

a.



b.

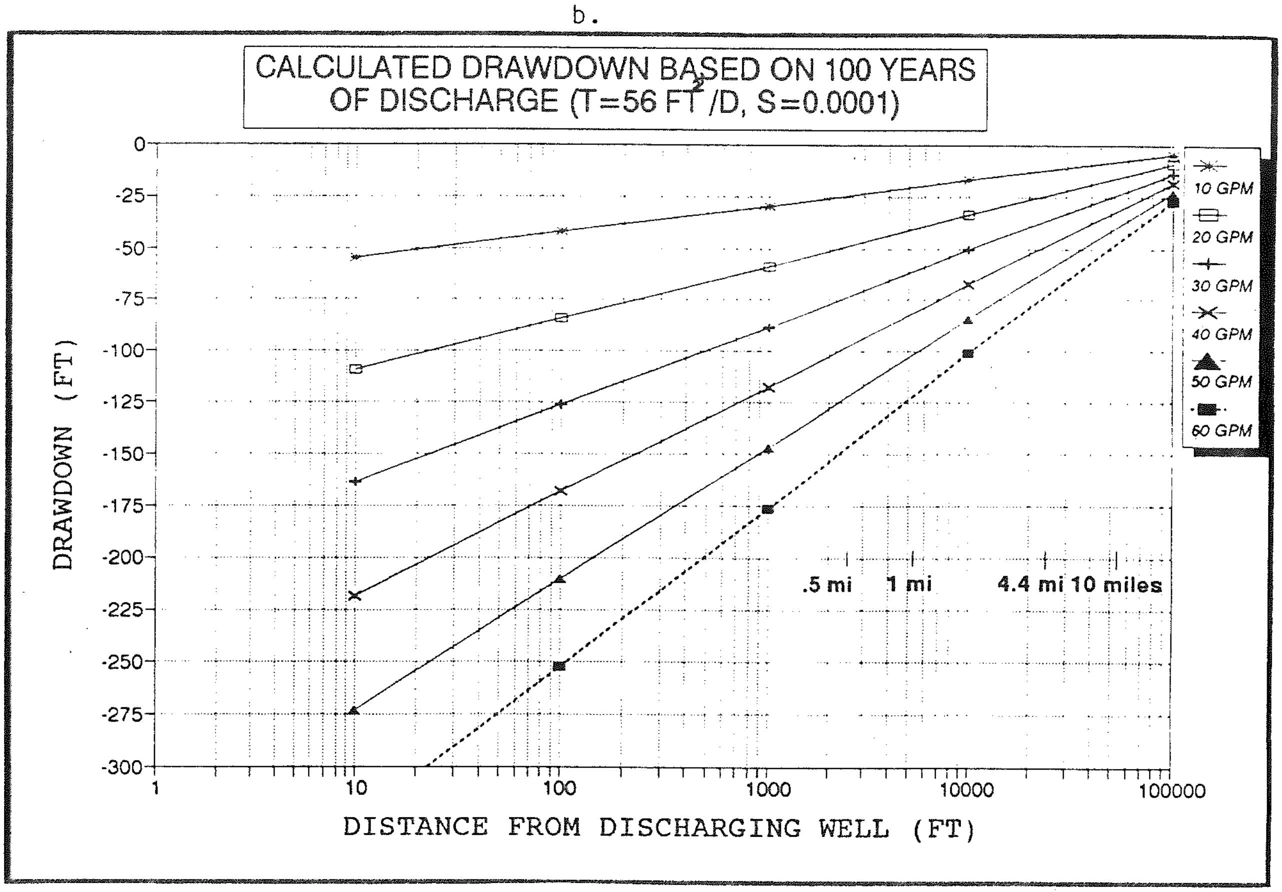


Figure 23. Predicted drawdown at distances ranging from 10 to 100,000 feet from a well producing for (a) 50, and (b) 100 years. Predicted values are based T = 56 ft^2, S = 1 X 10^{-4} with continuous discharge at listed flow rates.

rates can be shown to significantly reduce drawdown or head loss within the radius of influence.

Drawdown will spread radially around a well causing head losses dependent both on duration of production and distance from the well. The cone of depression formed by the drawdown will cause well interference at any point located within the radius influence of a producing well. If two or more wells have intersecting cones of depression, drawdown in all of these wells (mutual interference) will increase reducing the available head at all impacted wells. If this scenario is expanded over a large area, head losses can occur that would eliminate flowing well conditions over an entire artesian basin.

Although this work has focused on the Eagle aquifer, head declines in all flowing artesian aquifers in Fergus and Petroleum counties are causing concern to livestock operators and other water users. Other aquifers that are known to flow without adequate controls include Judith River aquifer, and the Third Cat Creek aquifer. A hydrostratigraphic column shown in Figure 24 depicts the stratigraphic and head relationships between these aquifers as well as the Madison Group aquifer. This diagram is based on conditions that are to be expected near the Marcott well. In general, artesian pressures increase with aquifer depth. Over-development of any of these aquifers can change the pressure-head relationships, potentially eliminating flowing well conditions in several aquifers.

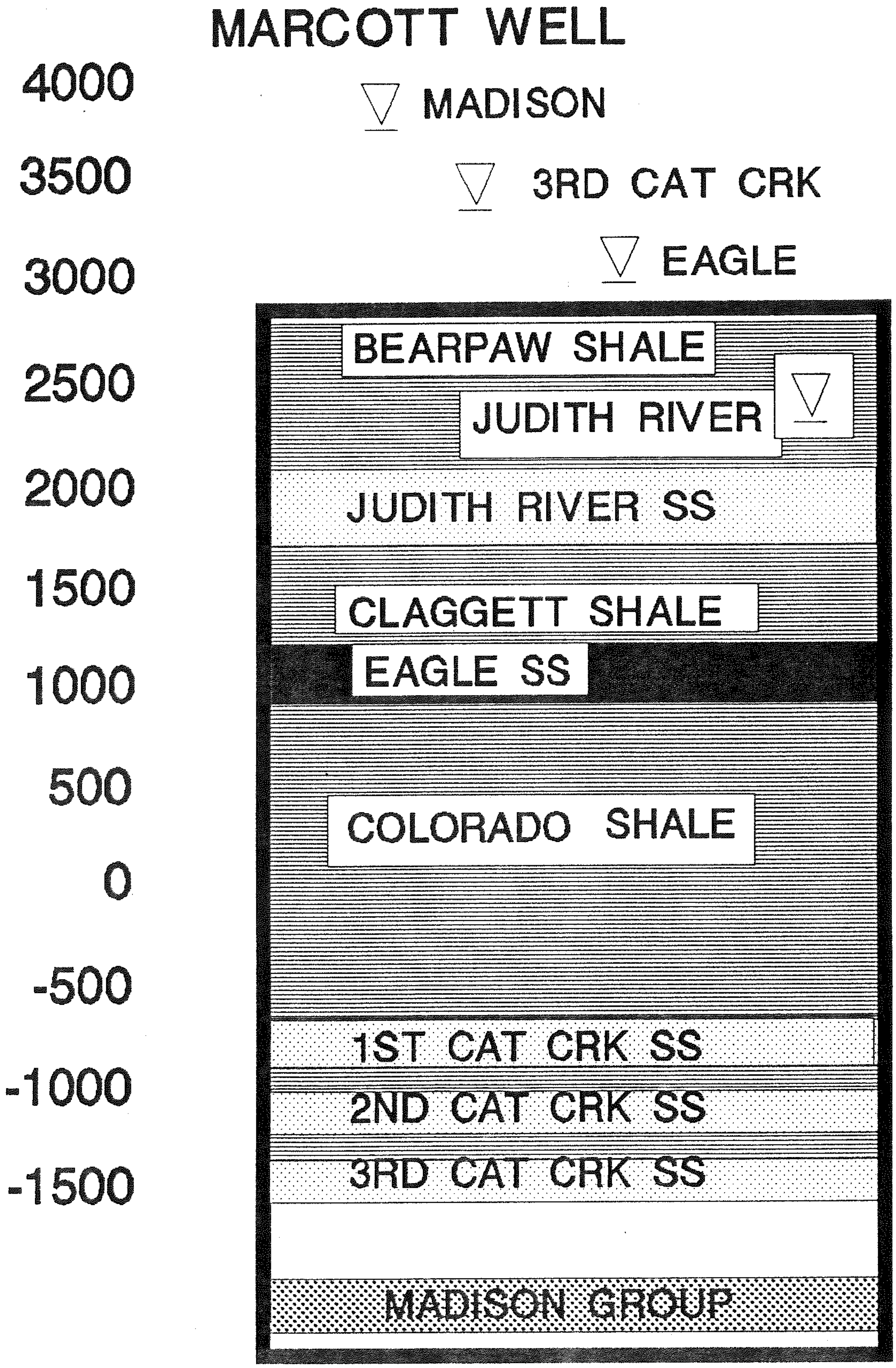


Figure 24. Hydrostratigraphic column depicting stratigraphic and head relationships between major aquifers at the Marcott well. Estimated water levels for each aquifer are shown by an inverted triangle (▿).

SUMMARY AND CONCLUSIONS

The Eagle aquifer is a reliable source of good quality water in much of central Montana. In addition to the quality, large areas underlying the aquifer are under flowing artesian conditions. Concern by landowners and BLM over declining pressures in this area has increased interest in protecting this resource. Predicted impacts to artesian pressures in the Eagle aquifer are based on hydrogeologic data compiled and collected for the BLM.

Data from three flowing well aquifer tests in eastern Fergus County, Montana were used to calculate aquifer characteristics of the Eagle aquifer. Aquifer characteristics are summarized in the following list:

Haines Ridge Well

Transmissivity = 78 ft^2/day

Storage Coefficient = 1.4×10^{-4}

Marcott Well

Transmissivity = 19.2 ft^2/day

Storage Coefficient = 1.1×10^{-4}

Elevator Ridge Well

Transmissivity = 70 ft^2/day

Storage Coefficient = 1.8×10^{-4}

The lower transmissivity at the Marcott well may be a result of reduced permeability or aquifer thickness as the aquifer pinches out to the east. Transmissivity values calculated from the tests are interpreted to be quite reliable based on the close agreement between values calculated from both the discharge and recovery parts of the tests. Storage coefficients are the best estimates available but may vary from the actual aquifer storage coefficient. These inconsistencies are to be expected because: 1) no drawdown was measured in observation wells during the test; 2) minor changes in the slope of the line used to calculate transmissivity can result in relatively large changes in storage coefficient; and 3) other impacts such as barrier boundaries, recharge boundaries, and leakage may impact test results. Nonetheless the best estimates of storage coefficients were made based on the available data.

Historical losses of pressure head between 1981 to 1992 ranged from 74 feet at the Haines Ridge well to 42 feet at the Elevator Ridge well. Minor pressure head declines were measured at the Marcott well from April, 1992 to November, 1992.

Flow rates declined during all three aquifer tests. At the Haines Ridge well flow dropped from an initial rate of 70 gpm to a final rate of 45 gpm after 26 hours of flow. At the Marcott well flow dropped from an initial rate of 36 gpm to a final rate of 18 gpm after 20 hours of flow. At the Elevator Ridge well flow dropped from an initial rate of 52 gpm to a final rate of 36 gpm after 22 hours of flow. Projecting these flow rates into the future indicate significant decline rates if flow is left unchecked. More optimistic trends were indicated by late time data from the Elevator Ridge well. These slower decline rates appear to be caused by leakage from overlying and underlying confining beds. Similar trends may eventually develop at the Haines Ridge well and Marcott well if discharges are monitored for a longer time period.

Well interference was not documented during monitoring at any of these wells. But as more water is extracted from existing wells and more wells are installed the potential for well interference increases. Reducing excess flow when water is being wasted and shutting wells in when water is not being put to beneficial use are the best means to conserve water. It is conceivable that in some instances abandoned flowing wells will require plugging.

In many cases well owners are not comfortable completely shutting in flowing wells because of potential damage to the well head caused by frezing and also potential damage to old well casing caused by large changes in borehole pressures. The most simplistic method of conserving water resources in the Eagle and other flowing artesian aquifers is to partially shut-in flowing wells. For example, there is a direct relationship between water conserved, as a function of drawdown, to reduced flow rate (Figures 20-23). Reducing the flow rate by a factor of 6 will reduce drawdown or head loss by a factor of 6, significantly conserving aquifer pressures and aquifer storage. Such simple conservation measures can maintain flowing well conditions and greatly extend the life of the aquifer.

Existing artesian pressures are large enough to sustain current users of the Eagle aquifer near the three BLM wells tested. Current shut-in-pressures are 68 psi at the Haines Ridge well, 111 psi at the Marcott well, and 72 psi at the Elevator Ridge well. Periodic monitoring of stabilized shut-in-pressures will indicate if excessive water level declines are occurring and allow water managers to assess additional aquifer development. Prior to additional development longer term flow tests at one or more of these wells would provide a better background for predicting long-term impacts.

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APPENDIX A

MONTANA BUREAU OF MINES AND GEOLOGY
BUTTE, MONTANA 59701 (406)496-4101

WATER QUALITY ANALYSIS
LAB NO.: 81Q5001

State:	MT	County:	FERGUS
Latitude-Longitude:	47D33'03'N 108D31'09'W	Site Location:	21N 25E 28 CACA 01
Topographic Map:		MBMG Site:	M:132077
Geologic Source:	211EGLE* *	Project Id:	
Drainage Basin:	DD	Station Id:	
Agency + Sampler:	BLM	Sample Source:	WELL
Bottle number:		Land Surface Altitude:	2960.0 FT.
Date Sampled:	31 MAR 1981	Sustained Yield:	
Time Sampled:		Yield Meas Method:	
Lab + Analyst:		Total Depth of Well:	1975.0 FT. rept.
Date Complete:		SWL above(-) or below GS:	
Sample Handling:		Casing Diameter:	8.0 In.
Method Sampled:	GRAB	Casing Type:	STEEL
Procedure Type:	Dissolved	Completion Type:	SS SCREEN
Water Use:		Perforation Interval:	1799.0 to 1809.0 FT.

Sampling Site: BUREAU OF LAND MANG * HAINES RIDGE WELL
Geologic Source: EAGLE SANDSTONE

	mg/L	meq/L		mg/L	meq/L
Calcium (Ca)	.8	0.04	Bicarbonate (HCO3)	940.	15.41
Magnesium (Mg)	4.4	0.36	Carbonate (CO3)		0.00
Sodium (Na)	375.	16.31	Chloride (Cl)	85.	2.40
Potassium (K)		0.00	Sulfate (SO4)	5.	0.10
Iron (Fe)	.26	0.01	Nitrate (as N)		0.00
Manganese (Mn)		0.00	Fluoride (F)		0.00
Silica (SiO2)			OrthoPhosphate (as P)		0.00
Total Cations:		16.73	Total Anions:		17.91

Standard Deviation of Anion-Cation Balance (Sigma): 3.30

Calculated Dissolved Solid:	933.51	Total Hardness as CaCO3:	20.11
Sum of Diss, Constituent:	1410.46	Field Hardness as CaCO3:	
Field cnductvy, micromhos:		Total Alkalinity as CaCO3:	770.96
Lab cnductvy, micromhos:	2500.	Field Alkalinity as CaCO3:	
Field PH:		Ryznar Stability Index:	17.32
Laboratory PH:		Langlier Saturation Index:	-8.66
		Sodium Adsorption Ratio:	36.39

Parameter	Value	Parameter	Value
Field Temp, Air		Field Temp, Water	

Field remarks:
1: ANALYSIS PROVIDED BY BUREAU OF LAND MANAGEMENT

Explanation: mg/L = milligrams per liter, ug/L = micrograms per liter, meq/L milliequivelents per liter. FT = feet, Mt = meters, TR = total recoverable, TOT = total, BIO = biologically available. Sigma includes AL, CU, SR, ZN, and H+ if reported.

Printed: 04 MAY 93

Percent Meq/L (For Piper Plot)

Ca	Mg	Na	K	Cl	SO4	HCO3	CO3
0.2	2.2	97.6	0.0	13.4	0.6	86.0	0.0

APPENDIX A (continued)

WATER QUALITY ANALYSES FROM THE EAGLE AQUIFER, EASTERN FERGUS COUNTY, MONTANA

MONTANA BUREAU OF MINES AND GEOLOGY
BUTTE, MONTANA 59701 (406)496-4101

WATER QUALITY ANALYSIS
LAB NO.: 92Q5000

State:	MT	County:	FERGUS
Latitude-Longitude:	47D30'25'N 108D24'12'W	Site Location:	20N 26E 09 CDAB 01
Topographic Map:		MBMG Site:	M:127844
Geologic Source:	211EGLE* *	Project Id:	
Drainage Basin:	EE	Station Id:	
Agency + Sampler:	BLM *DM1	Sample Source:	WELL
Bottle number:		Land Surface Altitude:	2885.0 FT.
Date Sampled:	30 JUN 1992	Sustained Yield:	
Time Sampled:	10::3	Yield Meas Method:	
Lab + Analyst:	ENLB*CRP	Total Depth of Well:	2102.0 FT. rept.
Date Complete:	20 JUL 1992	SWL above(-) or below GS:	
Sample Handling:		Casing Diameter:	6.0 In.
Method Sampled:	GRAB	Casing Type:	STEEL
Procedure Type:	Dissolved	Completion Type:	.035 JOHNSON SN
Water Use:	STOCKWATER	Perforation Interval:	1757.0 to 1767.0 FT.

Sampling Site: BUREAU OF LAND MANAGEMENT * MARCOTT WELL
Geologic Source: EAGLE SANDSTONE

	mg/L	meq/L		mg/L	meq/L
Calcium (Ca)	1.	0.05	Bicarbonate (HCO3)	1646.	26.98
Magnesium (Mg)		0.00	Carbonate (CO3)		0.00
Sodium (Na)	616.	26.80	Chloride (Cl)		0.00
Potassium (K)		0.00	Sulfate (SO4)	4.	0.08
Iron (Fe)	.14	0.01	Nitrate (as N)	<.05	0.00
Manganese (Mn)		0.00	Fluoride (F)		0.00
Silica (SiO2)			OrthoPhosphate (as P)		0.00
Total Cations:		26.85	Total Anions:		27.06

Standard Deviation of Anion-Cation Balance (Sigma): 0.42

Calculated Dissolved Solid:	1431.98	Total Hardness as CaCO3:	2.50
Sum of Diss, Constituent:	2267.14	Field Hardness as CaCO3:	
Field cnductvy, micromhos:		Total Alkalinity as CaCO3:	1350.00
Lab cnductvy, micromhos:	2390.	Field Alkalinity as CaCO3:	
Field PH:		Ryznar Stability Index:	8.14
Laboratory PH:	8.6	Langlier Saturation Index:	0.23
		Sodium Adsorption Ratio:	169.64

Parameter	Value	Parameter	Value
Field Temp, Air		Field Temp, Water	
ARSENIC,DISS(UG/L AS AS)	<5.	MERCURY,DISS(UG/L AS HG)	<1.
CADMIUM,DISS(UG/L AS CD)	<1.	RESIDUE, DISS,180C(MG/L)	1360.
LEAD,DISS(UG/L AS PB)	<10.		

Lab remarks:
1: ANALYSIS BY ENERGY LABS - BILLINGS - LAB NUMBER 92-25766

Explanation: mg/L = milligrams per liter, ug/L = micrograms per liter, meq/L milliequivelents per liter. FT = feet, Mt = meters, TR = total recoverable, TOT = total, BIO = biologically available. Sigma includes AL, CU, SR, ZN, and H+ if reported.

Printed: 04 MAY 93

Percent Meq/L (For Piper Plot)

Ca	Mg	Na	K	Cl	SO4	HCO3	CO3

MONTANA BUREAU OF MINES AND GEOLOGY
BUTTE, MONTANA 59701 (406)496-4101

WATER QUALITY ANALYSIS
LAB NO.: 81Q5000

State:	MT	County:	FERGUS
Latitude-Longitude:	47D32'53'N 108D36'41'W	Site Location:	21N 24E 26 CCBC 01
Topographic Map:		MBMG Site:	M:34882
Geologic Source:	211EGLE* *	Project Id:	
Drainage Basin:	DD	Station Id:	
Agency + Sampler:	BLM	Sample Source:	WELL
Bottle number:		Land Surface Altitude:	2940.0 FT.
Date Sampled:	31 MAR 1981	Sustained Yield:	
Time Sampled:		Yield Meas Method:	
Lab + Analyst:		Total Depth of Well:	1902.0 FT. rept.
Date Complete:		SWL above(-) or below GS:	
Sample Handling:		Casing Diameter:	8.0 In.
Method Sampled:	GRAB	Casing Type:	STEEL
Procedure Type:	Dissolved	Completion Type:	SS SCREEN
Water Use:		Perforation Interval:	1705.0 to 1715.0 FT.

Sampling Site: BUREAU OF LAND MANG * ELEVATOR RIDGE WELL
Geologic Source: EAGLE SANDSTONE

	mg/L	meq/L		mg/L	meq/L
Calcium (Ca)	.8	0.04	Bicarbonate (HCO3)	923.	15.13
Magnesium (Mg)	4.4	0.36	Carbonate (CO3)		0.00
Sodium (Na)	356.	15.49	Chloride (Cl)	57.5	1.62
Potassium (K)		0.00	Sulfate (SO4)	4.	0.08
Iron (Fe)	.21	0.01	Nitrate (as N)		0.00
Manganese (Mn)		0.00	Fluoride (F)		0.00
Silica (SiO2)			OrthoPhosphate (as P)		0.00
Total Cations:		15.90	Total Anions:		16.83

Standard Deviation of Anion-Cation Balance (Sigma): 2.72

Calculated Dissolved Solid:	877.59	Total Hardness as CaCO3:	20.11
Sum of Diss, Constituent:	1345.91	Field Hardness as CaCO3:	
Field cnductvy, micromhos:		Total Alkalinity as CaCO3:	757.02
Lab cnductvy, micromhos:	2250.	Field Alkalinity as CaCO3:	
Field PH:		Ryznar Stability Index:	17.34
Laboratory PH:		Langlier Saturation Index:	-8.67
		Sodium Adsorption Ratio:	34.55

Parameter	Value	Parameter	Value
Field Temp, Air		Field Temp, Water	

Lab remarks:
1: ANALYSIS RECEIVED FROM BUREAU OF LAND MANAGEMENT.

Explanation: mg/L = milligrams per liter, ug/L = micrograms per liter, meq/L milliequivelents per liter. FT = feet, Mt = meters, TR = total recoverable, TOT = total, BIO = biologically available. Sigma includes AL, CU, SR, ZN, and H+ if reported.

Printed: 04 MAY 93

Percent Meq/L (For Piper Plot)

Ca	Mg	Na	K	Cl	SO4	HCO3	CO3
0.3	2.3	97.5	0.0	9.6	0.5	89.9	0.0

APPENDIX B

WELL LOG
MONTANA BUREAU OF MINES AND GEOLOGY
GROUND WATER DIVISION

County: Fergus Location: T. 21N R. 25E Sec. 28 Tract: CACA01 Hole name or Number HAINES RIDGE

Hole location: M:132077

Recorded by: ED THATCHER Date hole Started: 09/16/80 Date hole Completed: 04/09/81 Driller: ED THATCHER Drilling Company THATCHER DRLG

Total well depth (ft) 1975 Well diameter: 12-3/4" from 0-100' 6-1/4" from - 1779' Casing diameter(s) and length (s): 8" from 0-100' 4-1/2" from 0-1779' Elevation: 2960

Type of casing(s): Steel Weight or gage of casing: Method-perforated or screened: 2-1/2" #20 slot stainless steel

Interval-perforated or screened: 1799-1809'; 1830-1850'; 1871-1881'; 1902-1912'

Has well been test pumped?: yes Were material samples taken?: no Was a water sample taken?: yes

Remarks: Total of 50 feet of screen in well. Casing was left open-ended. A cement basket was set at 1779' and well was grouted with cement. Well was completed in a pit. Closed-in pressure was 100 psi when completed. Well flowed at 65 gpm through a 4-1/2 inch pipe.

DRILLING LOG
Geological, drilling, and water conditions; remarks and sampling

From	To	
0	800	Gray shale. Bearpaw Shale
800	1260	Sandy shale. Judith River Formation
1260	1587	Gray shale and bentonite. Clagett Shale
1587	1627	Extremely hard materials, such as chirt, limestone or flint
1627	1780	Gray shale and bentonite.
1780	1920	Sandstone and grey shale layers. Eagle Sandstone
1920	1975	Gray shale with some ss traces. Telegraph Creek or Colorado Shale

APPENDIX B (continued)

WELL LOG
MONTANA BUREAU OF MINES AND GEOLOGY
GROUND WATER DIVISION

County: Fergus Location: T. 20N R. 26E Sec. 09 Tract: CDAB01 Hole name or Number MARCOTT

Hole location: M:127844

Recorded by: J. JOHNSON Date hole Started: ______ Date hole Completed: 04/17/92 Driller: J. JOHNSON Drilling Company J. JOHNSON DRG

Total well depth (ft) 2102 Well diameter: 8-3/4" from 0-1209' 5-7/8" from 1209-2102" Casing diameter(s) and length (s): 6" from 0-1209' 4" from 1155-2102' Elevation: 2885'

Type of casing(s): Steel Weight or gage of casing: .25" @ 6" 9.5" @ 4" Method-perforated or screened: 4" .035 slot stainless steel

Interval-perforated or screened: 1757-1767'; 1830-1840'; 1860-1880'

Has well been test pumped?: yes Were material samples taken?: no Was a water sample taken?: yes

Remarks: Total of 40 ft of screen in well. Well was grouted with cement to 1209'and used 260 sacks type G cement. Well was completed in a pit. Closed in pressure was 111 psi 11/30/92. Well flowed at 25 gpm when constructed.

DRILLING LOG
Geological, drilling, and water conditions; remarks and sampling

From	To	
0	735	Bearpaw Shale with stringers of bentonite and rock.
735	1160	Judith River Formation.
1160	1714	Claggett Shale.
1714	1990	Eagle Sandstone with stringers of clay and sand and rock.
1990	2102	Colorado Shale.

APPENDIX B (continued)

WELL LOG
MONTANA BUREAU OF MINES AND GEOLOGY
GROUND WATER DIVISION

County: Fergus Location: T. 21N R. 24E Sec. 26 Tract: CCBC01 Hole name or Number ELEVATOR RIDGE

Hole location: M:34882

Recorded by: ED THATCHER Date hole Started: 09/19/80 Date hole Completed: 04/09/81 Driller: ED THATCHER Drilling Company THATCHER DRLG

Total well depth (ft) 1902 Well diameter: 12-3/4" from 0-100' 6-1/4" from - 1665' Casing diameter(s) and length (s): 8" from 0-100' 4-1/2" from 0-1665' Elevation: 2940

Type of casing(s): Steel Weight or gage of casing: Method-perforated or screened: 2-1/2" 20-slot stainless steel

Interval-perforated or screened: 1705-1715'; 1757-1787'; 1850-1860'

Has well been test pumped?: yes Were material samples taken?: no Was a water sample taken?: yes

Remarks: Total of 50 ft of screen in well. Casing was left open-ended. A cement basket was set at 1655' and well was grouted with cement. Well was completed in a pit. Closed in pressure was 90 psi when completed. Well flowed at 25 gpm through a 4-1/2" pipe.

DRILLING LOG
Geological, drilling, and water conditions; remarks and sampling

From	To	
0	20	Overburden. Bearpaw Shale
20	703	Gray Shale. Bearpaw Shale
703	750	Gray sandstone. Judith River Formation
750	930	Gray sandy shale. Judith River Formation
930	1090	Sandy shale. Judith River Formation
1090	1150	Sandstone. Judith River Formation
1150	1190	Shale. Clagett Shale
1190	1578	Gray shale. Clagett Shale
1578	1583	Hard brown shale. Clagett Shale
1583	1657	Shale. Clagett Shale
1657	1700	Hard sandy shale. Clagett Shale
1700	1876	Sandstone. Eagle Formation
1876	1902	Gray shale. Telegraph Creek Formation or Colorado Shale

APPENDIX C

BACKGROUND WATER LEVELS - EAGLE SANDSTONE

HAINES RIDGE WELL

DATE	PSI	WATER LEVEL	WATER LEVEL ELEVATION	SURFACE ELEVATION	MP ELEVATION	REMARKS
04/09/81	100.0	230.7	3182.7	2960	2952	CONSTRUCTED
01/16/92	40.0	92.3	3044.3			SHUT IN
01/30/92	70.0	161.5	3113.5			RECOVERY AFTER 2 WEEKS
06/01/92	0.0	0.0	2952.0			FLOWING
11/16/92	0.0	0.0	2952.0			SHUT IN NO READING
11/18/92	66.0	152.3	3104.3			
11/20/92	66.8	154.0	3106.0			
11/30/92	68.0	156.9	3108.9			
12/02/92	68.0	156.9	3108.9			FLOW TEST START 11:30
12/03/92	0.0	0.0	2952.0			FLOW TEST END 13:28
12/04/92	66.8	154.0	3106.0			
12/05/92	0.0	0.0	2952.0			FILLING RESERVOIR
03/25/93	0.0	0.0	2952.0			SHUT IN
03/26/93	50.0	115.4	3067.4			ESTIMATED PSI
04/07/93	62.5	144.2	3096.2			
04/13/93	63.7	147.0	3099.0			

MARCOTT WELL

DATE	PSI	WATER LEVEL	WATER LEVEL ELEVATION	SURFACE ELEVATION	MP ELEVATION	REMARKS
04/17/92	115.0	265.3	3142.3	2885	2877	CONSTRUCTED
06/01/92	115.0	265.3	3142.3			FLOW TEST 22 GPM
06/11/92	115.0	265.3	3142.3			FLOW TEST 27 GPM
06/25/92	115.0	265.3	3142.3			FLOW TEST 30 GPM
10/08/92	113.0	260.7	3137.7			OLD GAUGE
11/16/92	113.0	260.7	3137.7			NEW GAUGE
11/17/92	111.0	256.1	3133.1			
11/18/92	110.5	254.9	3131.9			
11/20/92	110.5	254.9	3131.9			
11/30/92	111.0	256.1	3133.1			
12/03/92	111.0	256.1	3133.1			FLOW TEST START 14:55
12/04/92	0.0	0.0	2877.0			FLOW TEST END 10:55
12/05/92	111.0	256.1	3133.1			PSI ESTIMATED
12/21/92	111.0	256.1	3133.1			
03/25/93	112.0	258.4	3135.4			
04/07/93	112.0	258.4	3135.4			
04/13/93	111.8	257.8	3134.8			

ELEVATOR RIDGE WELL

DATE	PSI	WATER LEVEL	WATER LEVEL ELEVATION	SURFACE ELEVATION	MP ELEVATION	REMARKS
04/09/81	90	207.6	3139.6	2940	2932	ORIGINAL SWL WHEN DRILLED
01/16/92	60	138.4	3070.4			WELL SHUT IN
01/30/92	73	168.4	3100.4			
02/04/92	73	168.4	3100.4			
02/25/92	73	168.4	3100.4			
05/31/92	73	168.4	3100.4			ESTIMATED PSI
06/01/92	50	115.4	3047.4			ESTIMATED PSI - OPENED VALVE
11/06/92	55	126.9	3058.9			PSI ABOVE PRESSURE REDUCER
11/07/92	69	159.2	3091.2			ESTIMATED PSI
11/18/92	70	161.5	3093.5			
11/20/92	72	166.1	3098.1			
11/30/92	72	166.1	3098.1			
12/03/92	72	166.1	3098.1			
12/04/92	72	166.1	3098.1			
12/21/92	73	168.4	3100.4			CHANGED PLUMBING-LEAKY VALVE
03/25/93	71	163.8	3095.8			LEAKY VALVE
04/07/93	72	166.1	3098.1			FLOW TEST START 11:20
04/08/93	0	0.0	2932.0			FLOW TEST END 9:26
04/09/93	70	161.5	3093.5			ESTIMATED PSI
04/13/93	71	163.8	3095.8			

APPENDIX D

HAINES RIDGE FLOW TEST
DIAMETER = 6.25 IN 02DEC92
RADIUS = 0.26 FT
R**2 = .068 FT^2

TIME (MIN)	t/r**2 (min/sqft)	DISCHARGE (GPM)	CORRECTED DISCHARGE GPM	WELLHEAD PRESSURE (psi)	PRESSURE DRAWDOWN (psi)	DRAWDOWN (feet)	DD/Qcor psi/gpm
0	0		0	68.00			
0.5	7.37	69.8	77.0	2.00	66.00	152.262	0.857
1.5	22.12	68.2	75.4	1.25	66.75	153.992	0.885
2.0	29.49	69.8	77.0	1.00	67.00	154.569	0.870
2.5	36.86	65.2	72.4	1.00	67.00	154.569	0.925
3.0	44.24	62.5	69.7	1.00	67.00	154.569	0.961
3.5	51.61	61.2	68.4	0.90	67.10	154.800	0.981
4.0	58.98	61.2	68.4	0.90	67.10	154.800	0.981
4.5	66.36	61.2	68.4	0.75	67.25	155.146	0.983
5.0	73.73	61.2	68.4	0.75	67.25	155.146	0.983
5.5	81.10	60.6	67.8	0.75	67.25	155.146	0.992
6.0	88.47	60.0	67.2	0.60	67.40	155.492	1.003
6.5	95.85	58.8	66.0	0.50	67.50	155.723	1.023
7.0	103.22	57.7	64.9	0.50	67.50	155.723	1.040
7.5	110.59	57.7	64.9	0.50	67.50	155.723	1.040
8.0	117.96	57.7	64.9	0.50	67.50	155.723	1.040
8.5	125.34	57.7	64.9	0.50	67.50	155.723	1.040
9.0	132.71	55.6	62.8	0.50	67.50	155.723	1.075
9.5	140.08	55.6	62.8	0.40	67.60	155.953	1.076
10.5	154.83	57.7	64.9	0.40	67.60	155.953	1.042
11.0	162.20	54.6	61.8	0.40	67.60	155.953	1.094
12.0	176.95	53.6	60.8	0.25	67.75	156.299	1.114
13.0	191.69	51.7	58.9	0.25	67.75	156.299	1.150
14.0	206.44	54.6	61.8	0.25	67.75	156.299	1.096
15.0	221.18	51.7	58.9	0.25	67.75	156.299	1.150
16.0	235.93	50.8	58.0	0.25	67.75	156.299	1.168
18.0	265.42	50.8	58.0	0.25	67.75	156.299	1.168
20.0	294.91	50.0	57.2	0.25	67.75	156.299	1.184
22.0	324.40	49.2	56.4	0.25	67.75	156.299	1.201
24.0	353.89	49.2	56.4	0.10	67.90	156.645	1.204
26.0	383.39	49.2	56.4	0.10	67.90	156.645	1.204
28.0	412.88	49.2	56.4	0.10	67.90	156.645	1.204
30.0	442.37	49.2	56.4	0.10	67.90	156.645	1.204
32.0	471.86	47.6	54.8	0.10	67.90	156.645	1.239
35.0	516.10	46.7	53.9	0.10	67.90	156.645	1.260
40.0	589.82	48.4	55.6	0.10	67.90	156.645	1.221
45.0	663.55	55.6	55.6	0.10	67.90	156.645	1.221
50.0	737.28	54.6	54.6	0.10	67.90	156.645	1.244
60.0	884.74	51.7	51.7	0.10	67.90	156.645	1.313
70.0	1032.19	51.7	51.7	0.10	67.90	156.645	1.313
80.0	1179.65	50.8	50.8	0.10	67.90	156.645	1.337
90.0	1327.10	50.8	50.8	0.10	67.90	156.645	1.337
100.0	1474.56	51.7	51.7	0.00	68.00	156.876	1.315
120.0	1769.47	50.0	50.0	0.00	68.00	156.876	1.360
140.0	2064.38	50.8	50.8	0.00	68.00	156.876	1.339
160.0	2359.30	50.0	50.0	0.00	68.00	156.876	1.360
180.0	2654.21	50.0	50.0	0.00	68.00	156.876	1.360
200.0	2949.12	50.8	50.8	0.00	68.00	156.876	1.339
220.0	3244.03	50.0	50.0	0.00	68.00	156.876	1.360
240.0	3538.94	50.8	50.8	0.00	68.00	156.876	1.339
260.0	3833.86	50.8	50.8	0.00	68.00	156.876	1.339
280.0	4128.77	50.0	50.0	0.00	68.00	156.876	1.360
310.0	4571.14	49.2	49.2	0.00	68.00	156.876	1.382
320.0	4718.59	50.0	50.0	0.00	68.00	156.876	1.360
350.0	5160.96	49.2	49.2	0.00	68.00	156.876	1.382
400.0	5898.24	48.4	48.4	0.00	68.00	156.876	1.405
450.0	6635.52	48.4	48.4	0.00	68.00	156.876	1.405
500.0	7372.80	47.6	47.6	0.00	68.00	156.876	1.429
600.0	8847.36	46.9	46.9	0.00	68.00	156.876	1.45
700.0	10321.92	46.9	46.9	0.00	68.00	156.876	1.450
1000.0	14745.60	46.2	46.2	0.00	68.00	156.876	1.472
1230.0	18137.09	45.5	45.5	0.00	68.00	156.876	1.495
1400.0	20643.84	44.8	44.8	0.00	68.00	156.876	1.518
1558.0	22973.64	45.5	45.5	0.00	68.00	156.876	1.495

APPENDIX D (continued)

HAINES RIDGE WELL RECOVERY DATA

t min	t' min	t/t'	PRESSURE1 psi	PRESSURE2 feet
1558.5	0.5	3117.0	43.25	99.78
1559.0	1.0	1559.0	46	106.12
1559.5	1.5	1039.7	47.5	109.58
1560.0	2.0	780.0	48.75	112.47
1560.5	2.5	624.2	49.5	114.20
1561.0	3.0	520.3	50	115.35
1561.5	3.5	446.1	50.75	117.08
1562.0	4.0	390.5	51.25	118.23
1562.5	4.5	347.2	51.75	119.39
1563.0	5.0	312.6	52	119.96
1563.5	5.5	284.3	52.5	121.12
1564.0	6.0	260.7	53	122.27
1564.5	6.5	240.7	53	122.27
1565.0	7.0	223.6	53.25	122.85
1565.5	7.5	208.7	53.5	123.42
1566.0	8.0	195.8	53.75	124.00
1566.5	8.5	184.3	54	124.58
1567.0	9.0	174.1	54.25	125.15
1567.5	9.5	165.0	54.5	125.73
1568.0	10.0	156.8	54.75	126.31
1569.0	11.0	142.6	55	126.89
1570.0	12.0	130.8	55.25	127.46
1571.0	13.0	120.8	55.5	128.04
1572.0	14.0	112.3	55.75	128.62
1579.0	21.0	75.2	57.25	132.08
1580.0	22.0	71.8	57.5	132.65
1582.0	24.0	65.9	58	133.81
1584.0	26.0	60.9	59.25	136.69
2735.0	1177.0	2.3	66.25	152.84
2995.0	1437.0	2.1	66.75	153.99

APPENDIX D (continued)

MARCOTT WELL FLOW TEST
DIAMETER = 5.88 IN 03DEC92
RADIUS = 0.24 FT
R**2 = 0.06 FT2

TIME (MIN)	t/r**2 t/r**2 (min/sqft)	DISCHARGE (GPM)	CORRECTED DISCHARGE GPM	WELLHEAD PRESSURE (psi)	PRESSURE DRAWDOWN (psi)	DRAWDOWN (feet)	DD/Qcor FT/gpm
0			0	111	0	0	
0.5	8.34	36.6	43.8	4.50	106.50	245.696	6.717
1	16.69	34.1	41.3	4.50	106.50	245.696	7.205
1.5	25.03	33.0	40.2	4.75	106.25	245.119	7.428
2.5	41.72	31.3	38.5	4.50	106.50	245.696	7.862
3.0	50.06	30.6	37.8	4.50	106.50	245.696	8.027
3.5	58.41	30.3	37.5	4.50	106.50	245.696	8.109
4.0	66.75	29.4	36.6	4.50	106.50	245.696	8.354
4.5	75.10	29.4	36.6	4.50	106.50	245.696	8.354
5.0	83.44	29.1	36.3	4.50	106.50	245.696	8.434
5.5	91.78	29.1	36.3	4.50	106.50	245.696	8.434
6.0	100.13	28.0	35.2	4.00	107.00	246.849	8.803
6.5	108.47	28.9	36.1	3.75	107.25	247.426	8.576
7.5	125.16	28.6	35.8	4.00	107.00	246.849	8.640
8.5	141.85	27.3	34.5	4.00	107.00	246.849	9.052
9.0	150.19	27.0	34.2	4.00	107.00	246.849	9.132
14.0	233.63	26.6	33.8	4.00	107.00	246.849	9.298
15.0	250.32	26.6	33.8	4.00	107.00	246.849	9.298
16.0	267.01	26.1	33.3	4.00	107.00	246.849	9.461
18.0	300.39	28.6	35.8	4.00	107.00	246.849	8.640
20.0	333.76	26.1	33.3	4.00	107.00	246.849	9.461
22.0	367.14	26.1	33.3	4.00	107.00	246.849	9.461
24.0	400.51	26.1	33.3	4.00	107.00	246.849	9.461
26.0	433.89	26.1	33.3	4.00	107.00	246.849	9.461
28.0	467.27	26.3	33.5	4.00	107.00	246.849	9.379
30.0	500.64	25.9	33.1	4.00	107.00	246.849	9.546
32.0	534.02	25.0	32.2	4.00	107.00	246.849	9.874
35.0	584.08	25.4	32.6	4.00	107.00	246.849	9.711
40.0	667.52	25.2	32.4	4.00	107.00	246.849	9.792
45.0	750.96	23.8	55.6	4.00	107.00	246.849	10.367
50.0	834.40	23.7	54.6	4.00	107.00	246.849	10.416
55.0	917.85	23.8	54.6	4.00	107.00	246.849	10.359
60.0	1001.29	23.6	51.7	4.00	107.00	246.849	10.469
70.0	1168.17	23.1	51.7	4.00	107.00	246.849	10.681
83.0	1385.11	22.7	50.8	4.00	107.00	246.849	10.894
90.0	1501.93	22.8	50.8	4.00	107.00	246.849	10.822
100.0	1668.81	22.8	51.7	4.00	107.00	246.849	16.827
120.0	2002.57	22.4	50.0	4.00	107.00	246.849	11.025
140.0	2336.33	22.2	50.8	4.00	107.00	246.849	11.134
160.0	2670.10	21.8	50.0	4.00	107.00	246.849	11.349
180.0	3003.86	20.8	50.0	4.00	107.00	246.849	11.896
200.0	3337.62	21.2	50.8	4.00	107.00	246.849	11.655
220.0	3671.38	21.0	50.0	4.00	107.00	246.849	11.766
240.0	4005.14	21.0	50.8	4.00	107.00	246.849	11.749
260.0	4338.90	21.0	50.8	4.00	107.00	246.849	11.966
280.0	4672.67	20.6	50.0	4.00	107.00	246.849	11.966
300.0	5006.43	20.8	49.2	4.00	107.00	246.849	11.851
320.0	5340.19	20.9	50.0	4.00	107.00	246.849	12.800
350.0	5840.83	20.3	49.2	4.00	107.00	246.849	12.100
400.0	6675.24	19.7	48.4	4.00	107.00	246.849	12.518
450.0	7509.64	19.7	48.4	4.00	107.00	246.849	12.530
500.0	8344.05	19.7	47.6	4.00	107.00	246.849	12.516
635.0	0596.94	19.4	46.9	4.00	107.00	246.849	12.724
1000.0	6688.09	18.8	46.2	4.00	107.00	246.849	13.102
1115.0	8607.22	18.6	45.5	4.00	107.00	246.849	13.243
1200.0	20025.71	18.4	44.8	4.00	107.00	246.849	13.452

APPENDIX D (continued)

MARCOTT WELL RECOVERY

t	t'	t/t'	PRESSURE1 psi	PRESSURE2 feet
1206.0	6.0	201.0	74.00	170.72
1206.5	6.5	185.6	74.50	171.87
1207.0	7.0	172.4	75.00	173.03
1207.5	7.5	161.0	75.50	174.18
1208.0	8.0	151.0	76.00	175.33
1208.5	8.5	142.2	76.50	176.49
1209.0	9.0	134.3	77.00	177.64
1209.5	9.5	127.3	77.50	178.79
1210.0	10.0	121.0	77.75	179.37
1211.0	11.0	110.1	78.25	180.52
1212.0	12.0	101.0	78.75	181.68
1213.0	13.0	93.3	79.50	183.41
1214.0	14.0	86.7	80.00	184.56
1215.0	15.0	81.0	80.25	185.14
1216.0	16.0	76.0	80.75	186.29
1217.0	17.0	71.6	81.00	186.87
1218.0	18.0	67.7	81.50	188.02
1219.0	19.0	64.2	81.75	188.60
1220.0	20.0	61.0	82.25	189.75
1222.0	22.0	55.5	83.00	191.48
1224.0	24.0	51.0	83.50	192.63
1226.0	26.0	47.2	84.00	193.79
1228.0	28.0	43.9	84.50	194.94
1230.0	30.0	41.0	84.75	195.52
1232.0	32.0	38.5	85.25	196.67
1236.0	36.0	34.3	86.00	198.40
1240.0	40.0	31.0	86.50	199.56
1246.0	46.0	27.1	87.50	201.86
1251.0	51.0	24.5	88.25	203.59
1260.0	60.0	21.0	89.50	206.48
1270.0	70.0	18.1	90.00	207.63
1281.0	81.0	15.8	91.25	210.51
1290.0	90.0	14.3	91.75	211.67
1304.0	104.0	12.5	92.75	213.97
1317.0	117.0	11.3	93.50	215.70

APPENDIX D (continued)

ELEVATOR RIDGE FLOW TEST
DIAMETER = 6.25 07APRIL93
RADIUS = 0.26 FT
R**2 .068 FT^2

TIME (MIN)	WELLHEAD PRESSURE (psi)	DISCHARGE (GPM)	PRESSURE DRAWDOWN (psi)	RATIO1 DD/Q psi/gpm	t/r**2 (min/sqft)	DRAWDOWN (feet)	RATIO2 DD/Q ft/gpm
0	72	0	0				
0.5	4.00	50.00	68.00	1.360	7.37	156.876	3.138
3.0	3.75	52.63	68.25	1.297	44.24	157.453	2.992
3.5	3.75	51.28	68.25	1.331	51.61	157.453	3.070
4.0	3.75	51.36	68.25	1.329	58.98	157.453	3.066
4.5	3.75	51.90	68.25	1.315	66.36	157.453	3.034
5.0	3.75	51.36	68.25	1.329	73.73	157.453	3.066
6.0	3.75	49.75	68.25	1.372	88.47	157.453	3.165
7.0	3.75	50.00	68.25	1.365	103.22	157.453	3.149
8.0	3.75	47.32	68.25	1.442	117.96	157.453	3.327
9.0	3.75	48.00	68.25	1.422	132.71	157.453	3.280
10.0	3.75	48.78	68.25	1.399	147.46	157.453	3.228
13.0	3.75	48.46	68.25	1.408	191.69	157.453	3.249
14.0	3.75	47.32	68.25	1.442	206.44	157.453	3.327
16.0	3.75	48.00	68.25	1.422	235.93	157.453	3.280
18.0	3.75	47.77	68.25	1.429	265.42	157.453	3.296
20.0	3.75	46.80	68.25	1.458	294.91	157.453	3.364
22.0	3.75	46.51	68.25	1.467	324.40	157.453	3.385
25.0	3.75	47.10	68.25	1.449	368.64	157.453	3.343
30.0	3.75	45.11	68.25	1.513	442.37	157.453	3.490
35.0	3.75	44.91	68.25	1.520	516.10	157.453	3.506
40.0	3.75	43.04	68.25	1.586	589.82	157.453	3.658
45.0	3.75	42.86	68.25	1.592	663.55	157.453	3.674
50.0	3.75	43.23	68.25	1.579	737.28	157.453	3.642
60.0	3.75	42.25	68.25	1.615	884.74	157.453	3.727
70.0	3.25	41.90	68.75	1.641	1032.19	158.606	3.785
80.0	3.25	41.90	68.75	1.641	1179.65	158.606	3.785
90.0	3.25	42.31	68.75	1.625	1327.10	158.606	3.749
100.0	3.25	40.54	68.75	1.696	1474.56	158.606	3.912
120.0	3.25	40.82	68.75	1.684	1769.47	158.606	3.886
140.0	3.25	40.38	68.75	1.703	2064.38	158.606	3.928
160.0	3.25	39.73	68.75	1.730	2359.30	158.606	3.992
180.0	3.25	39.47	68.75	1.742	2654.21	158.606	4.018
200.0	3.25	39.47	68.75	1.742	2949.12	158.606	4.018
220.0	3.25	39.37	68.75	1.746	3244.03	158.606	4.029
240.0	3.00	39.11	69.00	1.764	3538.94	159.183	4.070
260.0	3.00	38.76	69.00	1.780	3833.86	159.183	4.107
280.0	3.00	38.61	69.00	1.787	4128.70	159.183	4.123
320.0	3.00	38.31	69.00	1.801	4718.59	159.183	4.155
350.0	3.00	38.07	69.00	1.812	5160.96	159.183	4.181
400.0	3.00	37.93	69.00	1.819	5898.24	159.183	4.197
470.0	3.00	37.69	69.00	1.831	6930.43	159.183	4.223
500.0	3.00	37.64	69.00	1.833	7372.80	159.183	4.229
600.0	3.00	37.50	69.00	1.840	8847.36	159.183	4.245
700.0	3.00	37.31	69.00	1.849	10321.92	159.183	4.266
800.0	3.00	36.85	69.00	1.872	11796.48	159.183	4.320
1000.0	3.00	36.63	69.00	1.884	14745.60	159.183	4.346
1200.0	3.00	36.50	69.00	1.890	17694.72	159.183	4.361
1326.0	3.00	36.27	69.00	1.902	19552.67	159.183	4.389

APPENDIX D (continued)

ELEVATOR RIDGE WELL RECOVERY DATA

t min	t' min	t/t'	PRESSURE1 psi	PRESSURE2 feet
1345.0	19.0	70.8	57.5	132.65
1347.0	21.0	64.1	58.25	134.38
1348.0	22.0	61.3	58.5	134.96
1350.0	24.0	56.3	58.6	135.19
1352.0	26.0	52.0	58.8	135.65
1354.0	28.0	48.4	59	136.11
1356.0	30.0	45.2	59.2	136.57
1361.0	35.0	38.9	59.75	137.84
1366.0	40.0	34.2	60.1	138.65
1371.0	45.0	30.5	60.5	139.57
1376.0	50.0	27.5	60.75	140.15
1381.0	55.0	25.1	61	140.73
1386.0	60.0	23.1	61.25	141.30
1396.0	70.0	19.9	61.75	142.46
1406.0	80.0	17.6	62.1	143.26
1416.0	90.0	15.7	62.5	144.19
1426.0	100.0	14.3	63	145.34
1446.0	120.0	12.1	63.4	146.26