



Hydrogeology and geothermal potential of the Radersburg Valley, Broadwater County, Montana by Glen Milton Wyatt

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in
Earth Sciences

Montana State University

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Abstract:

Two major aquifers occur in the Radersburg valley in southwest Montana. Irrigation and other wells discharge water from a Cenozoic basin-fill aquifer composed of up to 1000 feet of sand and gravel. During the 1979 growing season, irrigation wells withdrew about 300 million cubic feet of water from the aquifer. The Madison Group, composed of Mississippian-age limestone, is the other major aquifer. The yearly discharge from springs flowing from the Madison Group at Plunket Lake, in the southern part of the valley, approximately equals the total amount of water withdrawn from the basin-fill aquifer for irrigation during 1979.

Much of the irrigation water is withdrawn from an area north of Plunket Lake. This area is near the projected north-south subcrop trend of the Madison Group aquifer and suggests that the aquifer recharges the basin-fill. Ground-water temperatures and chemistry further support this idea. Ground-water temperatures in this area vary from less than 10°C to about 20°C. The highest temperatures are colinear with the Madison Group subcrop trend, implying deep circulation within the limestone aquifer before the water discharges to basin fill.

Ground-water compositions are generally dominated by calcium, sodium, bicarbonate, and sulfate ions. Sulfate to bicarbonate ratios are highest north of Plunket Lake and indicate that a sulfate-rich source of ground water is locally present. A possible source of such ground water could be remnant evaporite beds within the upper part of the Madison Group. Another indicator of Madison Group discharge to the basin fill is the ratio of strontium to total dissolved solids. High values for the ratio may indicate recharge by a carbonate or evaporite aquifer to an aquifer composed of clastic materials. The highest values for the ratio were obtained from water samples in the vicinity of the projected subcrop trend of the Madison Group.

A possible consequence of the use of an aquifer for irrigation may be the permanent depletion of the ground-water resource. This depletion from aquifer storage is indicated by a continuing drop in ground-water levels. Irrigation by ground water from the basin-fill aquifer began in the early 1960s. Since that time, water levels have generally declined by about 0.4 foot per year. The amount of water annually lost from aquifer storage as indicated by this average decline is less than one percent of the amount pumped for irrigation in 1979.

Ground water in the valley has a slight geothermal potential, as indicated by ground-water temperatures above 16°C. Water from such low-temperature thermal wells or springs may be used for space heating, greenhouses, or other low-temperature applications.

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BROADWATER COUNTY, MONTANA

by

GLEN MILTON WYATT

A thesis submitted in partial fulfillment
of the requirements for the degree

of

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MONTANA STATE UNIVERSITY
Bozeman, Montana

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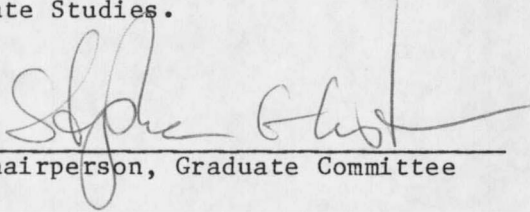
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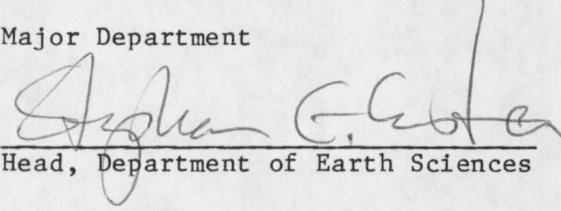
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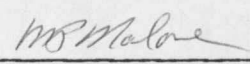
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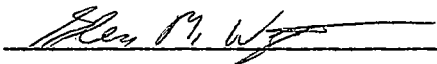
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TABLE OF CONTENTS

	Page
LIST OF TABLES	viii
LIST OF ILLUSTRATIONS	ix
ABSTRACT	x
INTRODUCTION	1
Purpose and Scope	3
Site Numbering System	4
DRAINAGE BASIN DESCRIPTION	7
Introduction	7
Regional Setting and Topography	7
Drainage	9
Climate	9
Vegetation and Land Use	13
Stratigraphy	15
Structural Geology	18
Geologic History	22
HYDROGEOLOGY	25
Introduction	25
Mississippian Madison Group Aquifer	29
Basin-Fill Aquifer	35
Geology	35
Hydrology	37
Well Design	37
Transmissivity and Hydraulic Conductivity	38
Storage Coefficient	42
Ground-Water Movement	43
EVIDENCE FOR RECHARGE TO BASIN-FILL AQUIFER BY MADISON GROUP AQUIFER	46
Introduction	46
Position of the Madison Group	46
Ground-Water Temperature	47

TABLE OF CONTENTS--Continued

	Page
Ground-Water Chemistry	53
Major Ions	55
Strontium	62
Multiple Recharge Sources	65
Processes Affecting Water Chemistry	65
GROUND-WATER WITHDRAWAL	67
Introduction	67
Recharge	68
Discharge	69
Change in Ground-Water Storage	72
Summary	78
GEO THERMAL POTENTIAL	80
SUMMARY AND CONCLUSIONS	83
REFERENCES CITED	87
APPENDICES	94
Appendix A - Field Investigation	95
Introduction	95
Well Inventory	95
Specific Capacity Tests	96
Seasonal Discharge by Irrigation Wells	97
Water Levels in Wells	98
Discharge Rates of Wells	98
Stream and Spring Discharge Rate Measurements	99
Aquifer Tests	99
Water-Quality Sampling	99
Appendix B - Aquifer Test Analysis	128
Introduction	128
Pumping Test	128
Efficiency of the Pumped Well	131
Recovery Test	133
Appendix C - Water Quality	149
Introduction	149
Water-Quality Sampling	149
Field Measurements	150
Laboratory Analyses	151

LIST OF TABLES

Table		Page
1.	Discharge from Crow Creek and Springs	10
2.	Climatic Data for Townsend and Toston	12
3.	Potential Evapotranspiration	12
4.	Water Use for Crow Creek Irrigation Unit	15
5.	Generalized Stratigraphic Section and Water-Bearing Properties of Rocks in the Crow Creek Drainage Basin . .	16
6.	Hydraulic Conductivities of Rocks and Unconsolidated Materials	28
7.	Water Temperatures from Springs	49
8.	Well-Water Temperature Data	51
9.	Change in Ground-Water Storage, 1979-1980 Irrigation Season	73
10.	Long-Term Change in Ground-Water Storage	76
11.	Well Construction Information	100
12.	Lithologic Logs	103
13.	Specific Capacity Test Results	109
14.	Seasonal Discharge by Irrigation Wells	112
15.	Ground-Water Level Measurements	121
16.	Discharge Measurements from Wells	124
17.	Discharge Measurements from Crow Creek and Springs	124
18.	Results of Aquifer Tests	134
19.	Pumping Test Data from Well 4-1-10bcb	135
20.	Pumping Test Data from Wells 4-1-10bbc and 4-1-9aac	137
21.	Recovery Test Data from Well 4-1-9ca	138
22.	Water-Quality Analyses from Wells	153
23.	Water-Quality Analyses from Springs and Crow Creek	157
24.	Water-Quality Analyses from Samples Collected During the Pumping Test of Well 4-1-10bcb	159
25.	Additional Temperature and Specific Conductance Measurements	160

LIST OF ILLUSTRATIONS

Figure		Page
1.	Location Map	2
2.	Site Numbering System	5
3.	Aquifer Types	26
4.	Ground-Water Level Map	44
5.	Well Location and Subcrop Trend of the Madison Group	47
6.	Isothermal Map	52
7.	Trilinear Diagram and Ground-Water Character	56
8.	Ground-Water Character Areal Distribution	58
9.	Sulfate to Bicarbonate Ratio Map	60
10.	Strontium to Total Dissolved Solids Ratio Map	64
11.	Area Used to Compute Short-Term Change in Storage	74
12.	Area Used to Compute Long-Term Change in Storage	77
13.	Locations of Wells Used During Pumping Test	139
14.	West-East Cross-Section Through Pumping Test Area	140
15.	Log-Log Plot of Pumping Test Data from Well 4-1-10bcb	141
16.	Semi-Log Plot of Pumping Test Data from Well 4-1-10bcb	142
17.	Residual Drawdown Plot of Pumping Test Data from Well 4-1-10bcb	143
18.	Log-Log Plot of Pumping Test Data from Well 4-1-10bbc	144
19.	Semi-Log Plot of Pumping Test Data from Well 4-1-10bbc	145
20.	Log-Log Plot of Pumping Test Data from Well 4-1-9aac	146
21.	Semi-Log Plot of Pumping Test Data from Well 4-1-9aac	147
22.	Residual Drawdown Plot of Pumping Test Data from Well 4-1-9aac	148

Plate

1. Generalized Geologic Map (In Pocket)

ABSTRACT

Two major aquifers occur in the Radersburg valley in southwest Montana. Irrigation and other wells discharge water from a Cenozoic basin-fill aquifer composed of up to 1000 feet of sand and gravel. During the 1979 growing season, irrigation wells withdrew about 300 million cubic feet of water from the aquifer. The Madison Group, composed of Mississippian-age limestone, is the other major aquifer. The yearly discharge from springs flowing from the Madison Group at Plunket Lake, in the southern part of the valley, approximately equals the total amount of water withdrawn from the basin-fill aquifer for irrigation during 1979.

Much of the irrigation water is withdrawn from an area north of Plunket Lake. This area is near the projected north-south subcrop trend of the Madison Group aquifer and suggests that the aquifer recharges the basin-fill. Ground-water temperatures and chemistry further support this idea. Ground-water temperatures in this area vary from less than 10°C to about 20°C. The highest temperatures are colinear with the Madison Group subcrop trend, implying deep circulation within the limestone aquifer before the water discharges to basin fill.

Ground-water compositions are generally dominated by calcium, sodium, bicarbonate, and sulfate ions. Sulfate to bicarbonate ratios are highest north of Plunket Lake and indicate that a sulfate-rich source of ground water is locally present. A possible source of such ground water could be remnant evaporite beds within the upper part of the Madison Group. Another indicator of Madison Group discharge to the basin fill is the ratio of strontium to total dissolved solids. High values for the ratio may indicate recharge by a carbonate or evaporite aquifer to an aquifer composed of clastic materials. The highest values for the ratio were obtained from water samples in the vicinity of the projected subcrop trend of the Madison Group.

A possible consequence of the use of an aquifer for irrigation may be the permanent depletion of the ground-water resource. This depletion from aquifer storage is indicated by a continuing drop in ground-water levels. Irrigation by ground water from the basin-fill aquifer began in the early 1960s. Since that time, water levels have generally declined by about 0.4 foot per year. The amount of water annually lost from aquifer storage as indicated by this average decline is less than one percent of the amount pumped for irrigation in 1979.

Ground water in the valley has a slight geothermal potential, as indicated by ground-water temperatures above 16°C. Water from such low-temperature thermal wells or springs may be used for space heating, greenhouses, or other low-temperature applications.

INTRODUCTION

Shortly after the valley in the vicinity of Radersburg, Montana (Figure 1) was settled by farmers, a drought occurred. This drought lasted from about 1917 until the early 1920s and demonstrated the need for irrigation of farmlands in the area. Irrigation water was first supplied to farms by diverting water from springs and creeks. Beginning in 1941, irrigation water was supplied to the Crow Creek area by a system of canals from the Missouri River. Operation of another canal system supplying water to land south of Crow Creek began in 1955. In 1955, approximately twenty-one square miles of land were irrigated by canal systems in this area.

Irrigation water has also been supplied to part of the valley by high-capacity wells. By 1979, irrigation wells were supplying water to about seven square miles of land which had previously been irrigated by canals and to about three square miles which had been dryland farmed. Twenty-seven irrigation wells pumped from 1,000 to 3,000 gallons per minute (gpm) or 134 to 401 cubic feet per second (cfs) during the summer months and discharged over three hundred million gallons of water. Future withdrawals must be balanced by adequate recharge to the aquifer to allow irrigation by wells to continue.

The irrigation wells have been completed in basin-fill sediments which overlie older bedrock units. Many of the wells have been installed in the Warm Springs Creek area north of Plunket Lake. Plunket

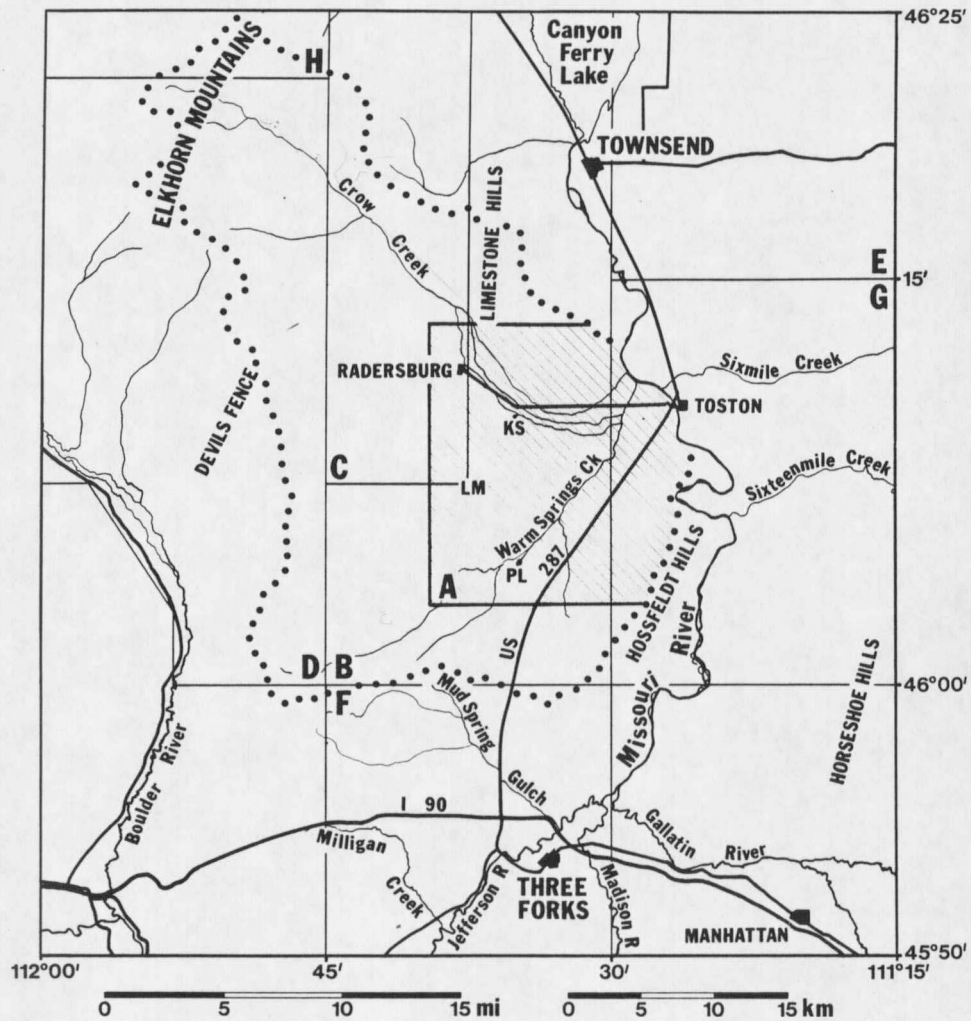
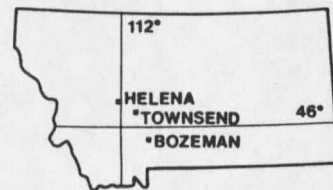


Figure 1. Location of the study area (A, shaded), Plunket Lake (PL), Kimpton Spring (KS), Lone Mountain (LM), the Radersburg drainage basin (dotted), other areas delineate published maps at a scale of 1:62,500 or greater:

- (B) Freeman and others (1958),
- (C) Klepper and others (1971),
- (D) Klepper and others (1957),
- (E) Nelson (1963),
- (F) Robinson (1963),
- (G) Robinson (1967), and
- (H) Smedes (1966)



Lake and Warm Springs Creek are fed by water issuing from Mississippian Madison Group limestone at Plunket Spring. The presence of the spring flowing from the limestone indicates that water from the Madison Group is recharging the basin-fill sediments in at least part of the valley.

The temperature of ground water flowing from Plunket Spring and Kimpton Spring was about 16°C to 18°C. This range was at least 10°C above the mean annual air temperature of 43°F (6°C), which enabled these springs to be classified as low-temperature thermal springs (Muffler, 1979). The presence of thermal springs in the Radersburg valley suggested that ground water in the area may be a potential source of energy.

Purpose and Scope

This study has three objectives. The first was to describe the hydrogeology of the basin-fill and Madison Group aquifers in the Radersburg drainage basin. The second objective was to determine if the amount of ground water discharged from the basin-fill aquifer is significantly greater than recharge to the aquifer. The final objective was to determine the temperature, areal extent and geologic source, and potential for development of the geothermal resource in the valley.

Work was divided into two phases. In the first phase of the investigation a compilation was made of water-well logs, ground-water appropriation documents, and land ownership for the study area. The

second phase was a field investigation consisting of locating wells; measuring water levels, discharge rates, and water temperatures; assessing the hydraulic properties of the basin-fill materials; and water-quality sampling.

The main study area consisted of land west of the Missouri River, within Townships 4 and 5 North and Ranges 1 and 2 East, in Broadwater County, Montana. The study area was limited to land west of the Missouri River because the river is a master river and because extensive development of irrigation by canal systems and high-capacity irrigation wells has occurred in this area. Warm-water springs also occur here.

Site Numbering System

Wells and other sampling sites were numbered according to the U.S. Bureau of Land Management land subdivision system. All sites are north of the Montana baseline and east of the principal meridian, in quadrant "A" of Figure 2, except the Crow Creek sampling site which is west of the principal meridian in the "B" quadrant. Therefore, the letter designation for quadrant was not used. The township in which a site is located is designated by the first number, either a 4 or 5, for Township 4 or 5 North. The second numeral identifies the range, either a 1 or 2, for Range 1 or 2 East. The third numeral identifies the section. Lower-case letters after the numerals indicate in which part of a section the site is located. The letters begin in the northeast quarter of a section with "a" and end with "d" in the southeast quarter. Parts of quarter sections are similarly divided. If two

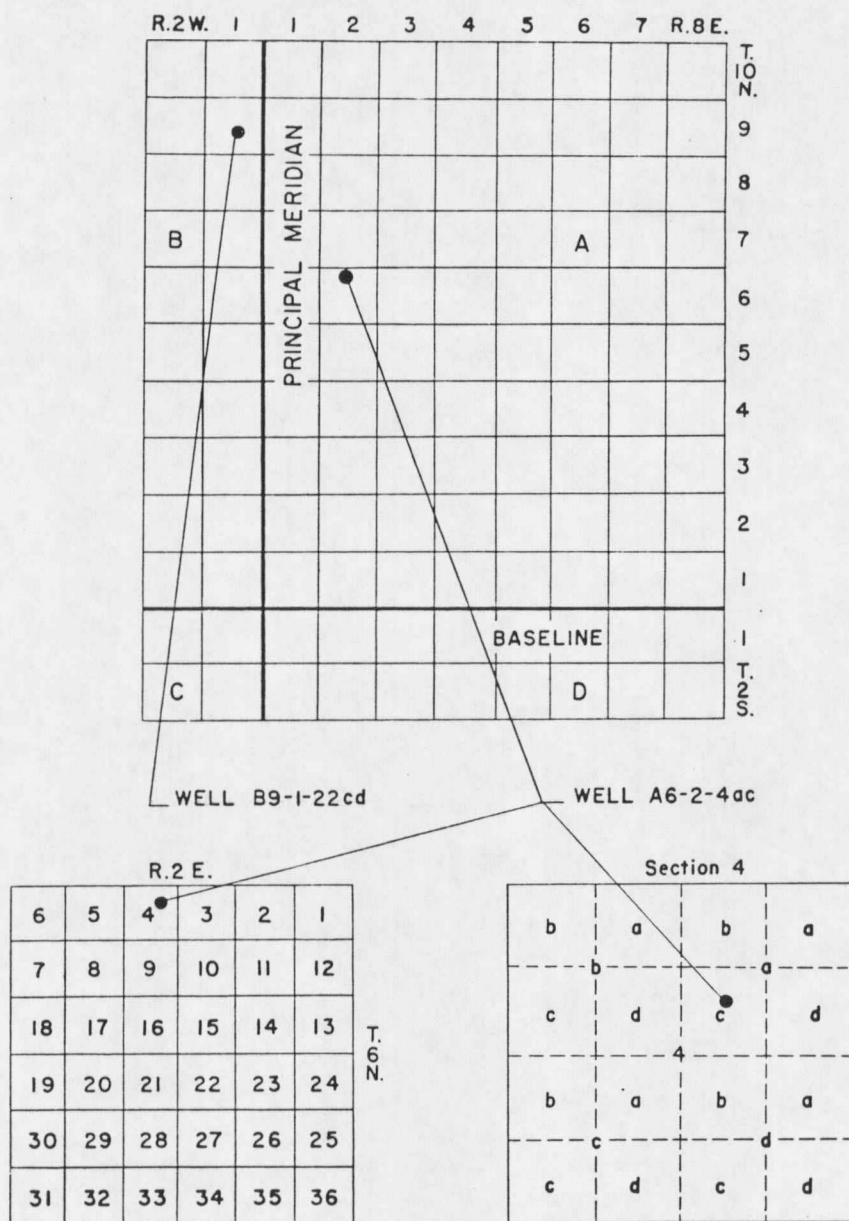


Figure 2. U.S. Bureau of Land Management Land Subdivision System
(Source: Lorenz and McMurtrey, 1956)

wells are located within the same quarter-quarter-quarter section, a serial number is added after the last letter. This system of site location should be considered as accurate to within 0.1 mile, as locations were determined from section corners using a car odometer or by pace.

DRAINAGE BASIN DESCRIPTION

Introduction

To assist with identification of possible recharge sources to irrigation wells, the drainage basin containing irrigated land in the Radersburg valley was identified on the basis of topography. The drainage basin outlines tributary areas of the Missouri River between the Limestone Hills and Hossfeldt Hills and includes the Crow Creek and Warm Springs Creek drainages. The identification of the drainage basin provided limiting boundaries of surface-water and ground-water flow through the Radersburg valley.

Regional Setting and Topography

The Radersburg valley is defined for the purposes of this report as the area below elevation 5000 feet west of the Missouri River and Hossfeldt Hills, south of the Limestone Hills, and east of the Devils Fence in the Radersburg drainage basin. The valley has an undulating surface which slopes to the east. Local relief is generally less than 150 feet, although 5024-feet-high Lone Mountain rises over 600 feet above the neighboring lowlands which slope to about 3880 feet elevation near the Missouri River. The study area is entirely within the Radersburg valley and is the only part of the valley where high-capacity irrigation wells have been drilled.

The Radersburg drainage basin, as shown on Plate 1 and Figure 1, occupies about 400 square miles in the north-central part of the Northern Rocky Mountains physiographic province of Fenneman (1931). The basin is outlined by a drainage divide and the Missouri River. The divide is a broad low rim which extends south from the Missouri River through the Hossfeldt Hills, curves to the west, and turns north through the Devils Fence area. The divide continues along the ridges of the Elkhorn Mountains, extends through the Limestone Hills to the east, and reconnects with the Missouri River. The highest point along the divide and in the basin is 9414-foot Crow Peak, and the lowest point is at about 3870 feet where the divide meets the Missouri River east of the Limestone Hills.

The surface-water and ground-water boundaries of the basin are assumed to be coincident. This assumption appears to be valid because the surface-water divide extends along the tops of mountain ranges or hills throughout much of its length. Drainage divides are usually ground-water boundaries (Toth, 1963), therefore it is unlikely that large volumes of ground water cross the divide. A small amount of ground water may locally pass under the divide because of geologic structure. In such local areas, bedrock under the divide dips into the drainage basin. This condition is of limited areal extent compared to the area of the drainage basin. The amount of ground water which may cross divides was assumed to be much smaller than the volume of ground water in the basin. It is also unlikely that the Missouri River is a source of recharge water to the basin because the river lies below the

rest of the basin and ground water generally discharges into master rivers (Toth, 1963).

Drainage

All streams in the Radersburg basin flow into the Missouri River. Crow Creek and Warm Springs Creek, fed by Plunket Spring, form the only perennial system (Table 1). Crow Creek and irrigation ditches from it lose water by seepage into outwash fan sand and coarse gravel in the vicinity of Crow Creek and Indian Creek north of Radersburg (Klepper and others, 1971; Straw, 1979).

Other streams in the basin are ephemeral and show evidence of recent flash floods and mud flows (Straw, 1979). Some of the ephemeral streams have local perennial spring-fed sections. These springs are small and the flow disappears into the streambed alluvium after a short distance. An example of this was seen in Johnny Gulch in May, 1979 where a spring 0.5 mile west of the Kimpton Cow Camp discharged 0.05 cfs of water, flowed downstream for about one-quarter mile, and then was absorbed into alluvium.

Climate

The Radersburg valley has a modified continental climate. The frequent invasions of Pacific Ocean air masses, flow of cool air from surrounding mountains into the valley, and nearness of the mountains combine to make temperature changes less extreme than in a true continental climate. About 40 inches per year of precipitation (as

Table 1. Discharge Measurements from Crow Creek and Springs

Date	Flow Rate (cfs)	Remarks
Crow Creek		
1919-1922 average	60.0	Colby and Oltman, 1938, <u>in</u> Lorenz and McMurtrey, 1956
1919-1929 average	48.3	Measured above Slim Sam Creek (Montana State Engineer, 1956)
7-14-20	1000	Do.
1-10-22	1.4	Do.
6-28-79	132.7	Measured at Helena National Forest boundary
7-9-79	60.4	Measured at Helena National Forest boundary
7-9-79	45.1	1.5 miles north of Radersburg
9-15-79	17.2	Measured at Helena National Forest boundary
Plunket Spring		
May, 1922	9.7	Pardee, 1925
August, 1949	8.7	Lorenz and McMurtrey, 1956
5-26-79	0.3	Southeast spring, not including discharge below water surface
5-26-79	0.2	Culvert 0.25 mile north of Plunket Lake
6-26-79	0.3	Culvert as above
10-13-79	10.3	Culvert as above
11-10-79	11.5	Culvert as above
Kimpton Spring		
July, 1921	0.2	Pardee, 1925
September, 1949	<0.2	Lorenz and McMurtrey, 1956
6-16-79	0.7	In stream 150 feet east of spring
Spring (SW1/4 sec. 17, T. 5 N., R. 1 W.)		
5-19-79	0.05	0.5 mile west of Kimpton Cow Camp

rain and snow) falls on the local mountains, but the mountains create a rain shadow and less than 12 inches per year falls on parts of the valley floor. Snow usually begins accumulating in the mountains in November, reaches maximum depth and water content in April or early May, and melts mostly in late May or in June. About 200 inches of snow falls each year on the mountains but only approximately 30 inches of snow falls on the valley floor (Olsen and others, 1977). The length of the frost-free growing season in the valley varies from about 110 to 120 days from May to September (Montana State Engineer, 1956). Temperature and precipitation data for the area are shown in Table 2.

An estimate of the amount of evaporation from near-surface soils plus transpiration by plants (evapotranspiration) was made using Thornthwaite's (1948) formula for calculating potential evapotranspiration (PET). The estimate is given in Table 3. Potential evapotranspiration estimates the amount of water lost from a vegetated surface to the atmosphere where the soil water supply is unlimited (Dunne and Leopold, 1978). Thornthwaite's (1948) formula based only on mean monthly air temperature and insolation, or received solar energy, was used to calculate PET:

$$PET = 1.6b(10T/I)^a;$$

where b = the insolation factor, based on the 46° 20' N latitude of Townsend;

T = the mean monthly air temperature (°C);

I = the mean annual heat index, $I = (T_i/5)^{1.514}$, (i = 1-12); and

a = $0.49 + 0.0179I - 0.0000771I^2 + 0.000000675I^3$.

Table 2. Climatic Data for Townsend and Toston
(Source: Olsen and others, 1977)

	Townsend						Toston	
	Average Daily Maximum (°F)	Average Daily Minimum (°F)	Average Monthly Maximum (°F)	Average Monthly Maximum (°F)	Precipitation		Precipitation	
					Total (in)	Snow (in)	Total (in)	Snow (in)
January	31	7	52	-20	0.5	6.6	0.4	6.0
February	38	14	56	-9	0.3	4.1	0.3	3.5
March	44	18	64	-6	0.5	4.2	0.7	4.6
April	57	28	76	14	0.7	1.7	1.0	3.6
May	66	37	84	24	1.8	1.0	1.8	0.2
June	73	44	89	32	2.5	Tr	2.7	0.2
July	84	48	95	35	1.1	0	1.1	0
August	83	46	95	35	1.1	0	1.1	0
September	71	38	88	24	1.2	0.3	1.0	0.4
October	60	29	79	16	0.7	0.8	0.7	1.2
November	44	20	63	-1	0.5	4.1	0.6	3.0
December	36	13	54	-13	0.5	5.7	0.4	7.3
Year	57	29	97	-25	11.6	28.5	11.8	30.0

Table 3. Potential Evapotranspiration

	Mean Monthly Air Temperature		Insolation Factor	Potential Evapotranspiration	
	(°C)	(°F)		(cm)	(in)
January	-7	19	0.78	---	---
February	-3	26	0.80	---	---
March	-1	31	1.02	---	---
April	6	43	1.13	3.6	1.4
May	11	52	1.29	7.8	3.1
June	15	59	1.31	10.9	4.3
July	19	66	1.33	14.2	5.6
August	18	65	1.22	12.5	4.9
September	13	55	1.05	7.3	2.9
October	7	45	0.93	3.6	1.4
November	0	32	0.78	---	---
December	-4	25	0.74	---	---
Year	6	43		59.8	23.6

Thorntwaite's method has been shown to underestimate PET in dry regions (Cruff and Thompson, 1967). Lake evaporation is approximately 28 inches per year in the Townsend area (Environmental Sciences Services Administration, 1968). Lake evaporation and PET may not be representative of the actual amount of evaporation from vegetated and non-vegetated soils because the soil dries and restricts evaporation. This drying occurs early in the year and invalidates the assumption of unlimited water supply. Nonetheless, PET and lake evaporation may place upper limits on the amount of water lost to the atmosphere.

Vegetation and Land Use

Vegetation within the basin is quite variable. Coniferous forests cover the mountains, deciduous and coniferous trees grow along streams, and sagebrush and grasses occur on the unfarmed valley floor and rangeland. Where dryland farming practices are used, winter wheat and barley are the main crops. Sugar beets, hay, alfalfa, corn, and sunflowers are the major crops produced on irrigated lands.

Before irrigation wells were drilled in the valley, all irrigation water was supplied by the diversion of streams and springs. Plate 1 shows the locations of some of the canals and ditches in the valley. As a result of a drought which began in 1917, the first irrigation district was formed in 1918 to develop irrigation in the Crow Creek area (Pardee, 1925; Montana State Engineer, 1956). This district was dissolved in 1940 after a period of tax delinquency. In 1941, water was first diverted from the Missouri River at the Toston Dam through

the State-funded Toston Canal West Fork (or West Side Canal) to the Crow Creek area west of Toston. Records of water use for the irrigation seasons from 1941 through 1949 indicate that water was diverted at rates ranging from 1.7×10^8 cubic feet per year (ft^3/yr) to 2.6×10^8 ft^3/yr with a mean of 2.3×10^8 ft^3/yr of water diverted for irrigation (Montana State Engineer, 1956). In 1955, approximately three square miles of land were irrigated by water from this canal system (Montana State Engineer, 1956).

The federally-funded Crow Creek Irrigation Unit began operation in 1955 to develop irrigation on an area of land which approximately equaled the total acreage flooded by the creation of Canyon Ferry Lake near Townsend. Water for irrigation is pumped from the Missouri River at a point about two miles upstream of the Toston Dam, through an inverted siphon, and into the Toston Canal. Table 4 is a summary of water use by the Irrigation Unit from 1968 to 1979. During that period, from 6.3×10^8 ft^3/yr to 10.9×10^8 ft^3/yr with a mean of 8.4×10^8 ft^3/yr was diverted from the Missouri River for irrigation use. In 1955, approximately 2.25 square miles of land were being irrigated by water from the Crow Creek Irrigation Unit (Montana State Engineer, 1956). The amount of land irrigated by this system had increased to about nine square miles by the late 1970s.

Privately-owned ditch systems have also been used to divert water from streams and springs to farmlands. In 1955, approximately sixteen square miles were under irrigation by privately-owned systems (Montana State Engineer, 1956).

Table 4. Water Use Data for Crow Creek Irrigation Unit. (Source: Unpublished U.S. Bureau of Reclamation data, furnished by Arnold Kohlberg, Toston, Montana)

Year	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Total water diverted from Missouri River (x10 ⁸ ft ³)	7.26	7.58	8.17	8.45	9.25	10.10	8.13	6.30	7.58	8.85	10.86	7.96
Main canal waste (x10 ⁷ ft ³)	3.41	2.51	3.27	1.81	3.26	4.05						
Main canal losses (x10 ⁷ ft ³)	6.73	7.75	8.16	12.68	13.00	17.17						
Delivered to laterals (x10 ⁸ ft ³)	6.25	5.12	5.49	5.73	5.97	6.01						
Lateral waste (x10 ⁷ ft ³)	7.07	4.41	7.19	8.82	12.65	11.46						
Lateral losses (x10 ⁸ ft ³)	1.15	1.30	1.28	1.26	1.29	1.32						
Delivered to farms (x10 ⁸ ft ³)	4.52	4.81	5.03	4.86	5.07	5.51	5.93	3.87	3.89	4.39	4.55	4.17
Acres irrigated	4644	4630	4603	4692	4712	5249	5249	5338	5498	5585	5842	5692

Irrigation wells have reduced the amount of land irrigated by water diverted from ditches, streams, and springs. Well water has replaced ditch water on about seven square miles of land in the area between Kimpton Spring and Plunket Lake. Well water has made an additional three square miles of land arable in this area.

Stratigraphy

A generalized stratigraphic column for the drainage basin is presented in Table 5. Ages, names, lithologies, and thicknesses were compiled from Davis and others (1980), Freeman and others (1958), Klepper and others, (1957, 1971), Kuenzi and Fields (1971), Lorenz and McMurtrey (1956), Robinson (1963, 1967), and Smedes (1966). Lithologies for each stratigraphic unit are listed in order of

Table 5. Generalized Stratigraphic Section and Water-Bearing Properties of Rocks in the Radersburg Drainage Basin (Compiled From: Davis and others, 1980; Freeman and others, 1958; Klepper and others, 1957, 1971; Kuenzi and Fields, 1971; Lorenz and McMurtrey, 1956; Robinson, 1963, 1967; Smedes, 1966)

ERA	SYSTEM or SERIES	FORMATION		LITHOLOGY and THICKNESS	WATER-BEARING PROPERTIES
Cenozoic	Quaternary	undifferentiated		Eolian silt; terrace gravel; alluvial fan sand and gravel; glacial deposits. 60' maximum.	Yields adequate supplies for domestic and stock purposes. In some places, yields may be sufficient for garden irrigation.
	Quaternary-Tertiary	undifferentiated		Pediment and fan gravels with clasts of limestone, quartzite, and volcanic rocks. 5-100'.	Extent too small to be considered as a source of water.
	Tertiary	Bozeman Group	Renova Formation	Rhyolitic sedimentary tuff with a thick lens of bentonitic clay. Intraformational gravel. 0-1900'.	Yields adequate supplies for domestic and stock purposes.
	Lower Tertiary to Upper Cretaceous	Intrusive rocks		Granitic to gabbroic rocks of the Boulder Batholith. Dioritic rocks related to the Elkhorn Mountains Volcanics. Thickness unknown.	Yields water to springs through fractures. Not an important source of water.
	Upper Cretaceous	Elkhorn Mountains Volcanics		Andestitic lava and volcanic breccia; some rhyolitic welded tuffs. 5000+'. — ANGULAR UNCONFORMITY —	Yields water to springs from fractures and breccias. Not an important source.
Mesozoic		CONFORMITY, DISCONFORMITY, AND ANGULAR UNCONFORMITY AT DIFFERENT PLACES			
		Slim Sam Formation		Crystal lithic tuff, andesitic sandstone, and black shale. 0-1200'.	Not water bearing.
	Upper & Lower Cretaceous	Colorado Formation		Black shale, sandstone, and siltstone. 0-1500' — DISCONFORMITY —	Not water bearing
	Lower Cretaceous	Kootenai Formation		Sandstone, conglomerate, shale and fossiliferous limestone. 0-650'. — DISCONFORMITY (?) —	Locally contains a little water.
	Upper Jurassic	Morrison Formation		Shale, mudstone, siltstone, limestone, and sandstone. 400-540'.	Not an important source of water in this area.
Paleozoic			Swift Formation	Sandstone and conglomerate. 20-35'. — DISCONFORMITY —	Not an important source of water in this area.
	Permian	Phosphoria Formation		Chert and quartzite, locally phosphatic. 40-120'.	Not water bearing.
	Pennsylvanian	Quadrant Formation		Quartzitic sandstone and dolomite. 225-325'.	Yields small supplies, but not important as source of water.

Table 5. (continued)

ERA	SYSTEM or SERIES	FORMATION		LITHOLOGY AND THICKNESS	WATER-BEARING PROPERTIES
Paleozoic	Pennsylvanian & Mississippian	Amsden Fm. & Big Snowy Gp.		Red calcareous siltstone, shale limestone, and dolomite. 200-300'.	Not an important source of water.
	Mississippian	Madison Group	Mission Canyon Limestone	— DISCONFORMITY — Fine- to coarse-grained, massive limestone. Local collapse breccia in upper part. 800-1500'.	Yields large supplies of water to many springs.
			Lodgepole Limestone	Thin- to medium-bedded fossil- iferous limestone; mudstone interbeds at base. 300-700'.	
	Upper Devonian	Three Forks Shale		Shale, siltstone, and limestone. 100-400'.	Generally not water bearing or produces only meager supplies.
		Jefferson Dolomite		Dolomite and limestone. 500-735'.	Source of small springs.
		Maywood Formation		Silty dolomite and calcareous siltstone and shale. 40'.	Yields very little water.
	Upper Cambrian	— DISCONFORMITY —			
		Red Lion Formation		Calcareous siltstone, shale, and sandstone. 0-90'.	Yields very little water.
		Pilgrim Dolomite		Mottled limestone and dolomite. 350-500'.	Yields water to small springs from joints and solution passages.
	Middle Cambrian	Park Shale		Fissile shale with a few lime- stone, siltstone, and sand- stone beds. 200-300'.	Not water bearing.
		Meagher Limestone		Mottled and banded limestone and dolomite. 360-500'.	Yields water to small springs from joints, bedding planes, and solution channels.
		Wolsey Shale		Shale and mudstone, commonly silty. Limestone near top, quartzite at base. 300-450'.	Not water bearing.
Flathead Quartzite		Quartzite with a few thin units of shale or siltstone. Finely conglomeratic at base. 25-120'.	Yields meager supply of water to small springs from many cracks and fractures.		
Precambrian	Precambrian	Belt Supergroup	— ANGULAR UNCONFORMITY —		
			Empire Shale	Drab siliceous mudstone. 0-800'.	Not water bearing.
			Spokane Shale	Red mudstone, shale, and sandstone. 0-5000'.	Yields small supplies of water to many springs.
		Greyson Shale	Gray and brown mudstone, shale, sandstone. 0-1500+.	Yields small supplies of water to many springs.	

Note: A thickness of "0" indicates that the unit is locally not present

decreasing occurrence within a unit. Water-bearing properties of the units shown are discussed in greater detail in the "Hydrogeology" section of this paper.

Where necessary, formational names were modified or replaced to conform with present usage. For example, Lorenz and McMurtrey (1956) considered the Cambrian "Dry Creek Shale" as the formation between the Cambrian Pilgrim Dolomite and Devonian Jefferson Dolomite. Klepper and others (1957) determined that these argillaceous rocks were equivalent to the Red Lion and Maywood formations of Cambrian and Devonian systems. The unit between the Mission Canyon Limestone and Quadrant Formation was called "Amsden Formation" by Klepper and others (1957) and Freeman and others (1958). This unit was split into the Amsden Formation and Big Snowy Group because of work done in the Limestone Hills by Blake (1959) and Dutro and Sando (1963). The lower Tertiary (Oligocene) Renova Formation is equivalent to all of the following: Freeman and others' (1958) Tertiary units 1, 2, and 3 (To, Tu₂, Tu₃); Klepper and others' (1957) rhyolitic tuff and gravel (Ttg); Klepper and others' (1971) conglomeratic or bentonitic rhyolitic sedimentary tuff (To, Tu); and Robinson's (1963, 1967) Dunbar Creek and Climbing Arrow formations of the Bozeman Group (Hughes, 1980; Kuenzi and Fields, 1971).

Structural Geology

The geologic structure in the vicinity of the Radersburg drainage basin has been described in detail by the authors listed on Figure 1.

Their descriptions were field-checked by Straw (1979) during this investigation. The following description of the structural geology of the area shown on Plate 1 was compiled from the available literature.

Pre-Tertiary layered rocks of the drainage basin have been compressed into a series of north-trending folds which have been cut by faults of differing orientations. From the northwest part of the basin to the southeast part of the basin are the Elkhorn Mountains syncline, the Devils Fence dome, the Radersburg syncline, and the Limestone Hills and Hossfeldt Hills anticlines. The axes of these folds generally trend from north to N 20° E (Plate 1).

The Elkhorn Mountains syncline is a very broad, open fold. In the area shown on Plate 1, the fold is about six to ten miles wide. The axial trace of the fold may only be approximately located because of the intrusive bodies and block faults which are present in the area (Smedes, 1966). South of Radersburg Pass, the fold splits into a series of synclines and anticlines.

The north-south elongated Devils Fence dome is made up of nearly concentric belts of post-Precambrian rocks around a core of Precambrian meta-sedimentary rocks. In the north, it is roughly symmetrical and has minor folds in the crest and on its flanks. The southern part is very broad and plunges more steeply than the northern part (Klepper and others, 1957).

The northward-plunging Radersburg syncline is best exposed in the Cold Springs Gulch area just north of Crow Creek, where the fold is ten to twelve miles wide. Here the west limb dips more shallowly than the

east limb. The trough of this fold has been partly invaded by intrusive and extrusive rocks so that the axial trace is nearly impossible to locate (Klepper and others, 1971). The location of the axis of the fold is unknown between Crow Creek and the vicinity of the Wheatland School because of intrusive and extrusive rocks and sedimentary cover. The axis of the fold extends to the south from the drainage basin to the area east of Milligan Creek (Robinson, 1963).

East of the Radersburg syncline are the Limestone Hills and Hossfeldt Hills anticlines. The Limestone Hills anticline has a broad crest, steeply dipping west limb, and gently dipping east limb. Minor folds occur on both limbs. The Hossfeldt Hills anticline has been slightly overturned to the east and cut by the Lombard thrust fault (Freeman and others, 1958).

Faulting has offset the axes of the major folds in the drainage basin. Many of the thrust and strike-slip faults which have been mapped in the area were formed at the culmination of folding. Freeman and others (1958, p. 525) suggested that

stresses in the overriding block near the thrust surface were relieved mainly by folding and minor thrusting, while at a greater distance from the thrust the relief was by strike-slip movement along faults that may have formed earlier in the deformation but that acted as tears during the latest stage of deformation.

Thrust faults occur in the eastern part of the basin. The Hossfeldt Hills anticline is cut by the west-dipping Lombard thrust fault. Minor thrusts are also present between the Hossfeldt Hills and Plunket Lake. These thrust faults in the southern part of the drainage basin may extend to the north, where they have been concealed by basin-fill sediments.

Steep, north-trending faults parallel the axial planes of folds and may have formed during the period of maximum compression as fold limbs slipped over each other (Klepper and others, 1957). Stratigraphic displacement on these faults is 200 to 3,000 feet. Conjugate northwest and northeast-trending faults and lineaments probably are younger than north-trending faults (Klepper and others, 1957). Displacement on the northwest-trending faults is mostly left-lateral and from 1,000 to 3,000 feet. The northeast-trending faults show mostly vertical offset.

Northwest-trending left-lateral faults have been mapped in the Limestone Hills. The valleys of Crow Creek and Indian Creek are partly controlled by northwest-trending faults. A concealed extension of the Crow Creek fault may have caused the southern termination of the Limestone Hills (Straw, 1979). The aeromagnetic map of the Devils Fence, Radersburg, and Toston 15-minute quadrangles (Kinoshita and others, 1965) shows left-lateral offset of the buried continuation of a Precambrian (?) diabase sill which is exposed in the Limestone Hills. Straw (1979) contends that the extension of the left-lateral Crow Creek fault into the Radersburg valley has offset the axial trace of the Radersburg syncline.

Other faults of varying orientations and offset of a few feet to hundreds of feet occur throughout the basin. Some may have been formed during emplacement of intrusives, collapse of magma chambers and uplift of the Elkhorn Mountains. Pre-Tertiary bedding-plane faults and faults in the Tertiary and younger sedimentary rocks and sediments were

mentioned by previous workers (Freeman and others, 1958; Klepper and others, 1957), but they did not map these faults.

Geologic History

The geologic history of the area has been described by the authors credited in Figure 1 and is summarized below. The history of the Elkhorn Mountains-Radersburg valley area may be divided into three stages. The first stage was a time when shallow-water sediments were deposited on a relatively stable surface. Crustal instability and igneous activity marked the second stage. The final, most recent stage has been one of uplift and erosion (Klepper and others, 1957).

The earliest stage lasted from Late Precambrian to Cretaceous. Belt Supergroup rocks were deposited in a shallow sea, then arched and eroded prior to deposition of the marine Middle Cambrian Flathead Quartzite. A conformable sequence of marine carbonates, shales, and sandstones was then deposited (Table 5). The sea regressed at the end of the Cambrian and erosion resulted. Transgression occurred in Late Devonian, when carbonates, sandstones, and shales were deposited without angular unconformity on a surface of negligible relief. Transgression continued until Permian time, with one minor withdrawal at the end of the Mississippian. After deposition of the Phosphoria Formation, the sea withdrew and there was a hiatus until brief transgression when the marine Swift Formation was laid down. Continental deposits of the Morrison and Kootenai formations conformably overlie the Swift. The period of relative stability ended in Colorado time

when the area was alternately above and below sea level (Freeman and others, 1958; Klepper and others, 1957).

The second stage began with volcanism and folding, recorded in the locally folded volcanoclastic rocks of the Slim Sam formation (Klepper and others, 1971). Andesitic breccias, tuffs, and flows of the Elkhorn Mountains volcanics were erupted. Some folding and faulting took place during this period, and concordant or partly concordant dioritic intrusives, compositionally similar to the volcanic rocks, were squeezed into weak zones (Klepper and others, 1971). The main episode of Laramide deformation began after volcanism. The volcanic rocks dip less steeply than the underlying units and the dioritic intrusives have been folded (Klepper and others, 1971). Eastward thrusting of the Elkhorn Mountains block occurred near the end of the period. Late Cretaceous to Paleocene (?) rocks related to the Boulder batholith were intruded after this faulting. Many of these rocks occupy fractured zones in synclinal troughs (Klepper and others, 1957).

Uplift and erosion took place during the third stage. This stage began after the intrusion of the Boulder batholith and has continued to the present. Prior to the ^{now Eocene} Oligocene, the Elkhorn Mountains were uplifted relative to the valley floor, and erosion of the mountains produced a mature topography. None of these pre-Oligocene sediments were preserved in the valley. During the Oligocene, sedimentary tuff and interbedded gravel were deposited in fluvial, deltaic, and lacustrine environments in the valley (Freeman and others, 1958).

From late Oligocene to Miocene time, the Limestone Hills and Elkhorn Mountains continued to be uplifted and to shed sediments to the ancestral Townsend valley, north of the Radersburg valley. The Radersburg valley was relatively stable, as suggested by thinning of Oligocene sediments in the study area (Freeman and others, 1958). During Pliocene time, there was a halt in uplift, the Missouri River maintained a nearly constant base level, and an eastern-sloping pediment formed on the west side of the valley (Pardee, 1925). Uplift then began again, which deformed the Tertiary rocks and rejuvenated the Missouri River. With this rejuvenation, tributaries of the Missouri River incised their drainages, cut into the pedimented surface, and formed alluvial fans. Quaternary time has been one of continued erosion, except during times when local glacial deposits have accumulated (Freeman and others, 1958). Minor uplift of the mountains has occurred to the west of the Devils Fence and along range front faults north of the Limestone Hills (Klepper and others, 1957).

HYDROGEOLOGY

Introduction

Geologic formations which are identified by distinctive lithologic characteristics may be grouped on the basis of water transmitting properties into aquifers and aquitards (Maxey, 1964). Aquifers are rock units which will transmit significant (or economically important) amounts of water to wells or springs under normal hydraulic gradients. Aquitards are less permeable rock units which will not easily transmit water to a well or spring, but may be highly porous and store great amounts of water and allow water to be transmitted to or from adjacent aquifers (Miller, 1980, p. 496).

There are two types of aquifers (Figure 3). Unconfined or water-table aquifers are bounded by an upper surface known as the water table, where water pressure is equal to atmospheric pressure. Confined or artesian aquifers contain water under pressure and are bounded above and below by aquitards. Water levels in wells emplaced in confined aquifers will usually rise above the top surface of the aquifer. Water level data for confined aquifers, which relate to hydraulic head or potential in the aquifer, may be plotted on a map and contoured to define the potentiometric surface of the aquifer.

The hydraulic conductivity, transmissivity, storage coefficient, and hydraulic gradient are used to characterize the amount of water stored in an aquifer and the rate of movement of water in an aquifer.

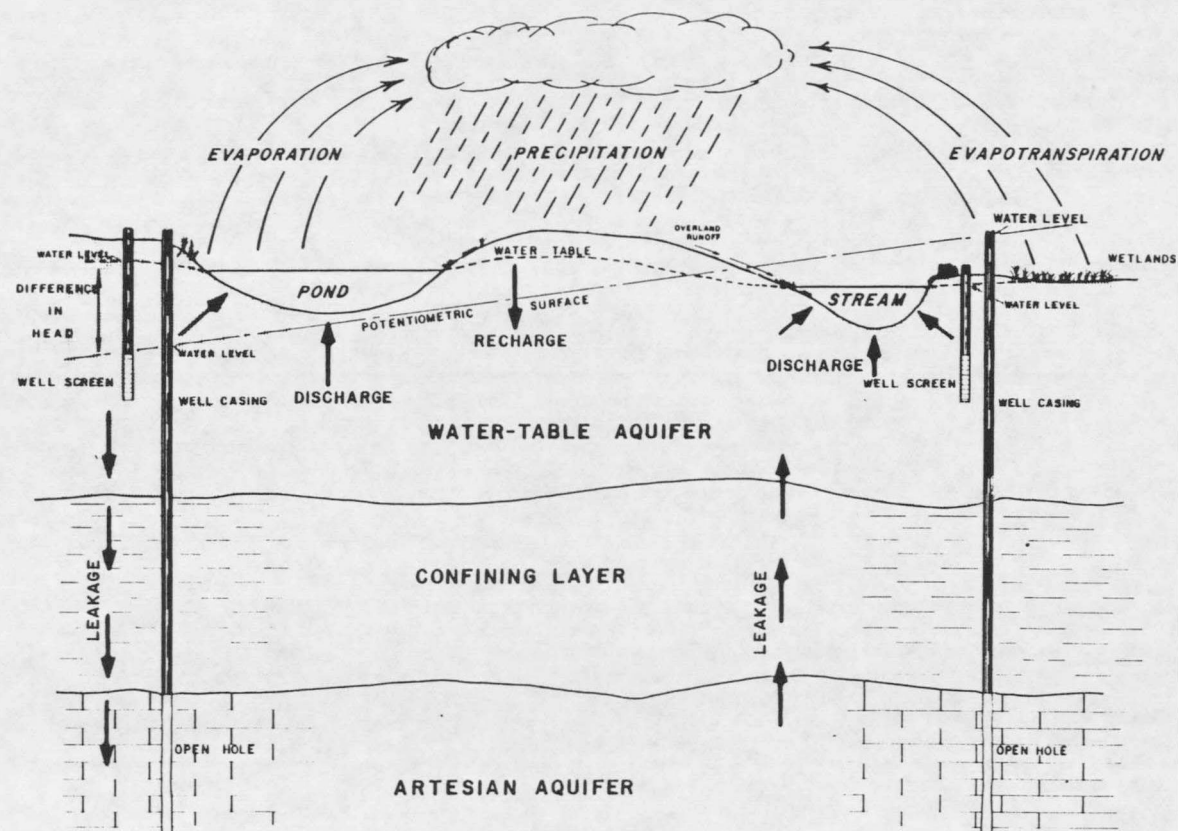


Figure 3. Aquifer Types (Source: Miller, 1980)

Hydraulic conductivity is a measure of permeability and describes the rate at which a unit volume of water will flow through a unit cross-sectional area of material under a unit hydraulic gradient. Transmissivity is the rate at which water will move through a unit width of an aquifer at a unit hydraulic gradient and is the product of the hydraulic conductivity multiplied by the aquifer thickness. The storage coefficient describes the volume of water an aquifer will lose or gain to storage per unit surface area per unit change in head (Lohman, 1972). The hydraulic gradient is the change in static head or potential per distance along a path of flow (Miller, 1980).

The formations listed in Table 5 have been grouped and classified as aquitards or aquifers based on descriptions given in Lorenz and McMurtrey (1956), Taylor (1978), and Bergeron (1979); typical values for hydraulic conductivity of unconsolidated sediments and rocks (Table 6); specific capacity tests (Table 13 in Appendix A); and hydraulic properties determined by my field work. Aquifers in the area are the Mississippian Madison Group and the Tertiary and Quaternary basin-fill and alluvial sediments. These aquifers yield great amounts of water to wells and springs in the basin and have hydraulic conductivities from about one hundred to over one thousand gallons per day per square foot (gpd/ft²). These aquifers are discussed in greater detail below.

Other formations in the basin have hydraulic conductivities much lower than the aquifers (Miller, 1976) and yield little or no water to wells or springs or are not water bearing (Lorenz and McMurtrey, 1956).

Table 6. Hydraulic Conductivities of Rocks and Unconsolidated Materials (Source: Freeze and Cherry, 1979)

Rocks	Unconsolidated deposits	K		
		(cm/s)	(m/s)	(gal/day/ft ²)
Karst limestone	Gravel	10 ²	1	10 ⁶
Permeable basalt		10	10 ⁻¹	10 ⁵
Fractured igneous and metamorphic rocks		1	10 ⁻²	10 ⁴
Limestone and dolomite		10 ⁻¹	10 ⁻³	10 ³
Sandstone		10 ⁻²	10 ⁻⁴	10 ²
Unfractured metamorphic and igneous rocks		10 ⁻³	10 ⁻⁵	10
Shale		10 ⁻⁴	10 ⁻⁶	1
Unweathered marine clay		10 ⁻⁵	10 ⁻⁷	10 ⁻¹
Glacial till		10 ⁻⁶	10 ⁻⁸	10 ⁻²
Silt, loess		10 ⁻⁷	10 ⁻⁹	10 ⁻³
Silty sand		10 ⁻⁸	10 ⁻¹⁰	10 ⁻⁴
Clean sand		10 ⁻⁹	10 ⁻¹¹	10 ⁻⁵
		10 ⁻¹⁰	10 ⁻¹²	10 ⁻⁶
		10 ⁻¹¹	10 ⁻¹³	10 ⁻⁷

These units (Table 5) are very poor aquifers or aquitards and include Precambrian through Upper Devonian formations underlying the Madison Group, Mississippian-Pennsylvanian through Upper Cretaceous sedimentary rocks overlying the Madison Group, and Upper Cretaceous to lower Tertiary extrusive and intrusive igneous rocks. The estimated hydraulic conductivities of these rocks are less than one hundred gpd/ft² (Table 13) and may be as low as 10⁻⁶ gpd/ft² (Table 6). These units have low hydraulic conductivities because the rocks are generally fine-grained, are cemented with silica or calcite, or have intergranular spaces which are filled with micaceous or argillaceous material. Small fractures, joints, bedding planes, and solution channels in these units probably act as zones through which water is transmitted. Evidence for the transmission of water through joints was seen at Hunsaker Spring, where water discharges from joints in Precambrian bedrock.

Mississippian Madison Group Aquifer

The most productive pre-Tertiary aquifer in the region is the Mississippian Madison Group. The aquifer has been extensively studied in Montana, Wyoming, and the Dakotas in connection with oil, coal, uranium, and geothermal resource development (Balster, 1974; Blankenagel and others, 1977; Brown and others, 1977; Head and Merkel, 1977; Hopkins, 1976; Miller, 1976; Swenson and others, 1976; Taylor, 1978). Well yields range from 20 to 9,000 gpm and water temperature varies from about 10°C near land surface to about 120°C where the unit is very deep (Taylor, 1978).

The Madison Group aquifer is composed of two formations in southwest Montana: the Mission Canyon Limestone and the Lodgepole Limestone (Table 5). The Mission Canyon Limestone in the Radersburg drainage basin is a medium-gray to light-gray, finely to coarsely crystalline, thick- to massively bedded limestone. Nodules and lentils of chert and locally fossiliferous beds occur in the upper part of the unit south of Plunket Lake. Solution breccias and karst features are present in the upper part of the Mission Canyon in the drainage basin (Klepper and others, 1957, p. 19-20; 1971, p. 5; Robinson, 1963, p. 43-44) as well as in other parts of the Northern Rockies (Aram, 1979; Aram and others, 1978; Campbell, 1977; Gries and Crooks, 1968; Roberts, 1966; Sando, 1974). The Mission Canyon Limestone grades downward into the thinly and well-bedded, medium-gray, fossiliferous, fine- to coarse-grained Lodgepole Limestone, in which mudstone interbeds are present.

Water is transmitted through the Madison Group aquifer by primary and/or secondary permeability. Primary permeability is a function of grain size, sorting, shape, and organic or inorganic origin of the sediment at the time of deposition (Moore, 1979). Primary permeability will be high in a carbonate unit made up of sand-sized particles or skeletal remains of reef-building organisms with minor amounts of intragranular carbonate mud. Primary permeability appears to be very low in the Madison Group because much of the unit is microcrystalline with only minor amounts of sand-sized or larger particles. Hydraulic conductivities of 83 Madison Group core samples from a test well 300 miles east of the study area, in Custer County, Montana, ranged from

less than 1.8×10^{-4} gpd/ft² to 0.33 gpd/ft² with a mean of 1.6×10^{-2} gpd/ft² (Brown and others, 1977). Twenty-nine of the samples were of unfractured, non-brecciated, microcrystalline to coarse-grained limestone. The samples yielded primary hydraulic conductivity values from 1.8×10^{-4} gpd/ft² to 5.8×10^{-3} gpd/ft² with a mean of 5.5×10^{-4} gpd/ft². Porosities of these samples ranged from 0.3 to 9.4 percent and averaged 3.2 percent (Brown and others, 1977).

Secondary permeability plays a more important role in water transmission in the Madison Group. Possible sources of secondary (post-depositional) permeability include dolomitization, formation of karst and solution breccias, and fracturing. Dolomitization is conversion of calcitic limestone to dolomitic limestone or dolostone. The process results in increased porosity and permeability (Blatt and others, 1972) and may be a possible source of secondary permeability in the Madison Group. Dolostone or dolomitic limestone has been observed in the Mission Canyon Formation near Livingston, Montana (Roberts, 1966); however, dolomitization may be neglected as a source of highly permeable zones in the Radersburg drainage basin. Thin sections of Mission Canyon Limestone samples collected during this study from south of Plunket Lake showed no dolomite, and dolomite is not mentioned in any of the Mission Canyon stratigraphic sections measured in the area (Klepper and others, 1957, 1971; Ruppel, 1950).

Karst features, such as caves, sinkholes, and enlarged joints, cut across strata in the Madison Group. Fossil karst topography in the Toston area and Limestone Hills has been described as an irregular

surface with up to 100 feet of local relief which marks the contact between the base of the Big Snowy Group and the upper surface of the Mission Canyon Limestone (Klepper and others, 1971; Robinson, 1963). Breccias within the Mission Canyon Limestone which have red and yellow limy-mud cement between angular limestone blocks occur in the Elkhorn Mountains and are remnants of collapsed caves and sinkholes (Klepper and others, 1971). These breccias, which are discontinuous, fill upward-widening cavities or joints formed between Mission Canyon Limestone and Amsden Formation deposition (Roberts, 1966).

In contrast with the karst features are stratigraphically controlled evaporite-solution breccia deposits. Solution breccia beds have a poorly defined upper surface and well defined lower boundary, are from 10 to 75 feet thick, and occur about 200 feet below the top of the Madison Group in the southern Elkhorn Mountains. Klepper and others (1957, p. 19) reported that the solution breccias consist of

a chaotic mass of angular blocks, slabs and finer textured rubble, in part cemented by laminated yellowish or reddish calcareous mudstone similar to beds in the lower part of the Amsden Formation and in part by finely crystalline calcium carbonate.

Solution breccia beds are very common in the Mission Canyon Limestone throughout the Northern Rockies. Solution breccias were formed by the leaching of evaporite beds after the Madison Group was uplifted during the Late Cretaceous to early Tertiary Laramide Orogeny (Roberts, 1966). In other places where there was no uplift, the evaporite beds are still present in the subsurface. Anhydrite beds were penetrated in a well near Ringling, Montana, 40 miles east of the study area. The anhydrite

beds correlate with exposed solution breccia intervals in the Mission Canyon Limestone near the study area (Roberts, 1966).

Laboratory and field evidence supports the contention that secondary permeability is greater than primary permeability in the Madison Group. Forty-six of the 83 Madison Group core samples from the Custer County well were of dolomitic limestone, dolostone, and brecciated or fractured limestone. Secondary hydraulic conductivities in this group of samples ranged from 1.8×10^{-4} gpd/ft² to 0.33 gpd/ft² and averaged 3.6×10^{-2} gpd/ft². Porosities ranged from 0.3 to 24 percent and averaged 7.0 percent. In addition to the rock-core permeability tests which indicate high secondary permeability, well drillers have reported lost-circulation zones in the Mission Canyon Limestone in southeastern Montana (Miller, 1976). Loss of drilling fluid circulation between the drill bit and land surface occurs because of voids in a formation. This may be an indication of karst or solution brecciated areas at depth.

Stress-caused fractures, such as faults and joints, also contribute to the secondary permeability of the Madison Group. Plunket Spring is formed by a series of north-south trending springs in the southern end of Plunket Lake. The springs are colinear with the north-south trend of joint sets in Mission Canyon Limestone outcrops just south of the lake. The springs issue over a distance of about 50 feet from openings in very close- to closely spaced joints (1 to 4 inches apart) in the Mission Canyon Limestone.

Plunket Spring and Big Spring show that the Madison Group is a significant source of water in and adjacent to the Radersburg basin and that water is confined or under pressure in the aquifer. Water flowing from Plunket Spring causes churning of the surface of Plunket Lake when about 1.5 feet of water covers the openings. The churning indicates a pressure head above land surface. Discharge from Plunket Spring is impounded to fill Plunket Lake. The lake level varies as water is stored or discharged into Warm Springs Creek for irrigation or stock watering. The amount of water discharged into Warm Springs Creek is controlled by a gate valve and varied from 0.2 to 11.5 cfs during 1979 (Table 1). Previous workers reported the spring flow to be constant throughout the year and gaged the discharge from the spring at 9.7 and 8.7 cfs (Pardee, 1925; Lorenz and McMurtrey, 1956). Using the latter figure, the discharge to the lake is about 3×10^8 cubic feet per year (ft^3/yr) or 2×10^9 gallons per year.

under pressure

approx 3858 gpm

Big Spring, on the east bank of the Missouri River, east of the drainage basin, flows from the basal part of the Amsden Formation, but is probably connected by a fault zone to a "cavernous reservoir" in the Madison Group (Lorenz and McMurtrey, 1956, p. 216). The flow rate of Big Spring in May of 1922 and 1951 was 64.4 and 56.7 cfs (Pardee, 1925, p. 46; Lorenz and McMurtrey, 1956, p. 216) or about 2×10^9 ft^3/yr . Water from this spring is diverted to the area north of Toston for irrigation.

Basin-Fill AquiferGeology

Thick Tertiary-age basin-fill deposits and thin Quaternary alluvium along stream channels occur in intermountain basins in southwestern Montana. These poorly consolidated to unconsolidated sediments of clay, silt, sand, and gravel form the principal aquifers in the area (Taylor, 1978).

Poorly consolidated Tertiary-age sediments in the Radersburg valley consist of rhyolitic or bentonitic sedimentary tuff. The rhyolitic part of this unit is made up of beds of clay- to fine sand-sized ash fragments and coarser sand grains and granules interbedded with beds of very-fine to coarse-grained conglomeratic sandstone with pre-Tertiary clasts up to one foot in diameter. The rhyolitic tuff beds are thin and distinct to thick and indistinct or lenticular, horizontal to gently dipping, and typically contain over fifty percent tuff with interbeds of fine- to coarse-grained sand and gravel. This lens is about 2.5 miles long and hundreds of feet thick, and crops out about 4 miles south of Lone Mountain. Thickness of the Tertiary unit ranges from a featheredge overlapping older rocks to about 1,000 feet in the southernmost part of the drainage basin (Klepper and others, 1957, p. 42; Klepper and others, 1971, p. 12-13; Freeman and others, 1958, p. 508-510; Robinson, 1967).

Unconsolidated Quaternary deposits overlie the Tertiary material. A ten-foot thick veneer of Late Tertiary to Quaternary pediment gravel,

consisting of locally derived gravel with a sand and clay matrix, is present near the Elkhorn Mountains. The pediment deposits thin to the east and are less than 5-feet thick near Plunket Lake (Freeman and others, 1958). Quaternary sediments in the valley are also locally derived and include glacial outwash near the Elkhorn Mountains, alluvial fan sand and gravel, alluvium of the present drainage systems, and eolian silt. The maximum thickness of these sediments is probably less than 60 feet (Lorenz and McMurtrey, 1956). Some domestic and stock wells along Crow Creek and Warm Springs Creek withdraw water from this aquifer.

Although many wells have been drilled in the Radersburg valley, the depth to the subsurface boundary between Tertiary basin-fill deposits and Quaternary alluvium is unknown. Logs of water wells (Table 12 in Appendix A) are generally not descriptive enough to allow distinction between Quaternary and Tertiary beds of clay, sand, and/or gravel. However, the contact between basin-fill sediments and alluvium probably is less than one hundred feet below the land surface. At depths between 100 and 400 feet are Tertiary sand and/or gravel beds from two to twenty feet thick and as much as 60 feet thick. These beds are interbedded with clay beds usually one to four feet thick and as much as 40 feet thick. Overlying the Tertiary beds are thinner beds of Tertiary and/or Quaternary sand and gravel interbedded with clay. Because of the inability to distinguish between the Quaternary and Tertiary sediments, and the relative thinness of the Quaternary sediments, the aquifer formed by both Tertiary and Quaternary

unconsolidated sediments is referred to as the basin-fill aquifer in this report.

Hydrology

Many wells have been drilled into the basin-fill aquifer in the Radersburg valley to supply water for domestic, stock, and irrigation uses. The hydrologic properties of the aquifer may be directly measured because of these wells.

Well Design. Water wells which have been drilled into the basin-fill aquifer were identified using existing drillers' well logs and ground water appropriation forms. Information from these documents is summarized in Appendix A. Water wells in the study area have been drilled for domestic, stock watering, and irrigation use. Table 11 in Appendix A lists well construction information. Domestic and stock wells are usually six inches in diameter and are equipped with submersible pumps. Most of the domestic and stock wells in the valley have been drilled to a maximum depth of less than two hundred feet using cable-tool drilling methods. Well construction methods vary; some wells draw water from torch-cut slots, some use commercially available slotted well screens, and others intake water from open-ended casing. The wells have been completed by natural development. This process involves over-pumping or rapid bailing after installation which creates a natural gravel pack around the intake zone. Over-pumping or rapid bailing removes fine-grained materials from water-bearing sand and gravel around the well and increases the permeability of the aquifer

around the intake zone (Johnson Division, 1975). Domestic and stock wells generally yield less than 50 gpm (Table 13). Although Lorenz and McMurtrey (1956, p. 189) found that "in some places yields [from the near-surface sediments] may be sufficient for irrigation," they were discussing garden irrigation using yields of 8 to 10 gpm (p. 218). Garden irrigation requires much less water than does the irrigation of large fields, which uses 1,000 to 3,000 gpm of water.

The large volumes of water are produced by high-capacity irrigation wells drilled into the basin-fill aquifer. High-capacity irrigation wells have greater maximum depths, are larger in diameter, and have been designed to draw water from greater thicknesses of sands and gravels than domestic or stock wells. Line-shaft turbine pumps supply from 1,000 to 3,000 gpm of water to side-roll sprinkler, center-pivot sprinkler, and flood irrigation systems. Cable-tool drilled wells are generally equipped with 16-inch diameter casing and have been naturally developed. Wells drilled by reverse rotary techniques are constructed of 16-inch or larger casing, centered in artificially gravel-packed boreholes up to 32 inches in diameter. Torch-cut slots, slotted well screens, and louvered screens have been used in the high-capacity irrigation wells (Table 11). Irrigation wells tested by water well drillers have yielded 600 to 3400 gpm in the basin-fill sediments (Table 13).

Transmissivity and Hydraulic Conductivity. The transmissivity and hydraulic conductivity of the basin-fill aquifer were estimated

throughout the study area using specific capacity data and were measured in the vicinity of two wells using aquifer test methods. The specific capacity of a well is a measure of well yield divided by the difference between static and pumping water levels and is expressed in gallons per minute per foot of drawdown (gpm/ft). Specific capacity data are affected by factors such as variations in well design, well efficiency, and test duration. Additionally, many of the specific capacity values reported in Table 13 were calculated from discharge and drawdown measurements reported on drillers' well logs. The accuracy of these measurements is unknown. Meyer's (1963) method was used to estimate transmissivity from specific capacity data. Estimated hydraulic conductivities of the aquifer were determined by dividing the estimated transmissivity by the total length of perforated or screened interval of each well. The test procedures, methods, and results are described in Appendix A.

Specific capacity tests of domestic, stock, and observation wells (Table 13) usually yielded estimated transmissivity values of less than 5000 gpd/ft but ranged up to 100,000 gpd/ft. Estimated hydraulic conductivity averaged 540 gpd/ft². Tests of larger diameter irrigation wells yielded basin-fill sediment transmissivity and hydraulic conductivity estimates averaging 50,000 gpd/ft and 430 gpd/ft².

Aquifer tests provide more accurate assessment of hydraulic conductivity and transmissivity than specific capacity tests. This is because aquifer tests are generally conducted under more controlled

conditions than specific capacity tests and because data from aquifer tests are analyzed by methods that best fit the aquifer geometry and test conditions (Stallman, 1971).

Aquifer tests consisted of a pumping test and a recovery test. Data from the tests and analyses of the tests are described in detail in Appendix B. The pumping test was performed by pumping irrigation well 4-1-10bcb at 1600 gpm for 44 hours. Wells 4-1-9aac and 4-1-10bbc were used as observation wells. Drawdown and recovery measurements were made during the pumping period and for nine hours after pumping ceased. The methods of Chow (1952), Cooper and Jacob (1946), Hantush (1956), and Theis (1935) were used to analyze the data. Because of equipment failures, variation in pumping rate during the test, and the relatively low efficiency of the pumping well, observation well data were used to determine aquifer properties. The four analytical methods used with recovery data consistently indicated that the transmissivity of the aquifer in the test area is 300,000 gpd/ft. The hydraulic conductivity of the aquifer is about 1800 gpd/ft².

The transmissivity of the aquifer in the vicinity of well 4-1-9ca was determined by a recovery test. The well was pumped for 52 minutes at 12 gpm. Insufficient drawdown measurements were made during the pumping period to allow analysis of these data. After the pumping period ceased, recovery measurements were made for 49 minutes. The recovery data were analyzed using the method of Cooper and Jacob (1946) and Theis (1935). The transmissivity determined was approximately 10,000 gpd/ft.

A comparison of the estimated and measured transmissivities shows that the estimated transmissivities derived from specific capacity tests may underestimate the aquifer's actual transmissivity. Estimated transmissivities of the aquifer in the areas of wells 4-1-9ca and 4-1-10bcb are 5000 gpd/ft and 80,000 gpd/ft, which are about 50% and 73% lower than the measured transmissivities of 10,000 gpd/ft and 300,000 gpd/ft, respectively. Order of magnitude approximations of the transmissivity of the aquifer near small-diameter and irrigation wells are 10,000 and 100,000 gpd/ft, respectively.

The estimated transmissivity values from tests of small and large diameter wells indicate that the aquifer's transmissivity is variable throughout the study area. This variability appears to be caused by the total thickness of the water-bearing beds of sand and gravel which yield water to each well and not because of variations in the hydraulic conductivity of the aquifer materials.

Because transmissivity is affected by aquifer thickness, the hydraulic conductivity appears to better describe the rate of water movement through the aquifer. There was no significant difference in estimated hydraulic conductivities derived from irrigation and small-diameter wells. Estimated hydraulic conductivities averaged 540 gpd/ft² from tests of small diameter wells and 430 gpd/ft² from tests of irrigation wells. There was no statistical difference between the means of the two types of wells when compared with the two-tailed t-test at a 10 percent confidence level using methods given in Davis (1973). The estimated hydraulic conductivity of the producing zones in the basin-fill aquifer is therefore on the order of 500 gpd/ft².

The estimated hydraulic conductivity is probably lower than the actual hydraulic conductivity of the aquifer. This may be because the same specific capacity data used to estimate transmissivities which are at least 60 percent lower than the measured transmissivities were used to compute estimated hydraulic conductivities. An order of magnitude estimate is that the hydraulic conductivity of the aquifer is 1000 gpd/ft².

Storage coefficient. Accurate determination of the storage coefficient of an aquifer requires the use of observation wells during a pumping test. The storage coefficient determined from the pumping test of well 4-1-10bcb indicates that ground water is confined in at least part of the basin. The value of 0.0016 obtained from the pumping test is within the 0.005 to 0.00005 storage coefficient range for confined aquifers given in Freeze and Cherry (1979). Other indicators of confined ground water are the presence of many clay layers in the valley sediments and the presence of at least one well (5-2-31dc) where the static water level is above the ground surface.

Although no pumping tests have been performed to confirm the presence of unconfined ground water, ground water is probably unconfined in some places. Lorenz and McMurtrey (1956, p. 208) state that "part of the ground water in Quaternary and Tertiary deposits is under water-table conditions." Drillers' logs listed by Lorenz and McMurtrey (1956) and Pardee (1925) indicate that unconfined ground water is present near Crow Creek and Warm Springs Creek. Near the creeks, the aquifer is composed of near-surface stream channel alluvial deposits

of sand and gravel with minor clay interbeds. The lack of low permeability confining beds and the shallow water levels near the creeks suggest water in the sand and gravel is not under pressure and is therefore unconfined. The storage coefficient has not been measured in unconfined parts of the aquifer. Storage coefficient values where the aquifer is unconfined may range from 0.01 to 0.30 (Freeze and Cherry, 1979). In similar unconfined deposits of the Gallatin Valley to the southwest, the measured storage coefficient was at least 0.05 (Hackett and others, 1960).

Ground-water movement. Ground-water levels in existing wells were measured from May, 1979 to April, 1980. The methods used to measure water levels are given in Appendix A. Measurements of water levels are presented in Table 15 in that appendix. Water levels were measured in wells which may penetrate multiple water-producing zones in both confined and unconfined parts of the basin-fill aquifer. For this reason, the water levels do not necessarily show the absolute water table elevation or potentiometric surface elevation. However, the water level measurements allow the determination of the general direction of ground-water flow and the approximate hydraulic gradient in the aquifer.

Figure 4 is a water-level contour map drawn from static water level measurements made during June to August, 1979. Water level elevations in Figure 4 are to plus or minus five feet because ground surface elevations were estimated from topographic maps. The water level surface shown sloped from above 4080 feet in the west to less

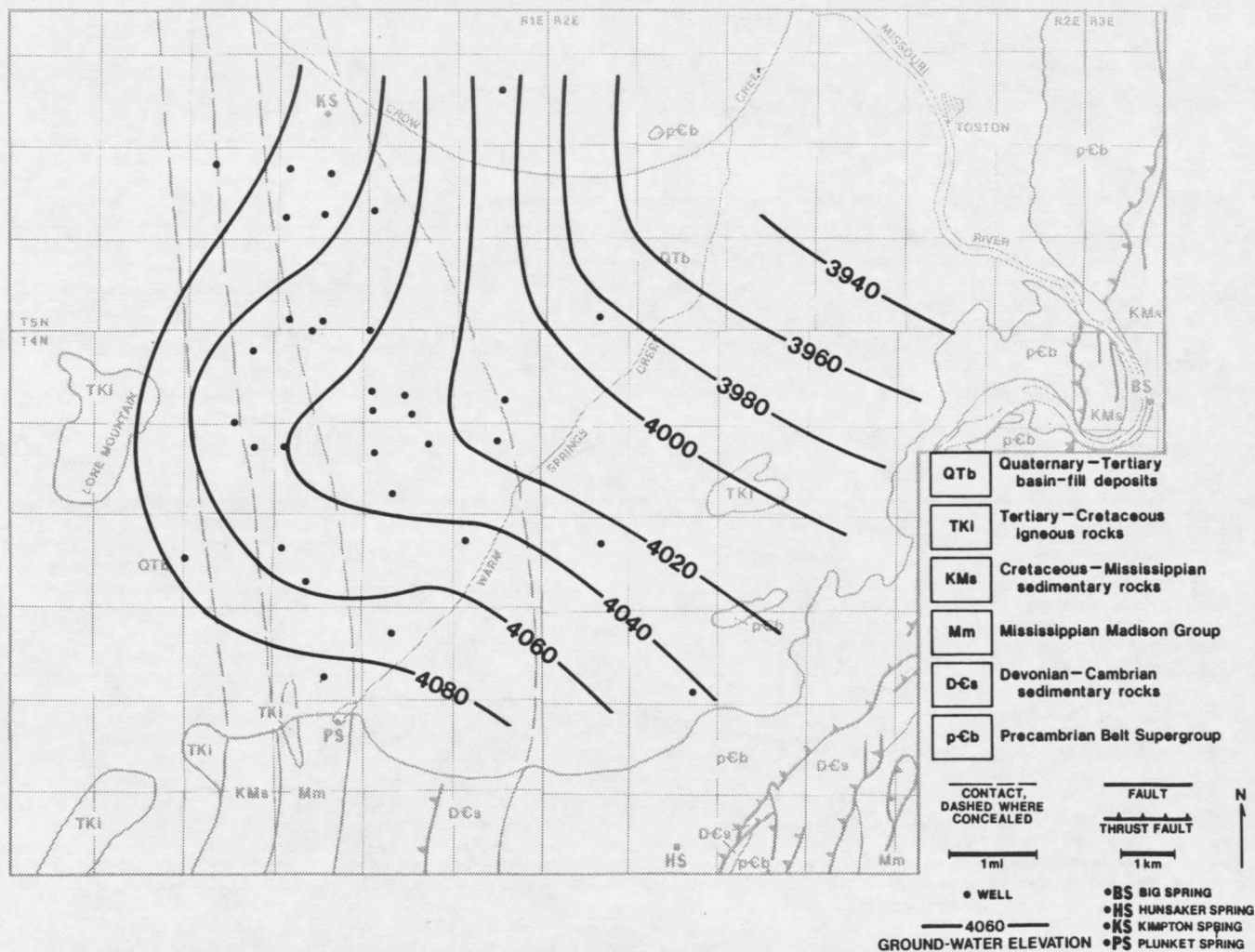


Figure 4. Ground-Water Level Map. Measurements obtained from June to August, 1979. Accuracy is to ± 5 feet

than 3940 feet in the eastern part of the study area. The direction of ground-water movement was to the east or northeast towards the Missouri River.

The hydraulic gradient and hydraulic conductivity may be used to determine the rate of ground-water movement through the aquifer. The rate of water movement may be calculated from Darcy's law (Freeze and Cherry, 1979), where

$$Q = KIA$$

and Q = discharge rate;

K = hydraulic conductivity;

A = cross-section area; and

I = hydraulic gradient.

During the summer of 1979, the hydraulic gradient throughout the study area varied from about 0.002 to 0.006 or from about 10 to 32 feet per mile. In much of the area, the gradient was about 0.004 or 21 feet per mile. Using the latter gradient and the hydraulic conductivity of 1000 gpd/ft², about 4 gallons per day or 0.003 gpm would have been flowing through an area of one square foot perpendicular to the flow direction.

EVIDENCE FOR RECHARGE TO BASIN-FILL AQUIFER BY MADISON GROUP AQUIFER

Introduction

Thirty irrigation wells had been drilled into the basin-fill aquifer in the Radersburg valley by 1979. Twenty-nine of the wells were located in the area between Kimpton Spring and Plunket Spring. The position of the wells within a relatively small area and the apparent lack of variation in hydraulic conductivity of the basin-fill aquifer throughout the valley suggests that there is a local geologic feature which enables the basin-fill aquifer to supply the large amounts of water needed for irrigation. The position of the Madison Group, the temperature of ground water in the area, and local ground-water chemistry indicate that the Madison Group aquifer is this geologic feature and that ground water from the Madison Group aquifer is leaking into the overlying basin-fill aquifer.

Position of the Madison Group

The Madison Group crops out in the vicinity of Plunket Lake and in the Limestone Hills to the north as shown on Plate 1. In the vicinity of Plunket Lake, the unit dips about 40° W. Where the unit is exposed in the southern end of the Limestone Hills, the bedding is nearly vertical. An undetermined thickness of basin-fill sediments covers the unit between the Limestone Hills and Plunket Lake. Figure 5 shows the projected subcrop trend of the Madison Group,

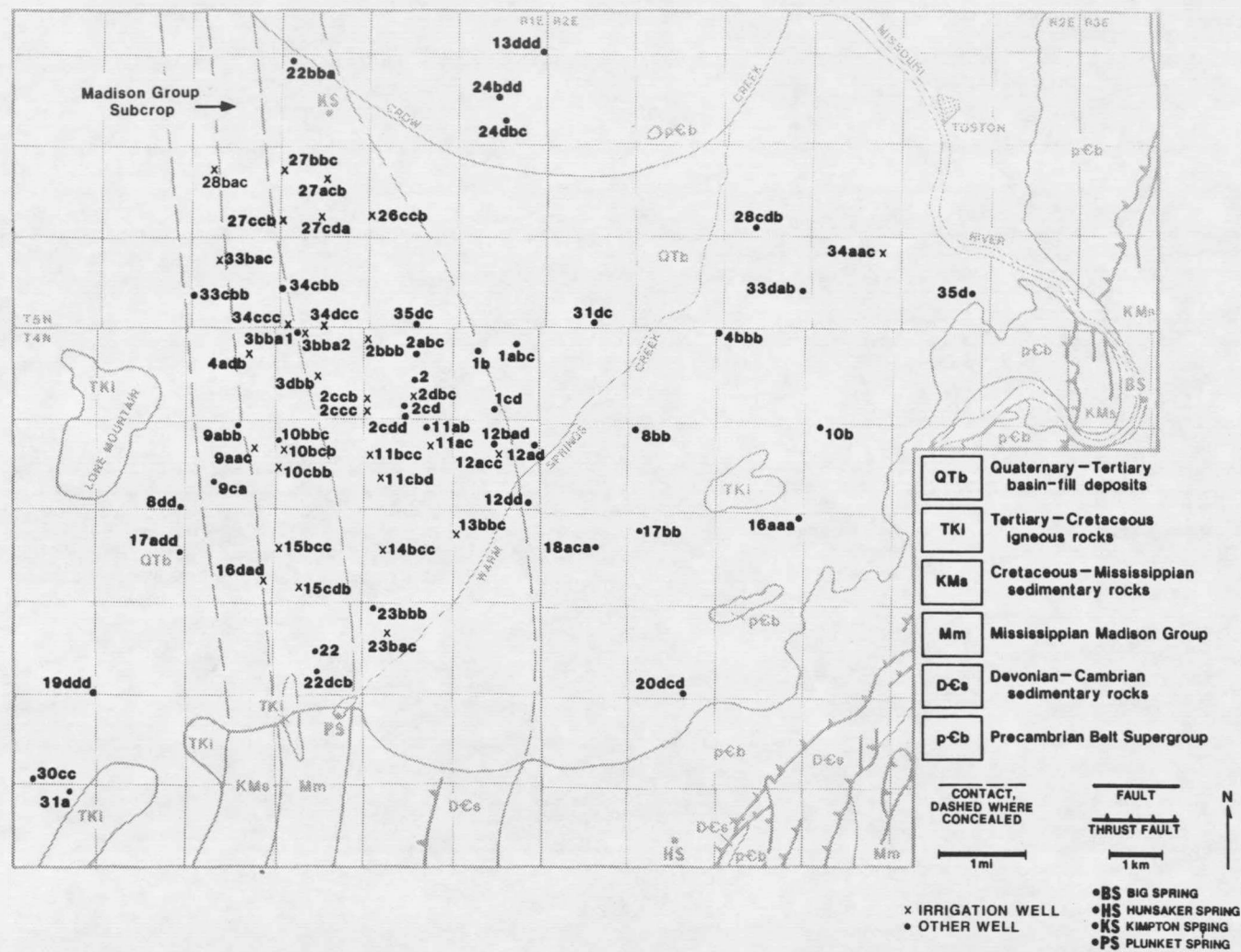


Figure 5. Well Locations and Subcrop Trend of the Madison Group

assuming that the unit is continuous between the Limestone Hills and Plunket Lake. The figure also shows the position of irrigation wells in the Warm Springs Creek area. The position of many of the wells, to the east and hydraulically downgradient from the projected subcrop trend of the Madison Group, suggests that the wells have been located in an area where the limestone aquifer may recharge the basin-fill aquifer by upward leakage of water. Even if the position of the irrigation wells in the Radersburg valley has been fortuitous, ground-water temperature and chemistry data further support the idea that water from the Madison Group recharges the basin-fill aquifer.

Ground-Water Temperature

The presence of warm-water springs issuing from the Madison Group in and adjacent to the study area suggests that ground-water temperature may be an indicator of recharge by the limestone aquifer to overlying basin-fill sediments. The temperatures of Plunket Spring and Big Spring measured during this investigation were 16.5°C and 15.5°C, respectively. These temperatures are within 0.5°C of temperatures measured during 1921, 1949, and 1950 (Table 7). Plunket Spring discharges from fractures in the Madison Group. Although Big Spring does not flow from outcrops of the Madison Group, Lorenz and McMurtrey (1956, p.216) stated that the Madison Group supplies water to this spring through a "fault zone that connects with a cavernous reservoir in a limestone of the Madison Group."

Field well-water temperature measurements were made to determine if there was a pattern of warm waters in the vicinity of the Madison

Table 7. Water Temperatures From Springs

Name and Location	Date	Temperature (°C)	Remarks
Plunket Spring 4-1-27ada	July, 1921	16.7	(62°F) Pardee, 1921
	September, 1949	16.7	(62°F) Lorenz and McMurtrey, 1956
	5-26-79	16.0	
	7-17-79	17.0	
	8-15-79	16.5	
	9-14-79	16.5	
	10-13-79	16.5	
	11-10-79	17.0	
Hunsaker Spring 4-2-32dbd	6-26-79	24.5	Measurement in pond
Big Spring 4-3-6dad	July, 1921	15.0	(59°F) Pardee, 1921
	September, 1949	15.0	(59°F) Lorenz and McMurtrey, 1956
	June, 1950	15.0	Do.
	6-29-79	15.5	
Kimpton Spring 5-1-22dbc	July, 1921	17.8	(64°F) Pardee, 1921
	September, 1949	17.8	(64°F) Lorenz and McMurtrey, 1956
	6-16-79	18.0	
	11-10-79	18.0	

Group subcrop north of Plunket Spring. Well-water temperature measurements are listed in Table 8. Ground-water temperatures ranged from 5.5 to 13.5°C and averaged 10.5°C in stock and domestic wells. Irrigation-well water temperatures varied from 10.5 to 22.5°C and averaged 13.0°C. To eliminate the effect of recharge by non-thermal water (i.e., infiltration by precipitation and surface water) into the basin-fill aquifer in the study area, temperature measurements from wells of less than 100-foot total depth were not used for the determination of recharge by the Madison Group. Temperature measurements from wells with intake depth (i.e., total depth or bottom of perforations) below 100 feet in the basin-fill aquifer and in bedrock wells 4-2-16aaa and 4-2-18aca were used to prepare an isothermal map of the study area (Figure 6). Water discharging from Hunsaker Spring collects in a large shallow pool; the temperature measured is not representative of subsurface conditions.

The isothermal map shows that ground-water temperatures are generally above 12°C between Kimpton Spring and Plunket Spring. Ground water temperatures are generally lower to the west and east, upgradient and downgradient from the trend of the Madison Group. The presence of warm water along the trend of the Madison Group implies that water from the limestone aquifer is leaking into the overlying basin-fill aquifer. Ground-water temperatures generally decrease to the east as the affect of leakage from the Madison Group decreases. The Madison Group aquifer does not appear to be uniformly recharging the basin-fill aquifer, because of the variability in temperature measurements along the subcrop trend.

Table 8. Well-Water Temperature Data

Well Number	Date	Temperature (°C)	Depth to Bottom of Intake Zone (ft)	Thermal Gradient (°C/100 ft)
Domestic and Stock Wells				
4-1-1abc	6-29-79	8.5	27	9.3
4-1-1cd	8-17-79	9.5	62	5.6
4-1-9ca	6-20-79	13.5	253	4.9
4-1-12ad	8-17-79	9.0	106	2.8
4-1-12bad	8-12-79	5.5	40	---
4-1-19ddd	7-24-79	10.5	146	1.6
4-1-31a	7-24-79	9.5	43	8.1
4-2-16aaa	6-29-79	12.5	320	2.0
4-2-18aca	6-12-79	15.0	109	8.3
5-1-24dbc	7-12-79	8.0	36	5.6
5-1-33cbb	7-12-79	12.0	174	3.4
5-2-31dc	8-16-79	12.0	125	4.8
5-2-33dab	11-2-79	12.0	148	4.1
5-2-35d	9-12-79	12.5	194	3.4
Irrigation Wells				
4-1-2bbb	6-29-79	11.5	186	3.0
4-1-3dbb	8-17-79	15.0	293	3.1
4-1-4adb	6-29-79	18.0	400	3.0
Do.	7-24-79	22.5	do.	4.1
4-1-9aac	6-29-79	15.0	335	2.7
4-1-10bcb	5-2-80	15.5	330	2.9
Do.	5-4-80	13.5	do.	2.3
4-1-11bcc	7-9-79	11.5	397	1.4
4-1-12acc	8-17-79	12.0	232	2.6
4-1-15bcc	7-24-79	13.5	348	2.2
4-1-15cdb	6-20-79	12.5	342	1.9
Do.	6-29-79	13.0	do.	2.0
Do.	7-24-79	13.5	do.	2.2
4-1-23bac	6-28-79	14.0	332	2.4
Do.	7-24-79	12.0	do.	1.8
5-1-26ccb	7-12-79	11.0	165	3.0
5-1-27acb	6-28-79	10.5	225	2.0
Do.	7-24-79	11.0	do.	2.2
5-1-27bbc	6-29-79	10.0	300	1.3
5-1-27ccb	8-17-79	10.0	215	1.9
5-1-27cda	8-17-79	10.0	295	1.4
5-1-28bac	10-13-79	16.0	339	2.9
5-1-33bac	7-24-79	11.0	252	2.0

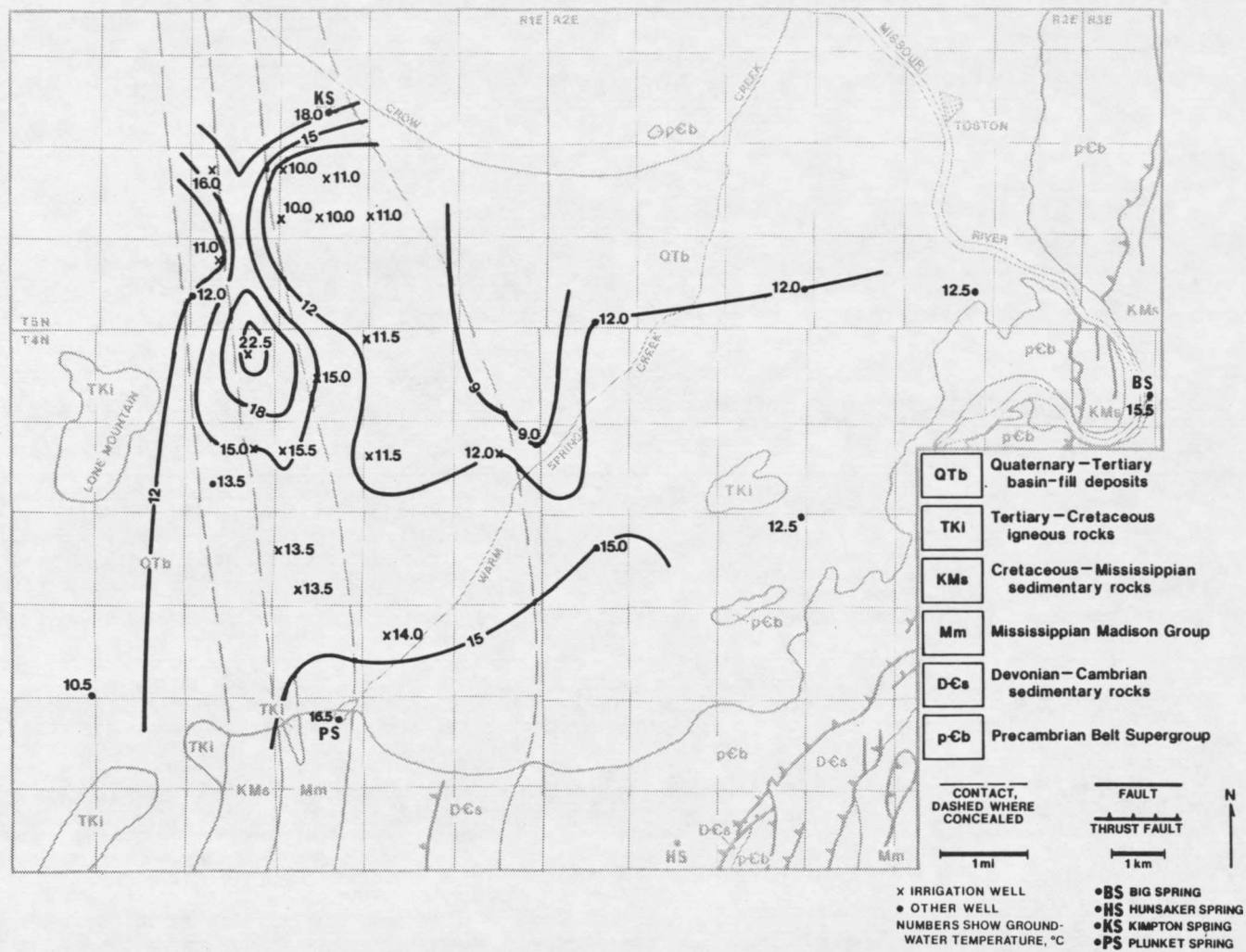


Figure 6. Isothermal Map

Ground-water flow through fractures may cause the variability in ground-water temperature along the Madison Group subcrop trend. Intersections or concentrations of north-south and east-west trending fractures may allow leakage from the Madison Group into overlying rocks in the Milligan Canyon area south of the Radersburg valley (Bergeron, 1979; Krothe and Bergeron, 1981). Similar fractures may locally increase the amount of water leaking from the Madison Group into the basin-fill aquifer and may account for the variations in temperature along and away from the subcrop trend (Figure 6).

Fractures may also provide a means for water from the Madison Group to flow from Kimpton Spring. Kimpton Spring flows from unconsolidated sand and gravel. The 18°C temperature of the water has been constant since 1921 (Pardee, 1925; Lorenz and McMurtrey, 1956). Lorenz and McMurtrey (1956, p. 217) believed that water discharging from the spring originates "from deep within the Tertiary beds and probably reaches the surface through small fissures or cracks in the overlying sediments." The position of the spring and its temperature suggests that water discharging from the spring originates in the Madison Group and then moves through fractures in the basin-fill aquifer.

Ground-Water Chemistry

Water chemistry was used as a tool to determine if the Madison Group aquifer could be recharging the basin-fill aquifer, to identify

other possible sources of recharge water, such as streams, and to attempt to identify if chemical processes such as mixing, solution, precipitation, and ion exchange were occurring in the basin-fill aquifer. Water samples were collected to determine if chemical fingerprints could be used to identify sources of recharge, even if affected by the above processes.

Twenty-nine water samples were obtained from wells, springs, and Crow Creek between June 1979 and May, 1980. Twenty samples were from sixteen wells in the basin-fill aquifer, including four samples from well 4-1-10bcb during the pumping test in May, 1980. Two samples were from wells which, based on well logs, had been drilled in bedrock units. These samples were from wells 4-2-16aaa, which is perforated in Belt Supergroup (?) sandstone, and 4-2-18aca, which is cased apparently without perforations to a layer of sand and fragmented shale within a pre-Madison Group unit. The lithologic units penetrated by these wells could not be positively identified because the well logs do not allow determining of rock units. Six samples were obtained from springs and one sample was taken from Crow Creek near the Helena National Forest boundary northeast of Radersburg. Appendix C details water-quality sampling methods and lists analyses in Tables 22-24.

To facilitate comparisons of analyses, the analytical results expressed in milligrams per liter (mg/l) were converted to the units of milliequivalents per liter (meq/l). The use of meq/l units enables one to compare the amounts of dissolved ionic species on a chemically equivalent basis and recognizes variations in valences and atomic weights between analyzed parameters.

Major Ions

To allow for grouping of analyses in terms of major ions (calcium, magnesium, sodium, potassium, bicarbonate, sulfate, and chloride), a trilinear diagram of ionic ratios was prepared using the method of Piper (1944), where each analysis is represented by three points. Each point in the left triangle of Figure 7 represents the relative proportion of the positively charged ions (cations) calcium, magnesium, and sodium plus potassium in a water sample, in meq/l, normalized to 100 percent. Each apex of the triangle represents 100 percent of concentration for a given parameter. Each point in the right triangle represents the relative concentrations of the major negatively charged ions (anions) chloride, sulfate, and bicarbonate. The composition of a water sample, relative to the major ions, is represented by projecting the points from the lower triangles into the upper diamond-shaped field along lines parallel to the upper boundaries of this field. Waters which are similar in composition will be grouped together in this field.

The trilinear diagram may be used to describe the chemical type and character of a water sample. The chemical type of water and chemical character of a water sample were defined by Back (1966, p. A13). The dominant ion on a greater than 50 percent basis determines the anion or cation type of water. The left triangle of Figure 7 shows that three cation types of water (calcium, sodium, and no dominant type) are present in the study area. The anion triangle shows that bicarbonate, sulfate, and no dominant type waters are present.

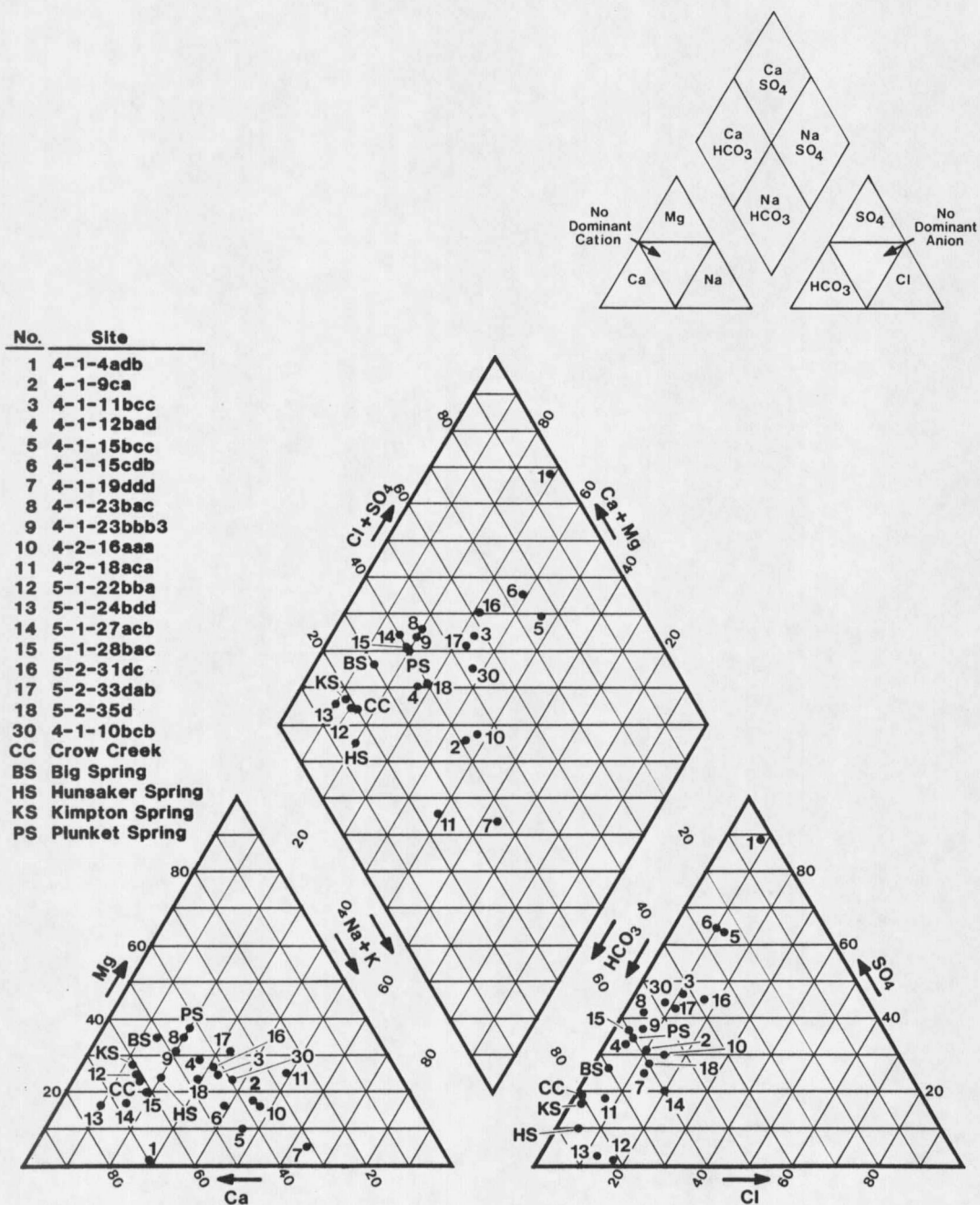


Figure 7. Trilinear Diagram and Ground-Water Character.
 Note: Numbers refer to analyses in Appendix C.

The combination of dominant ion types determines the character of the water. Water of calcium bicarbonate, calcium sulfate, and sodium bicarbonate character were analyzed during this investigation. Sodium sulfate water was not present in the area. The diamond-shaped field of Figure 7 was used to determine the areal distribution of the chemical character of water, shown in Figure 8. Calcium bicarbonate water occurred at 15 ground-water sampling sites and in Crow Creek. Calcium sulfate water occurred at seven sites in the study area and one site had sodium bicarbonate water.

The presence of ground waters of three chemical characters in the study area may be the result of differences in sampling depth, multiple recharge sources, or multiple processes affecting ground-water chemistry. With the exception of wells 4-1-12bad, 5-1-22bba, and 5-1-24bdd, samples from wells in the basin-fill aquifer were obtained from wells with perforations or open intervals below 100 feet. Samples from wells less than 100 feet deep may be influenced by local surface-water infiltration. While the 100-foot depth is somewhat arbitrary, clay layers in the basin-fill deposits should act as aquitards to reduce the influence of surface-water infiltration on ground-water chemistry. For the purposes of this report, samples from wells in the basin-fill aquifer with total depths below 100 feet will be considered as representative of ground water which may be recharged by an aquifer underlying the basin-fill aquifer.

Possible recharge sources to the basin-fill aquifer within the study area include precipitation onto the valley floor, influent surface water from streams and irrigation return flow, and the Madison

↳ what about ag. signatures.

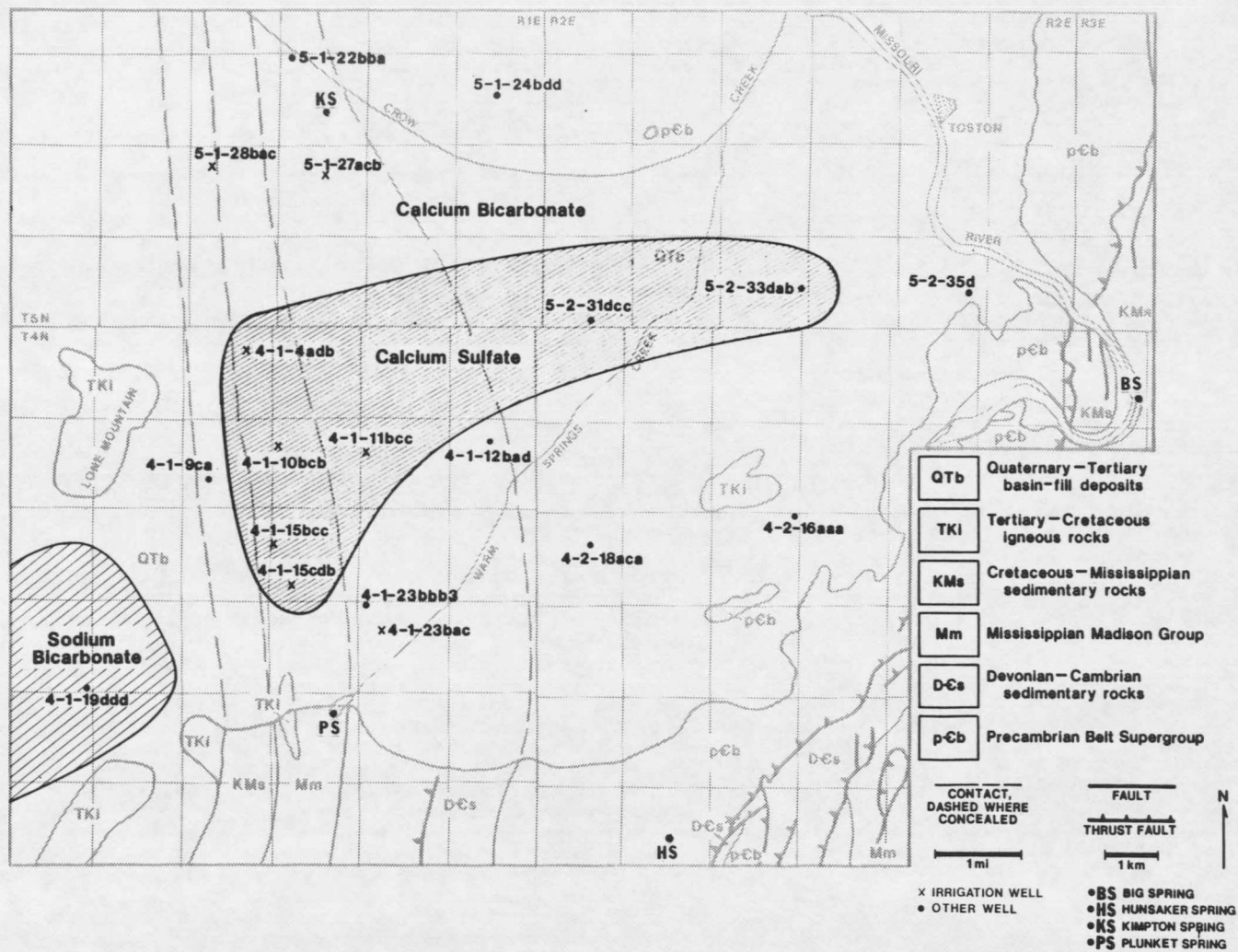
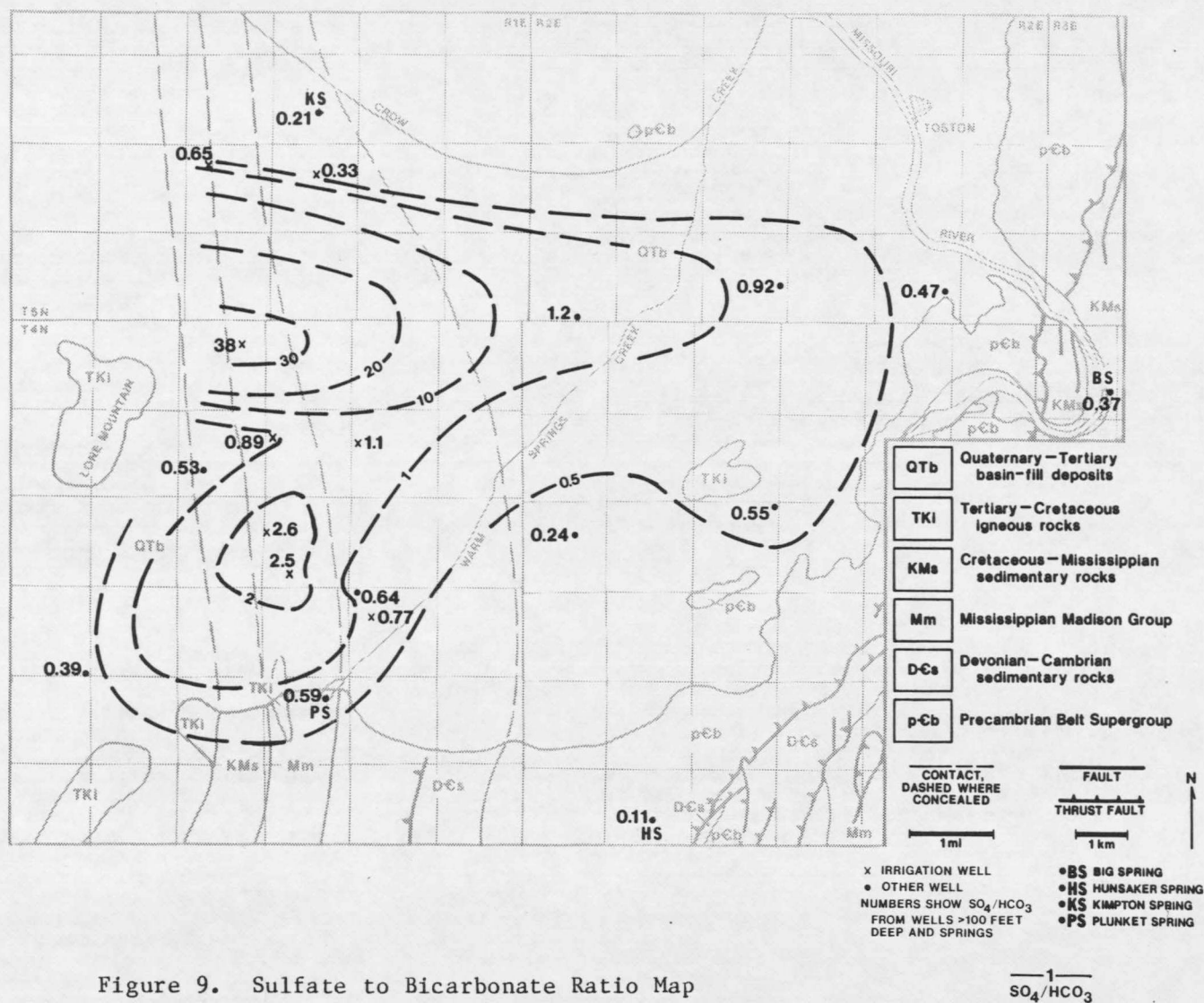


Figure 8. Ground-Water Character Areal Distribution

Group aquifer. The effects of precipitation are not known. Surface water from the Elkhorn Mountains, as represented by the Crow Creek sample, is a likely source of calcium bicarbonate water to the aquifer in the northern part of the study area. Crow Creek loses water to the valley sediments as it approaches the Missouri River (Klepper and others, 1971; Straw, 1979). Ground water from wells 5-1-22bba and 5-1-24bdd and Kimpton Spring are similar in composition to water from Crow Creek (Figure 7). The major difference between the waters is the amount of total dissolved solids (TDS). The TDS of Crow Creek water is about 110 mg/l and the TDS of the three ground waters ranges from about 130 to 230 mg/l. It appears that infiltrating Crow Creek water dissolves some of the aquifer material but does not undergo major chemical changes as it moves downgradient towards the wells.

Bicarbonate and sulfate are the dominant anions in the valley. Water recharging the basin-fill aquifer from the Elkhorn Mountains is of bicarbonate type, as shown by the analysis from Crow Creek and wells in the vicinity of Crow Creek. To the south is an area of water which is enriched in sulfate ions. The Madison Group could supply sulfate ions by the solution of gypsum or anhydrite where these evaporite minerals were not leached during the formation of evaporite-solution breccia beds. Figure 9 shows the sulfate/bicarbonate ratio in wells deeper than 100 feet in the valley. The ratio of sulfate to bicarbonate was used because the dominant anion in analyzed waters was sulfate or bicarbonate. Water between Plunket Spring and Kimpton Spring is enriched in sulfate. Because sulfate is not the dominant



anion in wells upgradient from the Madison Group subcrop trend or in wells in alluvium, the sulfate source must be the Madison Group. The area enriched in sulfate extends downgradient from the subcrop trend of the Madison Group, which would be expected if water from the limestone aquifer was leaking into the overlying basin-fill aquifer.

Plunket Spring discharges water of calcium bicarbonate composition which is higher in sulfate and TDS than the water from Crow Creek. In the area north of Plunket Spring, where the Madison Group is covered by basin-fill sediments, wells 4-1-23bac, 4-1-23bbb3, 5-1-27acb, and 5-1-28bac discharge water similar in composition (Figures 7 and 8). The TDS of Plunket Spring is slightly lower than the TDS of the well waters. The higher TDS of the well waters is probably from the dissolution of basin-fill aquifer material.

Calcium sulfate water occurs in the area north of Plunket Spring and wells 4-1-23bac and 4-1-23bbb3 and south of wells 5-1-27acb and 5-1-28bac. Water from well 4-1-4adb is almost entirely composed of calcium and sulfate (Figure 7) and has the highest TDS of any water analyzed for this project. Other sulfate type waters were from wells 4-1-15bbc and 4-1-15cdb south of 4-1-4adb. No high-sulfate water was sampled to the west, upgradient from these wells. High-sulfate ground waters are discharged from basin-fill deposits overlying the projected north-south subcrop trend of the Madison Group. The presence of the sulfate-rich water points to a sulfate source. A reasonable sulfate source is the dissolution of remnant gypsum or anhydrite in the upper Madison Group in the area north of Plunket Spring.

Strontium

Another indicator of recharge to the basin-fill aquifer by the Madison Group aquifer may be the trace ion strontium. Strontium may be an indicator ion because it substitutes for calcium in carbonate minerals. The ionic radius of strontium will allow the substitution for calcium in aragonite, the orthorhombic form of calcium carbonate which is present in the skeletons of some invertebrate organisms (Blatt and others, 1972). However, ground-water flushing of marine carbonates containing aragonite results in the dissolution of aragonite or in the inversion of aragonite to calcite, which is rhombohedral. Strontium ions do not readily fit into the crystal lattice of calcite, and strontium moves from aragonite into the ground water (Hanshaw and Back, 1979).

Minerals enriched in strontium may also form in closed (evaporite) marine basins, when carbonate mineral precipitation decreases and sulfate minerals begin to precipitate. Strontium sulfate (celestite) will begin to precipitate from brines in evaporite basins before the precipitation of gypsum or anhydrite. Strontium may also isomorphically substitute for calcium in anhydrite, which is orthorhombic (Vlasov, 1966).

The concentration of strontium in ground water in the basin might indicate recharge from a carbonate aquifer to an aquifer composed of sediments. Carbonate and evaporitic rocks are enriched in strontium relative to clastic rocks. The average concentration of strontium in carbonate rocks is about 0.06%. The average strontium concentration

in marine shales and clays is about 0.03% and is lower in non-marine shales and clays. Sandstones generally contain about 0.002% strontium (Vlasov, 1966). Therefore, an evaporite-bearing carbonate aquifer might be expected to be relatively enriched in strontium compared to an aquifer composed of continental sediments.

If the Madison Group aquifer is recharging the basin-fill aquifer, the highest concentration of strontium in the basin should be in the area where the limestone is covered by basin-fill sediments. Figure 10 is a map of the ratio of the strontium concentration to TDS in groundwater samples. The map shows that the highest strontium concentrations occur in the area north of Plunket Lake, and decrease to the east, hydraulically downgradient from this area. If the basin-fill aquifer was contributing strontium to ground water in the same concentrations as the Madison Group, the strontium level would be constant throughout the basin.

The sedimentary aquifer is not recharged by water of constant character from the Madison Group. The change in character from calcium bicarbonate water at Plunket Spring to calcium sulfate water to the north and the corresponding increase in strontium may be the result of dissolution of remnant evaporite minerals in the Madison Group. A possible explanation for this change could be because water which issues from the Madison Group at Plunket Spring has followed the same flow path for enough time to dissolve residual evaporites which contain strontium. To the north, the installation of high-capacity irrigation wells has placed a new stress on the Madison Group aquifer

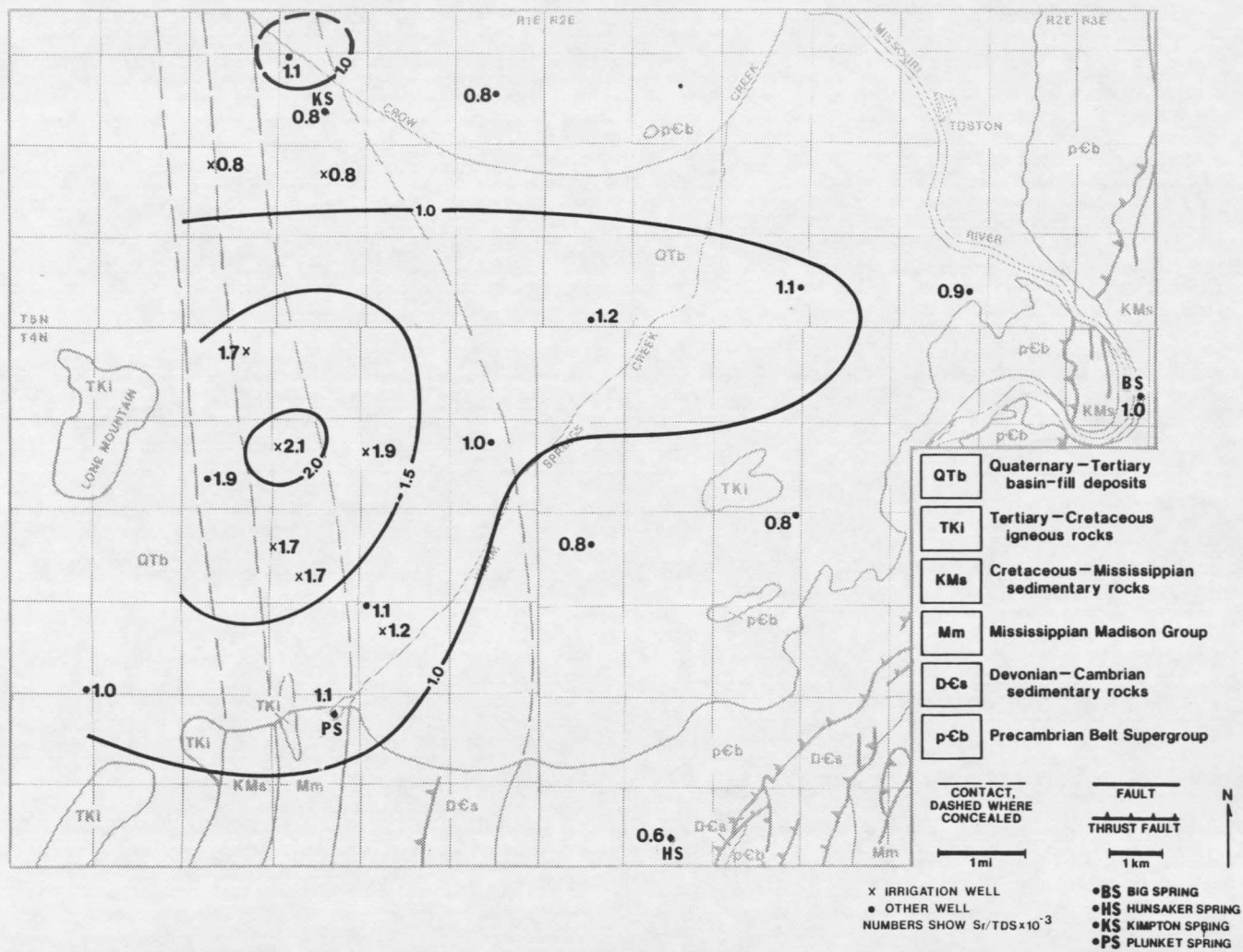


Figure 10. Strontium to Total Dissolved Solids Ratio Map

1.0
 $Sr/TDS \times 10^{-3}$

and caused new flow paths to form. If these new flow paths intercepted evaporite minerals, the resulting dissolution could release sulfate and strontium ions to the ground water system in the basin.

Multiple Recharge Sources

The relative concentrations of sulfate, bicarbonate, and strontium ions in the basin indicate that at least two sources recharge the the basin-fill aquifer. Ground water is recharged in some areas by infiltration of surface water which is high in bicarbonate ion concentration and low in sulfate and strontium ion concentrations and TDS.

In the zone between Plunket Lake and Kimpton Spring, the Madison Group aquifer recharges the basin-fill aquifer. The calcium bicarbonate character of the Plunket Spring water must be representative of water which flows from limestone beds in the Madison Group aquifer. Similar waters occur in wells in this vicinity. Waters enriched in sulfate and strontium ions have probably come in contact with evaporite minerals in the Madison Group.

Processes Affecting Water Chemistry

Ground-water compositions within the basin-fill aquifer vary throughout the study area because processes such as mixing and ion exchange are occurring. If simple mixing (i.e., no precipitation or solution reactions occurring during mixing) of water from the basin-fill and Madison Group aquifers were occurring, a linear plot of ground-water composition would be shown on the Piper diagram. The ends

of the line would represent the composition of the two mixing waters. Figure 7 shows that this is not the case. Ground water compositions do not plot on a straight line, but are scattered. The scatter is probably because several processes which affect ground-water composition. The composition of water from the Madison Group is variable and depends on whether or not contact with evaporites takes place. Ion exchange probably affects the cation composition. Calcium-rich water may react with sodium smectite minerals (bentonite or montmorillonite) to release sodium ions to the ground water. Hydrolysis of volcanic glass to produce smectite minerals may also alter ground-water chemistry. Because many possible reactions may occur in this system and because the ground-water chemistry does not show a simple pattern, no prediction of water chemistry appears to be possible from the available data.

GROUND-WATER WITHDRAWAL

Introduction

Well logs show that basin-fill and alluvial sediments form the aquifer from which most of the water is withdrawn for stock, domestic, and irrigation uses. This discharge plus natural discharge must equal the amount of water replenished to the system (recharge) and variations in the amount of water contained in the aquifer (changes in storage) for an overall water balance to occur. If long-term discharge is greater than recharge, ground water will be furnished by a reduction in aquifer storage known as ground-water mining. To assess the long-term ground-water development potential, the quantities of recharge, discharge, and change in storage must be evaluated. Recharge to the basin-fill aquifer and discharge from the aquifer by evapotranspiration could not be accurately assessed. Therefore, the ground-water balance could not be calculated. The amount of water discharged by wells, springs, and effluent streams and the amount of change in ground-water storage could be estimated. The amount of water annually lost from storage in the basin-fill aquifer is approximately two orders of magnitude less than estimated natural annual discharge.

The following sections describe the components of recharge, discharge, and change in ground-water storage in the basin-fill aquifer.

Recharge

Ground water may be recharged to the basin-fill aquifer by precipitation and losses from influent streams, irrigation ditches, well-water irrigation return flow, and the Madison Group aquifer. Precipitation on the valley floor falls as rain and snow. The amount of recharge by rain and snow is affected by snow sublimation, rate of snow melt, rainfall intensity, duration, and distribution, infiltration rates of soils, soil-water use by plants, and runoff. Although average annual precipitation onto the valley floor is about 12 inches, the amount of recharge to the basin-fill aquifer by precipitation is unknown. ←

Recharge by streams and irrigation is also unknown. The discharge of Crow Creek was gaged above Slim Sam Creek from 1919 to 1929 and averaged 48.3 cfs (1.5×10^9 ft³/yr) (Montana State Engineer, 1956). Measurements of Crow Creek's flow on July 9, 1979, near the Helena National Forest boundary and about 1.5 miles north of Radersburg were 60.4 and 45.1 cfs, respectively (Table 1). This represents a loss of 25% of flow over approximately 3 miles. The reduction in Crow Creek's discharge may be from leakage into sediments or from diversion for irrigation ditch use. Plate 1 shows Crow Creek as a distributary stream which locally feeds irrigation ditches. Leakage from the Crow Creek Irrigation Unit, Toston Canal West Fork, and other irrigation canals and ditches represent additional but unmeasured sources of ground-water recharge to the basin-fill aquifer, although the

U.S. Bureau of Reclamation (1967) estimates irrigation efficiencies of 24.5 to 71.0 percent, depending on crop and soil type. No detailed analysis of water loss to the ground-water system is possible with the present data. Additionally, the amount of recharge by Warm Springs Creek and ephemeral streams is unknown. As a result, the quantity of surface-water recharge is unknown.

An additional source of recharge to the basin-fill aquifer is the Madison Group aquifer. Snow and rain in the Elkhorn Mountains and other high areas may replenish the Madison Group aquifer in two ways. Direct recharge may occur where precipitation falls on outcrop surfaces and infiltrates into joints and voids in the formation. Recharge may also occur where streams cut across the Madison Group, as has been demonstrated in the Black Hills where streams lose between 7.8 and 49.0 percent of total discharge to the Madison Group as they cross it (Gries and Crooks, 1978). Ground-water chemistry and temperature data point to the Madison Group aquifer as a source of recharge water to the basin-fill sediments, but the amount of recharge is not known.

Discharge

Valley sediments lose ground water to domestic, stock, and irrigation wells, to springs, to portions of streams that are effluent, and to evapotranspiration. Irrigation wells withdraw water from about 100 to 400 feet below ground surface and pump less than 1,000 to over 3,000 gallons per minute during the irrigation season (Appendix A). Twenty-seven of the 30 irrigation wells in the study area were used to

irrigate about 11 square miles of farmland during the 1979 season. Electrical power consumption by irrigation wells indicates that twenty-five of the irrigation wells were pumped for an average of 1100 total hours during the 1979 irrigation season (Table 14 in Appendix A). The estimated amount of water withdrawn for irrigation by wells in this season was about 3×10^8 ft³.

Domestic and stock wells withdraw water from about 30 to 200 feet below the valley surface. An estimate of the amount of water withdrawn for domestic, stock, and gardening needs was arrived at by use of population data. One hundred to two hundred people live in the Radersburg-Toston area west of the Missouri River (Montana State Highway Commission, 1978). If each person required 100 gallons of water per day (Jones, 1964), then $3.7-7.3 \times 10^6$ gallons of water per year were needed for domestic use. Doubling these figures to provide for stock and garden water implies that the annual withdrawal from domestic and stock wells is $7.4-14.6 \times 10^6$ gallons ($9.8-19.5 \times 10^5$ ft³).

Springs in the valley are another major source of ground water discharge. Small fissures in the basin-fill aquifer appear to supply water to Kimpton Spring (Lorenz and McMurtrey, 1956). The water forms a pond used for stock watering and then flows into a small stream. The discharge rate was measured at 0.7 cfs (300 gpm) in 1979 (Table 1) and estimated at less than 100 gpm in 1949 (Lorenz and McMurtrey, 1956). Using the 1979 figure, the amount of ground water discharged by the spring is estimated to be 1×10^7 ft³/yr. Plunket Spring discharges from the Madison Group, therefore it will not be considered as a discharge source for the basin-fill aquifer.

A swampy area in T.5N., R.1E., where there are "other small springs" (Lorenz and McMurtrey, 1956, p. 217) near the junction of Crow Creek and Warm Springs Creek, indicates that ground water discharges into streams in the lower areas of the valley. Prior to the installation of the deep irrigation wells, Lorenz and McMurtrey (1956) described loss of ground water to streams, including the Missouri River, as the greatest source of ground water depletion. An estimate of the amount of water lost to the Missouri River was calculated using an aquifer transmissivity of 100,000 gpd/ft, the hydraulic gradient of about 20 feet per mile to the northeast (from Figure 4), and aquifer width of about five miles through which ground water probably flows out of the eastern basin boundary. The amount of water moving out of the eastern basin boundary is at least about 5×10^8 ft³/yr.

An unknown amount of water is discharged by evapotranspiration. Although PET and lake evaporation are approximately twice the annual average precipitation and PET is greater than precipitation during the growing season (see Table 2 and Table 3), the actual evapotranspiration (AET) is impossible to assess. Factors such as vegetation type, depth to the water table, amount of vegetative cover, soil type, soil moisture, rainfall intensity and distribution, wind direction, and climate affect AET. Actual evapotranspiration is usually less than PET because soils are not continuously saturated during the growing season. Although various workers have derived formulas for estimating evapotranspiration, the relative importance of the above factors is not well understood, and there is little agreement between estimated and actual

evapotranspiration (see Dunne and Leopold, 1980, p. 95-156). Ground-water discharge by evapotranspiration cannot be accurately estimated.

Change in Ground-Water Storage

Two estimates of the change in ground-water storage within the area where irrigation wells have been drilled in the basin were made. The first estimate was for the change in storage which occurred from 1979 to 1980. Static water levels in 17 wells were measured prior to the start of the 1979 and 1980 irrigation seasons (Table 9). The total area occupied by these wells was divided into polygons, with each polygonal area containing a well, using the method of Theissen (1911). For each well, the change in water level between measurements was multiplied by the polygonal area to give the change in volume of saturated material. This volume was multiplied by the storage coefficient of 0.0016 obtained from the pumping test of well 4-1-10bcb. The average change in water level was a decline of 1.8 ft over the 3.4×10^8 ft² area. A loss of 9.8×10^5 ft³ of ground water from aquifer storage within the area shown on Figure 11 occurred during this period.

An estimate of long term change in storage was also made because short term changes may be spurious. One approach used was to compare water levels measured from 1949 to 1953 by Lorenz and McMurtrey (1956) with static water levels measured during the course of this study in 1979, twenty-five years later. This approach was abandoned because many of the wells monitored by Lorenz and McMurtrey could not be located and because wells monitored by them were generally less than 100 feet deep. During the 1949 to 1953 period when they monitored

Table 9. Change in Ground-Water Storage, 1979-1980 Irrigation Season

Well Number	Polygonal Area (ft ² x 10 ⁷)	Change in Water Level (ft)	Change in Saturated Volume (ft ³ x 10 ⁷)	Figure 11 Reference
4-1-2bbb	1.2	-0.4	-0.5	1
4-1-2ccb	1.2	-3.8	-4.7	2
4-1-2ccc	1.1	-2.4	-2.5	3
4-1-9aac	1.0	-2.2	-2.1	4
4-1-9abb	2.5	-1.0	-2.4	5
4-1-9ca	1.7	-1.4	-2.3	6
4-1-10bbc	0.5	2.5	1.3	7
4-1-10bcb	0.9	5.0	4.6	8
4-1-11bcc	1.3	-2.2	-2.8	9
4-1-11cbd	2.8	-1.6	-4.6	10
4-1-13bbc	2.9	-0.2	-0.7	11
4-1-15bcc	3.3	-0.4	-1.2	12
5-1-26ccb	3.1	-2.0	-6.0	13
5-1-27ccb	3.3	-8.3	-27.0	14
5-1-33bac	2.6	-1.1	-2.9	15
5-1-34ccc	2.8	-1.3	-3.7	16
5-1-34dcc	1.6	-2.4	-3.7	17

Total area: 33.6x10⁷ ft²

Total change in saturated volume: 61.3x10⁷ ft³

Change in storage: -9.8x10⁵ ft³

Average change in volume stored
per square foot of land: -2.9x10⁻³ ft³

Note: See Table 15 for water-level measurements used to determine change in water level

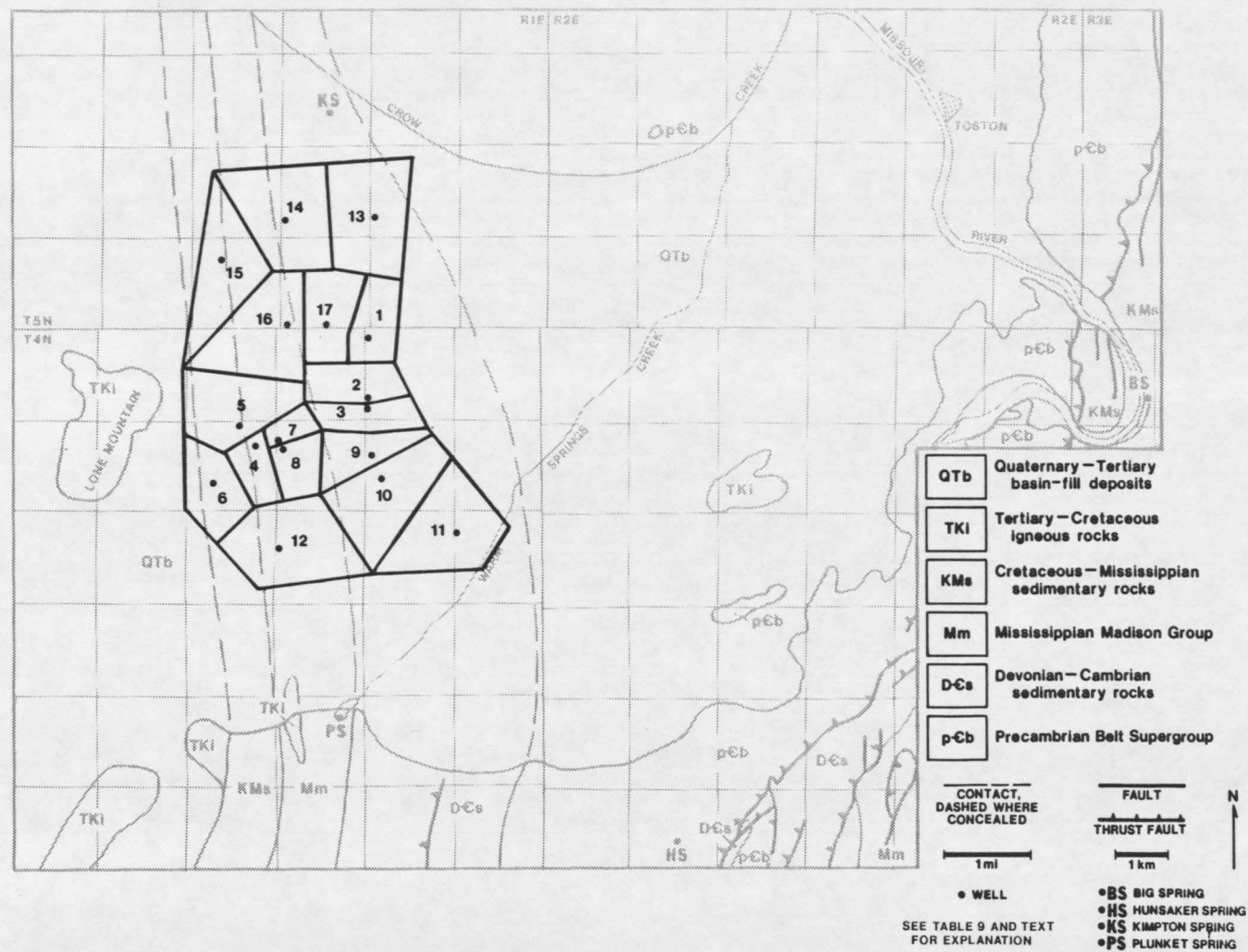


Figure 11. Area Used to Compute Short-Term Change in Ground-Water Storage

water levels in the Townsend Valley, irrigation wells had not been drilled. Therefore, an alternative method was used. For each of 29 wells, the static water level reported on the driller's well log at the time of well completion was compared with a static water level measured during 1979 or 1980 prior to the irrigation season. In most cases, the latter measurement was obtained when no irrigation was occurring in the valley. Table 10 lists these water levels and dates. The average yearly decline or gain in water level was computed for each well since the time of completion. The area occupied by the 29 wells was divided into polygons (Figure 12) and the change in storage was computed for each well as described above. The average change in potential was a decline of less than 0.4 feet per year for each square foot of the $9.2 \times 10^8 \text{ ft}^2$ area in the vicinity of the irrigation wells. This method gives an estimated $5.6 \times 10^5 \text{ ft}^3$ of water lost from storage per year for the area shown on Figure 12.

From the long-term estimate, an average annual loss of about $6.1 \times 10^{-4} \text{ ft}^3$ of water per square foot of land may be used to estimate the total amount of water annually removed from storage within the basin-fill sediments. This estimate, based on a surface area of 144 square miles, is a loss of $2.5 \times 10^6 \text{ ft}^3$ of water from groundwater storage per year.

The above numbers should be considered as order of magnitude estimates, because many sources of error may be associated with them. Possible error sources include the use of short-term data for the first estimate, the averaging method for determining the yearly decline in

Table 10. Long-Term Change in Ground-Water Storage

Well Number	Polygonal Area (ft ² x 10 ⁷)	Date	Static Water Level (ft)	Number of Years	Change in Water Level (ft)	Average Change in Water Level (ft/yr)	Change in Saturated Volume (ft ³ x 10 ⁷)	Figure 12 Reference
4-1-2bbb	2.52	5-28-66	27	13.8	-5.8	-0.4	-1.00	1
		3-29-80	32.8					
4-1-2ccb	1.16	3-29-74	54	6.1	4.0	0.7	0.81	2
		4-26-80	50.0					
4-1-2ccc	1.03	10-21-64	39.5	15.5	-12.0	-0.8	-0.82	3
		4-26-80	51.6					
4-1-3bba1	1.63	2-27-73	68	7.2	-4.7	-0.7	-1.14	4
		4-26-80	72.7					
4-1-9aac	1.68	3-12-76	121	4.1	-7.7	-1.9	-3.20	5
		4-26-80	128.7					
4-1-9abb	3.79	3-26-61	112	19.1	-14.0	-0.7	-2.65	6
		4-26-80	126.0					
4-1-10bbc	1.26	2- -58	100	22.2	-8.8	-0.4	-0.51	7
		4-26-80	108.8					
4-1-10bcb	1.39	10-13-62	91	17.5	-21.3	-1.2	-1.67	8
		4-26-80	112.3					
4-1-11bcc	1.29	8-8-64	45	15.7	-11.2	-0.7	-0.92	9
		4-26-80	56.2					
4-1-11cbd	2.34	3-10-77	46	3.1	-4.7	-1.5	-3.51	10
		3-29-80	50.7					
4-1-12acc	2.55	12-15-73	9	5.8	-1.4	-0.2	-0.51	11
		9-15-79	10.4					
4-1-12bad	2.10	11-20-65	5.5	14.4	-3.4	-0.2	-0.42	12
		4-26-80	8.9					
4-1-13bbc	5.00	2-9-79	32	1.1	-2.6	-2.4	-12.00	13
		3-29-80	34.6					
4-1-15bcc	6.42	5-29-67	123	12.9	-12.6	-1.0	-6.42	14
		4-26-80	135.6					
4-1-15cbd	5.79	11-14-72	125	6.5	2.9	0.4	2.31	15
		5-15-79	122.1					
4-1-19ddd	9.42	3-15-62	120	18.1	10.8	0.6	5.65	16
		3-29-80	109.2					
4-1-23bac	7.21	6-27-64	59.5	14.5	-10.5	-0.7	-5.04	17
		5-26-79	70.0					
4-2-18aca	7.97	5-5-72	70	7.9	-2.7	-0.3	-2.39	18
		3-29-80	72.7					
4-2-20dcd	5.73	1-6-64	270	15.8	-3.2	-0.2	-1.15	19
		11-2-79	273.2					
5-1-24bdd	2.52	4-27-63	20	16.2	11.4	0.7	1.77	20
		6-17-79	8.6					
5-1-24dcb	3.73	10-26-59	4	19.7	1.8	0.1	0.37	21
		7-12-79	2.2					
5-1-26ccb	3.55	5-20-67	22.5	12.9	-0.2	-0.02	0.07	22
		3-29-80	22.7					
5-1-27acb	2.63	3- -72	48	8.1	-5.1	-0.6	-1.58	23
		3-28-80	53.1					
5-1-27bbc	1.76	2-28-73	81	7.1	-0.9	-0.1	-0.18	24
		3-29-80	81.9					
5-1-27ccb	1.29	3-17-62	90	18.1	3.2	0.2	0.26	25
		4-26-80	86.8					
5-1-27cda	0.10	11-28-77	54	2.3	-0.7	-0.3	-0.30	26
		3-29-80	54.7					
5-1-33bac	4.08	4-15-67	120	13.0	-2.7	-0.2	-0.82	27
		4-26-80	122.7					
5-1-34cbb	1.08	11-1-68	64	10.6	-5.8	-0.5	0.54	28
		6-20-79	69.8					
5-1-34ccc	0.79	4-4-73	80	7.1	-7.3	-1.0	-0.79	29
		4-26-80	87.3					

Total area: $91.8 \times 10^7 \text{ ft}^2$

Total change in saturated volume: $35.2 \times 10^7 \text{ ft}^3$

Change in storage: $-5.6 \times 10^5 \text{ ft}^3$

Average change in volume of water
stored per square foot of land: $-6.1 \times 10^{-4} \text{ ft}^3$

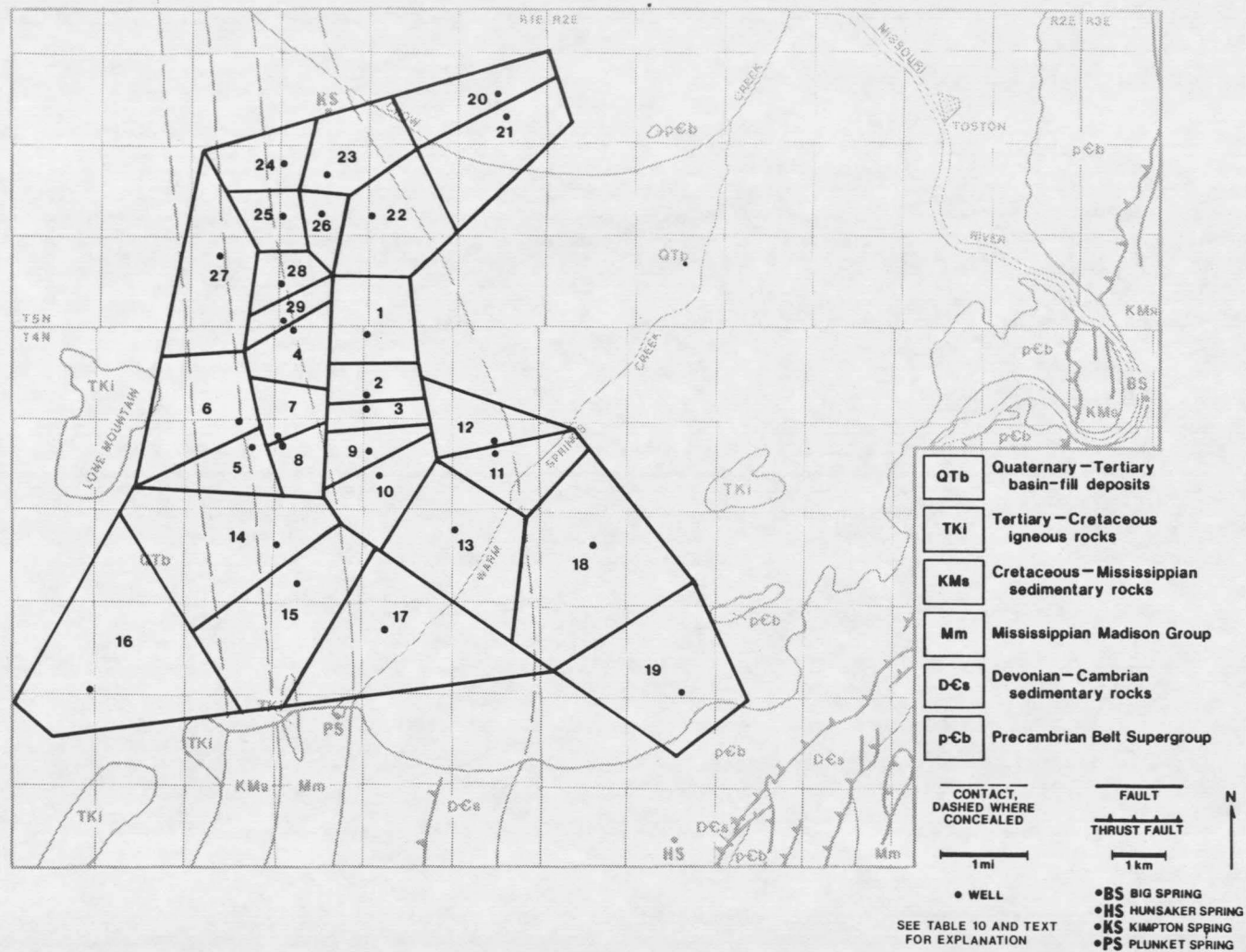


Figure 12. Area Used to Compute Long-Term Change in Ground-Water Storage

water levels for the second method, and the use of well drillers' measurements of static water levels, which may be in error by an undetermined amount. Additional error sources may be the lack of ground-water level data from wells located throughout the valley, necessitating the use of the somewhat arbitrary boundaries for the area of influence used in the first and second estimates, and the use of only one storage coefficient value to estimate the short-term and long-term changes in storage. More long-term water level monitoring data and measurements of the storage coefficient throughout the valley are needed to more accurately assess the change in ground-water storage within the basin, but these preliminary estimates indicate little annual impact by irrigation wells. The long-term impact may be severe. If the average water level decline of 0.4 foot per year continues, water levels will decline by 40 feet in 100 years.

Summary

Because of the unmeasured components, no ground-water balance estimate is possible and no conclusion is possible regarding the occurrence of ground-water mining. It is probable that the ground-water system was in equilibrium or nearly so before the large withdrawals of ground water began in the early 1960s. Since that time, large quantities of ground water have been pumped from the aquifer which has resulted in the apparent loss of ground water from storage. The total amount of ground water lost from storage from 1960 to 1980 is 5×10^7 ft³, based on the 2.5×10^6 ft³/yr average. This quantity is much less than the 3×10^8 ft³ withdrawn during the 1979 irrigation season.

Therefore, the system must be responding to the pumpage by increasing the amount of recharge relative to the amount of discharge. The mechanism for this relative increase in recharge is not known, but could include the reduction in discharge from non-pumping sources in the basin, the increase in recharge from surface-water sources in the basin, or the increase in recharge to the basin-fill aquifer from another deeper aquifer underlying the basin-fill aquifer. This deeper aquifer could be the Madison Group aquifer. Although no irrigation wells have been drilled into the Madison Group, this unit appears to contain large quantities of water as evidenced by Plunket Spring. This spring annually discharges about 3×10^8 ft³ of water from the Madison Group, an amount of discharge approximately equal to the total quantity of water withdrawn by irrigation wells from the basin-fill aquifer.

GEOTHERMAL POTENTIAL

Previous investigators in the Radersburg valley, including Pardee (1925) and Lorenz and McMurtrey (1956) had noted the presence of warm springs in the area. Plunket Spring has been classified as a low-temperature (less than 90°C) thermal spring (Muffler, 1979). The mean annual air temperature in the area is about 43°F (6°C). Thermal springs are those with temperatures at least 10°C above the mean annual air temperature, or 16°C, therefore, Kimpton Spring is also a low-temperature thermal spring.

Thermal wells must additionally have a thermal gradient of at least 30°C/km or about 1°C per 100 feet, determined by subtracting the mean annual air temperature from the maximum water temperature and dividing by total depth (Muffler, 1979, p. 87). Table 8 lists thermal gradients for wells in the area calculated using this method. Many wells have thermal gradients greater than 1°C per 100 feet, but only wells 4-1-4adb and 5-1-28bca may be classified as thermal wells.

The occurrence of low-temperature thermal springs and wells is limited to the area near the subcrop trend of the Madison Group (Figure 6). Chemical geothermometer work by Chadwick and Kaczmarek (1975) indicated that water from Plunket Spring is warmed by circulation through fractures in the Madison Group. Plunket Spring discharges calcium bicarbonate water. North of Plunket Spring, water temperatures decrease locally, then increase to as much as 22.5°C where calcium

sulfate water is discharged from well 4-1-4abd. A temperature of 18°C was measured at this well on an earlier date. The lower temperature may have been caused by dilution of warm deep water by cool shallow water. Further northward water temperatures decrease to about 16°C and water becomes enriched in calcium and bicarbonate ions at well 5-1-28bca. This well plots very close to the point which represents Plunket Spring water in the diamond-shaped field of Figure 7, but the well has a higher calcium/magnesium ratio. The two thermal wells are colinear with Plunket Spring and overlie the subcrop trend of the Madison Group. The temperatures and water composition data indicate that the basin-fill sediments around these wells are recharged by the Madison Group aquifer. Ground water may be warmed by circulation through fault zones, fractures, and cavern systems in the limestone. Using the 1°C/100 feet geothermal gradient for the area (Chadwick and Kaczmarck, 1975), annual air temperature of 6°C, and maximum groundwater temperature of 22.5°C, ground water circulates to a depth of at least 1,650 feet below ground surface to warm before rising into the basin-fill sediments in the Radersburg Valley.

The source of warm water at Kimpton Spring is not understood. The position of the Madison Group makes this aquifer a likely source for the warm water, but chemical data indicate that Kimpton Spring is recharged by water from Crow Creek. Wells 5-1-22bba and 5-1-24bdd, with water chemistry similar to Kimpton Spring, discharge water that is 6°C to 9°C cooler. This difference in temperature implies that water from the Madison Group mixes with water from Crow Creek or that water

from Crow Creek travels downward through 600 to 900 feet of basin-fill sediments before emerging "through small fissures or cracks in the overlying sediments" at Kimpton Spring (Lorenz and McMurtrey, 1956, p.217).

The Tertiary to Cretaceous ages of the intrusive bodies in the area make it unlikely that intermediate to high temperature (90°C to greater than 150°C) water heated by near-surface cooling intrusives exists beneath the valley floor (Chadwick and Kaczmarek, 1975). Therefore, the use of the valley's warm water is limited to low temperature applications. Although only two wells may be classified as thermal wells, ground water from many other wells is warmer than the mean annual air temperature. Ground water beneath the valley floor may be put to limited use, as collector wells could be used to supply warm water to heat pumps or radiator systems for space heating in buildings or greenhouses.

SUMMARY AND CONCLUSIONS

Crops have been grown in the Radersburg valley on irrigated farmland since the early 1900s. At first, irrigation water was supplied by canals from surface water sources. Since about 1960, the water-use pattern has shifted, with ground water supplanting surface water for irrigation.

Ground water is supplied for irrigation by wells which have been drilled into a basin-fill aquifer composed of Tertiary- and Quaternary-age sediments. Irrigation wells are generally less than 400 feet deep and are capable of delivering thousands of gallons per minute of water to farmlands. During the 1979 irrigation season, these wells withdrew about 3×10^8 cubic feet of water for irrigation. The wells pump water from sand and gravel beds in the aquifer. These beds have hydraulic conductivities of approximately 1000 gpd/ft² and storage coefficients of about 0.002.

Underlying the basin-fill aquifer are older formations trending approximately north-south. With one exception, the older formations transmit small amounts of water and are aquitards. The Mississippian-age Madison Group is the exception. The unit crops out in the vicinity of Plunket Lake, where Plunket Spring discharges about 3×10^8 cubic feet of water per year. The large volume of water discharged by the spring and the documented ability of the Madison Group to transmit large volumes of water in other areas indicate that the Madison Group

is an aquifer in the Radersburg valley. Fractures, paleokarst features, and solution breccia features have given the unit high secondary permeability.

Ground-water chemistry data indicate that the basin-fill aquifer is recharged by Crow Creek in the northern part of the study area. Water from Crow Creek is low in dissolved solids and high in relative proportions of calcium and bicarbonate ions. As the water infiltrates, it becomes higher in dissolved solids from the dissolution of aquifer materials, but remains dominated by calcium and bicarbonate ions, as seen in water analyses from shallow wells near Crow Creek.

The restricted area of successful irrigation wells, which are generally located within a few miles of the projected subcrop trend of the Madison Group, suggests that the Madison Group aquifer recharges the basin-fill aquifer in the area between Kimpton Spring and Plunket Spring. Upward leakage of water from the carbonate aquifer into the basin-fill aquifer in this area could be supplying the large amounts of water needed for irrigation. Although the locations of the irrigation wells may be fortuitous, ground-water temperature and chemistry data from the irrigation wells and other wells within the study area do indicate that the Madison Group is supplying water to the basin-fill aquifer in this area.

The main indicators of recharge from the Madison Group aquifer to the basin-fill aquifer are the distribution of bicarbonate and sulfate ions, the enrichment of strontium in ground water, and ground-water temperature. Calcium bicarbonate character water is discharged by Plunket Spring. The temperature of this water is 16.5°C. In the

area up to one mile north of the spring the ground-water temperature decreases, but the water is of the same composition. One to four miles north of the spring, ground water becomes calcium sulfate in character and well-water temperatures are the highest in the basin. Farther to the north, west of Kimpton Spring, water is calcium bicarbonate enriched.

The changes in water composition along the Madison Group trend may be caused by variations in the mineralogy of the Madison Group rocks. Bicarbonate-rich waters may result from ground water flowing within brecciated or karstic limestone zones in the aquifer which formed before the deposition of the Amsden Formation or during the Laramide Orogeny. Such beds or zones were probably created by the leaching of evaporite minerals. Sulfate- and strontium-rich ground water may be caused by ground water flowing within beds in which evaporite minerals are still present.

The relatively high ground-water temperatures in the area between Kimpton Spring and Plunket Spring also indicate that the basin-fill aquifer is recharged by the Madison Group. Water recharges the Madison Group aquifer in the structurally higher mountains to the west, flows downgradient through fractures and karst features in the western limb of a large syncline, increases in temperature with depth below the ground surface, and enters the valley sediments north of Plunket Lake.

Hydraulically downgradient from the area where the basin-fill aquifer is recharged by the Madison Group, ground-water temperatures, strontium concentrations, and sulfate/bicarbonate ratios decrease. The

relative concentrations of sodium increase. Cation exchange and mixing processes affect ground-water chemistry as water moves from recharge areas to discharge areas in the basin-fill aquifer. As water passes through clayey interbeds in the sediments, adsorbed sodium is exchanged for calcium in water. Mixing of ground water from the Madison Group with water from the basin-fill aquifer is indicated by the decrease in sulfate/bicarbonate and strontium/TDS ratios.

The chemical and temperature trends suggest that water is leaking upward along the north-south subsurface extension of the Madison Group aquifer north of Plunket Lake. The water recharges the basin-fill aquifer in the vicinity of the high-capacity irrigation wells, is confined by clay beds of low hydraulic conductivity, and moves laterally through layers of gravel and sand in the basin-fill material.

The use of irrigation wells has increased the amount of ground water withdrawals in the valley. Although some loss of water from storage in the basin appears to be occurring, the errors associated with ground-water balance estimates do not allow any firm conclusions regarding ground-water mining.

The geothermal potential of the valley appears to be restricted to low-temperature applications within the area overlying the projected subcrop trend of the Madison Group. In this area, collector wells may be used for geothermal heat pumps or radiator systems.

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APPENDICES

APPENDIX A

FIELD INVESTIGATION

Introduction

The data collection part of this investigation was conducted in two phases. The first phase consisted of obtaining logs of wells in the Radersburg valley to create a well inventory. The second phase was a field investigation.

Field work was conducted from May 1979 to July 1980 and included field checking well locations; measuring water levels in wells; measuring discharge rates of wells, streams, and springs; conducting specific capacity and aquifer tests; and obtaining water samples.

Geologic maps at usable scales were available (see Figure 1), therefore no mapping was done. The maps were field checked for accuracy by W.T. Straw, working for the Montana Bureau of Mines and Geology. Plate 1 is a generalized geologic map of the study area and vicinity compiled from previously published maps.

Well Inventory

Well log reports and ground-water appropriation documents were obtained from the files of the Montana Bureau of Mines and Geology (MBMG), the Montana Department of Natural Resources and Conservation, and Broadwater County within the area of Township 4 and 5 North and Range 1 and 2 East. Table 11 lists well construction information from

these logs, and Table 12 is a listing of representative lithologic logs. Information on static and pumping water levels and pumping rates were also used for part of Table 13, which is a table of specific capacity test results.

All irrigation, observation, and test wells were inventoried and lithologic logs for these wells are shown in Table 12, unless the log was not available. Not all domestic and stock wells in the study area were inventoried because of limitations of time and the availability of well logs. Well locations on drillers' logs were field checked and verified. When possible, well locations were determined within 0.1 mile accuracy using a car odometer or by pacing from section corners.

Specific Capacity Tests

Specific capacity test data, generally derived from well logs, provided order of magnitude estimates of transmissivity and hydraulic conductivity of material penetrated by wells in the study area (Table 13). Specific capacity is a measure of well yield per unit drawdown and is expressed in gallons per minute per foot (gpm/ft). Specific capacity data were obtained from well logs and from seven tests during the field investigation. Meyer's (1963) graphical method was used with a storage coefficient value of 0.002 to estimate transmissivities based on the 0.0016 value from the aquifer test of 4-1-10bcb (Appendix B). The estimated transmissivities are probably one half to two times larger than the actual aquifer transmissivity in the area of influence of each well because the method assumes

100 percent well efficiency, the effective diameter of the well is limited to from six to twenty-four inches, the storage coefficient could vary by orders of magnitude from 0.002, and the length of each test was variable. Additionally, specific capacity tests do not take into account hydrologic boundaries or partial penetration effects. Data from a recovery test and a pumping test (Appendix B) indicate that estimated transmissivities are at least 50 percent low.

Estimated hydraulic conductivities were determined by dividing the estimated transmissivity by the length of perforated or screened interval of each well. Although the length perforated or screened may deviate from the true aquifer thickness, the estimated hydraulic conductivities provide an indication of the ability of the water-supplying beds to transmit water. Again, the estimates are probably 50 percent low.

Seasonal Discharge by Irrigation Wells

Irrigation wells could not be directly monitored for total discharge during the irrigation season, therefore total discharge for most of the irrigation wells (Table 14) was estimated using electrical power consumption data. Kilowatt-hour (kwhr) meters were periodically read and the differences between readings were used to determine total power consumption. Power consumption rates in kilowatts per hour (kw/hr) were determined from meter readings or were estimated based on motor horsepower and pumping lift where meter readings were not available. Total power consumption divided by consumption rate gave the number of hours each well was pumped. The discharge rate, measured or

estimated from motor horsepower and well-log data, was multiplied by the total number of hours pumped. This gave the total discharge value for the 1979 irrigation season.

Water Levels in Wells

Water levels in wells were measured intermittently from May, 1979 to April, 1980 (Table 15). Depth to water in each well was gaged with a chalked Lufkin Peerless Nubian 300-foot steel tape, graduated in 0.01 foot increments, or with a Fisher M-Scope 300-foot electrical tape. Additional water level data for 1977, 1978, and May 15, 1979 were provided for some wells by T. E. Reed of the U.S. Geological Survey (USGS) Water Resources Division office in Helena, Montana.

Depth to water is reported from the ground surface. Ground surface elevation at each well was not surveyed during this investigation. Instead, ground surface elevations were estimated from the Toston and Radersburg 15-minute topographic quadrangle maps with topographic contour interval of 40 feet. Ground surface elevations are accurate to plus or minus 5 feet.

Discharge Rates of Wells

Discharge measurements (Table 16) could only be made on wells which did not deliver water into closed, pressurized systems. Flow rates of irrigation wells were measured when possible using a Marsh-McBirney, Inc., Model 201 Water Current Meter, an electromagnetic flow meter, giving water velocity in feet per second. The flow meter sensor

was placed in the discharge line or ditch and velocity versus cross-section area was used to compute discharge.

Pumping rates of stock wells were determined by measuring the amount of time necessary to fill a calibrated bucket.

Stream and Spring Discharge Rate Measurements

Spring and stream velocities were measured with the Marsh-McBirney electromagnetic current meter. Channel cross-section dimensions were measured perpendicular to the bank at straight sections and the velocity versus depth data (Table 17) were converted to discharge rates (Table 1) using a program from Croley (1978).

Aquifer Tests

Two aquifer tests were performed during this investigation. One test was a recovery test and the other test was a pumping test. The methods used to conduct these tests and the results of these tests are presented in Appendix B.

Water-Quality Sampling

Twenty-nine water-quality samples were obtained from wells, springs, and streams during the field investigation. The methods used for obtaining water-quality samples and the results of field and laboratory water-quality analyses are presented in Appendix C.

Table 11. Well Construction Information

Well Number	Use	Drilling Method	Date Completed	Total Depth (ft)	Borehole Diameter (in)	Casing Bottom Depth (ft)	Casing Diameter (in)	Perforations			
								Type	Size	From (ft)	To (ft)
4-1-1abc	S	C	9-30-62	27	6	27	6	S	0.188"x6.0"	20	27
4-1-1b	S	C	10-31-62	70	6	70	6	S	0.25"x3.0"	48	54
4-1-1cd	S	C	7-9-64	62	6	62	6	N	---	--	--
4-1-2abc	D	C	3-21-79	91.5	6	91.5	6	S	0.063"x6.0"	89.5	91.5
4-1-2bbb	I	RR	5-28-66	191	32	186	16	L	0.25"	100	186
4-1-2ccb	I	C	3-29-74	275	16	na	16	S	0.375"x1.5"	117	246
4-1-2ccc	I	RR	10-21-64	250	32	246	18	S	0.25"x2.0"	97	137
							20	S	0.125"x2.0"	154	156.5
							20	S	0.125"x2.0"	162	163
							18	S	0.25"x2.0"	186	246
4-1-2cd	D	C	3-1-57	111	6	111	6	S	na	109.5	111
4-1-2cdd	D	C	8-3-67	131	6	124.5	6	SS	0.025"	123	129
4-1-2dbc	I, U	na	na	na	na	na	16	na	na	na	na
4-1-2	D	C	1-28-78	190	6	129.5	6	SS	0.035"	128	133
4-1-3bba1	O	C	2-27-73	220	6	128.1	6	na	na	na	na
4-1-3bba2	I	C	3-12-73	220	16	170	16	SS	na	170	220
4-1-3dbb	I	RR	7-27-70	313	32	293	16	S	0.188"x2.0"	146	166
										168	293
4-1-4adb	I	RR	6-6-78	400	26	400	16	S	0.188"x48'	165.5	400
4-1-8dd	Dry	R	1-28-78	248	6	180	6	N	---	--	--
4-1-9aac	I	C	3-12-76	349	16.	335	16	S	0.25"x1.0"	150	335
4-1-9abb	S	C	3-26-61	139	6	139.3	6	N	---	--	--
4-1-9ca	S	C	7-1-78	253	6	253	6	N	---	--	--
4-1-10bbc	O	C	2-58	447	7	447	7	N	---	--	--
4-1-10bcb	I	RR	10-13-62	330	32	330	16	S	0.188"x1.25"	164	330
4-1-10cbb	I	C	4-19-59	199	12	199	12	S	0.375"x3.0"	100	105
										118	195
4-1-11ab	D	C	1968	160	6	150	6	SS	na	150	160
4-1-11ac	I	RR	7-29-78	242	26	242	16	S	0.188"x48'	120.6	242
4-1-11bcc	I	RR	8-8-64	431	32	404	16	S	0.188"x1.25"	94	149
										174	194
										202	226
										264	284
										320	340
										352	372
										392	397

Table 11. (continued)

Well Number	Use	Drilling Method	Date Completed	Total Depth (ft)	Borehole Diameter (in)	Casing Bottom Depth (ft)	Casing Diameter (in)	Perforations			
								Type	Size	From (ft)	To (ft)
4-1-11cbd	I	C	3-10-77	245	16	245	16	S	0.25"x1.0"	75	225
4-1-12acc	I	C	12-15-73	250	16	250	16	S	0.375"x1.5"	43	232
4-1-12ad	S	na	na	106	na	106	4	na	na	na	na
4-1-12bad	S	C	11-20-65	41	6	40	6	N	---	--	--
4-1-12dd	D	C	12-5-57	46	6	46	6	N	---	--	--
4-1-13bbc	I	C	2-9-77	240	16	240	16	S	0.25"x1.0"	65	230
4-1-14bcc	I	C	4-14-77	260	16	260	16	S	0.25"x1.0"	70	254
4-1-15bcc	I	RR	5-29-67	355	32	348	16	S	0.5"x2.0"	208 328	308 348
4-1-15cdb	I	RR	11-14-72	360	32	342	16	S	0.188"x2.0"	212	342
4-1-16dad	I	C	4-30-74	450	6	450	6	S	na	200 250 290 350	225 273 300 375
4-1-17add	S	C	2-27-69	220	6	206	6	S	0.25"x4.0"	202	205
4-1-19ddd	S	C	3-15-62	291	6	275.8	6	S	0.25"x3.0"	139 143	141 146
4-1-22	T	C	2-29-74	435	16	435	16	S	0.375"x1.5"	165	355
4-1-22dcb	D	na	na	na	na	na	6	S	0.25"x2.0"	364	434
4-1-23bac	I	RR	6-27-64	345	32	332	16	S	0.188"x1.25"	na 140 172 207 262	na 160 187 247 332
4-1-23bbb2	D	C	1930	100	6	100	6	na	na	na	na
4-1-30cc	S	C	6-15-63	135	6	135	6	S	0.25"x3.0"	50	135
4-1-31a	S	C	6-29-67	45	6	43	6	N	---	--	--
4-2-4bbb	S	C	2-17-63	40	7	40	6	S	0.25"x2.0"	35	40
4-2-8bb	S	C	12-11-69	65	6	62	6	SS	0.180"	57	62
4-2-10b	S	C	9-26-46	200	6	200	6	na	na	na	na
4-2-16aaa	S	C	13-31-62	325	6	323	6	S	0.25"x3.0"	265	320
4-2-17bb	S	C	3-15-79	154	6	154	6	na	na	na	na
4-2-18aca	S	C	5-5-72	110	6	109.3	6	na	na	na	na
4-2-20dcd	S	C	1-4-64	425	6	280	6	N	---	--	--

Table 11. (continued)

Well Number	Use	Drilling Method	Date Completed	Total Depth (ft)	Borehole Diameter (in)	Casing Bottom Depth (ft)	Casing Diameter (in)	Perforations			
								Type	Size	From (ft)	To (ft)
5-1-8bd	D	C	3-11-66	67.5	6	57.5	6	na	na	na	na
5-1-8ca	D	C	4-30-63	40	6	40	6	S	0.5"x3.0"	25	40
5-1-8cd	D	C	2-11-70	110	6	109	6	N	---	--	--
5-1-13ddd	S	C	6-20-38	60	6	60	6	N	---	--	--
5-1-17	D	C	8-3-77	66	6	61	6	S	0.313"x2.0"	42	44
5-1-17ac	S	C	8-31-65	60	6	41.5	6	N	Open Hole	41.5	60
5-1-22bba	S	C	2-17-79	82	6	82	6	na	na	na	na
5-1-24bdd	D	C	4-27-63	43	6	43	6	S	0.25"x3.0"	30	43
5-1-24dbc	S	C	10-26-59	36	6	36	6	na	na	na	na
5-1-26ceb	I	RR	5-20-67	172	32	165	16	S	0.25"x2.0"	70	165
5-1-27acb	I	C	3-72	331	16	354(?)	16	S	0.375"x1.5"	50	225
5-1-27bbc	I	C	2-28-73	305	16	305	16	S	0.438"x3.0"	100	300
5-1-27ceb	I	RR	3-17-62	221	36	215	16	S	0.188"x3.0	119.5	165
										172	188
										200	215
5-1-27cda	I	C	11-28-77	302	16	302	16	S	0.25"x1.0"	70	295
5-1-28bac	I	C	9-9-78	340	16	339	16	S	0.188"x2.0"	152	339
5-1-33bac	I	RR	4-15-67	255	32	252	20(1)	S	0.25"x2.0"	152	252
5-1-33ebb	S	C	2-16-79	177	6	176	6	S	na	170	174
5-1-34cbb	S	C	1-1-68	80	6	80	6	S	0.125"x2.0"	70	80
5-1-34ccc	I	C	4-4-73	325	16	325	16	S	0.438"x1.25"	90	315
5-1-34dcc	I	na	na	na	na	na	na	na	na	na	na
5-1-35dc	S	C	11-20-67	37	6	37	6	S	na	15	37
5-2-28cdb	S	C	12-23-68	148	6	147	6	S	0.25"x4.0"	143	145
5-2-31dc	S	C	2-12-58	125	6	125	6	N	---	--	--
5-2-33dab	D	na	10-27-54	152	6	148	6	na	na	na	na
5-2-34aac	I	na	na	na	na	na	na	na	na	na	na
5-2-35d	D	AR	9-9-77	195	6	188	6	S	na	174	194

Notes: (1) 16" casing from 152 feet

Use: S, stock; D, domestic; I, irrigation; O, observation; T, test; N, unused

Drilling Method: C, cable-tool; RR, reverse rotary; R, rotary; AR, air rotary

Perforation Type: S, slotted; L, louvers; SS, slotted well screen; N, none

na: information not listed on well log

Table 12. Lithologic Logs

4-1-2bbb (I)			4-1-3bba1 (OR)		
Depth (ft)		Description	Depth (ft)		Description
From	To		From	To	
0	9	Top soils and clays	0	76	Clay-overburden sand and rocks
9	97	All claybound sand and gravels	76	220	Interblended lenses of sand and gravels fine to coarse
97	102	Cemented sand and gravels with a few boulders			
102	114	Claybound gravels	4-1-3bba2 (I)		
114	121	Cemented gravels	Depth (ft)		Description
121	124	Clays embedded with some gravels	From	To	
124	136	Loose clean gravels	0	76	Clay overburden
136	137	Clays	76	220	Interblended lenses of fine to coarse sand and gravels
137	140	Loose gravels			
140	151	Lightly cemented sand and gravels	4-1-3dbb (I)		
151	155	Lenses of sandstone and loose gravels	Depth (ft)		Description
155	160	Clean gravels	From	To	
160	162	Clays	0	8	Clays
162	168	Clean loose gravels	8	18	Claybound gravels and boulders
168	174	Clays and gravels	18	20	Clays
174	184	Embedded sandstone with gravels	20	35	Claybound gravels and boulders
184	191	Claybound sand and gravels	35	44	Clays
			44	125	Claybound sand and gravels with a few lenses of clays and clean gravels. Water at 55'
4-1-2ccb (I)			125	130	Clays
Depth (ft)		Description	130	244	Claybound sand gravels with lenses of 1' to 2' clays and cemented gravels
From	To		244	248	Clays
0	40	Clay streaks, gravel, sand	248	264	Clean gravel lenses and claybound lenses of coarse gravel
40	117	Clay streaks, gravel	264	274	Clays
117	118	Gravel	274	276	Loose clean gravels
118	150	Clay streaks and gravel	276	279	Clays
150	170	Gravel	279	296	Gravels with small lenses of clays, cemented gravels, and claybound sand and gravels
170	207	Clay	296	313	Clays and hardpan
207	211	Gravel			
211	216	Clay	4-1-4adb (I)		
216	223	Gravel	Depth (ft)		Description
223	234	Clay	From	To	
234	248	Gravel	0	5	Topsoil
248	250	Sand	5	11	Silty fine brown sand
250	257	Gravel	11	18	Gravel with some rocks
257	261	Sand	18	22	Sand and tan clay
261	275	Gravel	22	29	Coarse sand with few rocks
			29	32	Soft tan clay and sand
			32	48	Sand with some clay with rocks
			48	51	Coarse sand with some cemented gravel and a little clay
			51	108	Coarse sand with little clay and scattered rocks
			108	111	Clay with some gravel and cemented rocks
			111	118	Coarse sand and gravel with rocks
			118	123	Tan clay with sand and gravel
			123	127	Sand and gravel, some clay
			127	158	Sand, gravel with rocks (cemented)
			158	164	Clay with sand and gravel
			164	260	Cemented sand and gravel
			260	264	Clay with coarse sand and gravel
			264	266	Coarse sand and small gravel with some clay
			266	275	Cemented coarse sand and small gravel
			275	279	Clay with sand
			279	287	Coarse sand and gravel with clay
			287	293	Clay with sand and gravel
			293	298	Cemented coarse sand and gravel
			298	303	Clay with sand and gravel
			303	310	Cemented coarse sand and gravel
			310	317	Clay with gravel
			317	359	Cemented coarse sand and gravel
			359	364	Soft tan clay with gravel
			364	366	Coarse sand and gravel with clay
			366	400	Cemented coarse sand and gravel
4-1-2ccc (I)					
Depth (ft)		Description			
From	To				
0	19	Clays			
19	51	Claybound sand and gravels			
51	54	Cleaner sand and gravels			
54	58	Claybound sand and gravels			
58	68	Clean sand and gravels			
68	70	Claybound gravels			
70	72	Sand			
72	78	Clean sand and gravels			
78	81	Sandy clays			
81	88	Sand and gravels cemented with clay			
88	98	Claybound sand and gravels			
98	100	Clean sand and gravels			
100	124	Claybound sand and gravels, some cementation			
124	153	Cemented gravels with clean gravel lenses			
153	164	Cleaner sand and gravels, lightly cemented			
164	185	Gritty clays			
185	201	Cemented gravels with clay binder			
201	209	Clay			
209	219	Cemented sand and gravels			
219	232	Gritty clays			
232	246	Cemented sand and gravels, some clay			
246	250	Clays			

Table 12. (continued)

4-1-8dd (Dry)

Depth (ft)		Description
From	To	
0	5	Topsoil
5	70	Soft brown clay
70	120	Hard dry clay
120	165	Sandstone
165	248	Gravel with no water

4-1-9aac (I)

Depth (ft)		Description
From	To	
0	40	Clay sand mixture
40	47	Rock and gravel
47	100	Clay and gravel
100	125	Clay, gravel, and sand mixture
125	142	Clay
142	160	Clay and gravel
160	165	Gravel and clay
165	175	Clay
175	183	Gravel
183	188	Clay
188	190	Gravel
190	204	Clay
204	212	Clay and gravel mixture
212	230	Sand and gravel
230	231	Rocky
231	248	Sand and gravel
248	260	Clay, sand, and gravel
260	265	Gravel
265	274	Clay
274	276	Rock and gravel
276	291	Clay
291	296	Gravel
296	300	Clay
300	311	Gravel
311	322	Clay
322	345	Gravel
345	349	Sandstone and clay

4-1-10bbc (O)

Depth (ft)		Description
From	To	
0	33	Clay
33	34	Rocks
34	78	Clay
78	78.6	Sand
78.6	112	Clay
112	122	Quick sand
122	164	Clay
164	167.5	Gravel
167.5	174	Clay
174	179	Gravel
179	193	Clay
193	197	Gravel
197	199	Clay
199	203.5	Sand, some rock
203.5	214.5	Clay
214.5	220.5	Sand and gravel
220.5	225	Clay
225	240	Fine sand
240	278	Clay
278	281	Claybound rock
281	284	Fine sand
284	285	Large rocks
285	297.5	Clay with large rocks
297.5	299	Rocks
299	303	Loose sand
303	305	Running sand, brown water
305	308	Gravel
308	317.5	Clay
317.5	325	Sand
325	330	Large gravel
330	340	Clay rocks
340	349	Sandstone
349	354	Quick sand
354	356	Large rocks
356	358	Fine gravel
358	360	Good pea gravel
360	364	Claybound gravel, some fine sand
364	368	Sandstone
368	370	Gravel

Continued on next column

4-1-10bbc, continued

Depth (ft)		Description
From	To	
370	372	Clay
372	384	Sandstone
384	401.5	Clay, sticky
401.5	414	Gravel
414	419.5	Claybound gravel
419.5	435	Gravel
435	437	Cemented gravel
437	442	Same
442	443.5	Clay
443.5	447	Extra good gravel

4-1-10bcb (I)

Depth (ft)		Description
From	To	
0	7	Clays, gritty
7	15	Gravels with few 6" boulders
15	28	Light buff color clays
28	40	Gravels fine and coarse, few 8" boulders
40	49	Small gravels
49	57	Clays with a few small pebbles
57	75	Small gravels, clay bound
75	78	Cemented fine gravels
78	80	Clays with some small pebbles
80	82	Large boulders
82	91	Clays, gritty
91	95	Gravels and boulders
95	97	Clay with small pebbles
97	104	Gravels, coarse and fine
104	110	Clay with pebbles
110	116	Small gravels, clay mixed
116	117	Coarse gravels and boulders
117	128	Clays with some small gravels
128	131	Clean coarse gravels and boulders
131	148	Clays with pebbles
148	150	Small clean gravels
150	154	Light color clay
154	165	Gravels, boulders 60%, clays 40%
165	180	Clean gravels
180	189	Small gravels 60%, clays 40%
189	193	Clays with a little gravel
193	203	Cemented gravels, lime coated
203	209	Clays embedded with small gravels
209	219	Cemented gravels, coarse
219	235	Clays with some small gravels
235	242	Cemented lime coated gravels
242	260	Clays embedded with small gravels
260	265	Soft porous sandstone
265	275	Loose clean gravels
275	288	Clays and gravels mixed
288	292	Medium and large gravels
292	298	Sticky clay
298	301	Coarse clean gravels
301	308	Coarse porous sandstone
308	312	Clays
312	314	Clay and gravels
314	318	Sandstone, soft and porous
318	323	Clean coarse gravel
323	324	Clay
324	326	Large gravels
326	330	Clays with pebbles

4-1-10cbb (I)

Depth (ft)		Description
From	To	
0	60	Clays and small gravels
60	73	Gravels
73	92	Gravels, clays
92	97	Clays
97	99	Gravels
99	104	Clays
104	108	Sands
108	116	Clay mixed gravels
116	131	Coarse broken rock
131	156	Clays and sands
156	170	Clays and rocks
170	173	Gravels
173	187	Clays
187	195	Gravels and clays
195	199	Gravels

Table 12. (continued)

4-1-11ac (I)			4-1-12acc (I)		
Depth (ft)		Description	Depth (ft)		Description
From	To		From	To	
0	4	Topsoil	0	3	Soil
4	6	Clay, tan	3	10	Clay
6	9	Sand, fine, brown, with clay	10	15	Gravel and sand
9	18	Clay, dark brown, soft	15	43	Soft mud
18	23	Clay, tan, soft	43	48	Gravel
23	27	Sand, coarse to fine gravel	48	55	Clay and rock
27	29	Gravel with some rocks	55	60	Sand and gravel
29	33	Sand, coarse with some clay	60	78	Brown clay soft
33	45	Clay, tan, soft	78	89	Sandy gravel
45	51	Gravel	89	106	Sandy clay, sticky
51	56	Clay, tan, soft	106	120	Sandy gravel
56	67	Sand, coarse, with some clay	120	127	Brown clay
67	75	Clay, tan, soft	127	150	Sand and gravel
75	88	Sand, coarse, small gravel	150	166	Clay
88	106	Clay, tan, soft	166	171	Gravel
106	108	Coarse sand and small gravel with clay	171	230	Clay
108	117	Clay, tan	230	232	Gravel
117	140	Gravel	232	250	Clay
140	144	Clay, tan	4-1-12bad (S)		
144	149	Gravel	Depth (ft)		Description
149	156	Clay, tan	From	To	
156	163	Coarse sand to fine gravel	0	11	Topsoil
163	172	Clay, tan	11	21	Sand and gravels
172	218	Sand, coarse	21	31	Clay and sands
218	229	Clay, tan, with some sandstone	31	41	Coarse sand and gravels
229	233	Clay and sand	4-1-13bbc (I)		
233	238	Coarse sand to fine gravel	Depth (ft)		Description
238	242	Clay, tan	From	To	
4-1-11bcc (I)			0	6	Sandy loam
Depth (ft)		Description	6	18	Tight gravel and clay mix
From	To		18	60	Clay, streaks of gravel
0	92	Claybound gravels and boulders with a few lenses of clays	60	80	Good clean gravel
92	104	Coarse cemented gravels with layers of hardpan	80	85	Clay
104	109	Sands	85	114	Gravel, streaks of clay
109	117	Clays	114	117	Rock and gravel
117	142	Alternate lenses of clays and gravels	117	175	Clay, sand, and gravel streaks
142	144	Loose clean gravels	175	210	Gravel and clay mix
144	162	Claybound gravels	210	220	Gravel
162	165	Clean gravel	220	227	Clay and some gravel
165	182	Cemented sands and gravels, clay lenses	227	230	Clean gravel
182	190	Sandstone	230	240	Clay
190	249	Claybound gravels	4-1-14bcc (I)		
249	269	Same but cleaner	Depth (ft)		Description
269	328	Claybound gravel and sandstone lenses	From	To	
328	338	Clean gravels	0	4	Clay
338	368	Claybound gravels	4	8	Gravel
368	378	Clays	8	55	Clay and gravel mix
378	397	Gravels and clay lenses	55	58	Gravel
397	431	Claybound sand and gravels with small lenses of sandstone. Clay from 405' to 412'	58	74	Clay
4-1-11cbd (I)			74	90	Gravel
Depth (ft)		Description	90	92	Clay and gravel
From	To		92	102	Running gravel
0	1	Clay	102	120	Clay
1	10	Gravel	120	140	Gravel, cement gravel, rock
10	55	Clay and sand mixed	140	152	Clay and gravel mix
55	65	Rock and gravel	152	173	Clean gravel
65	110	Clay and sand mixed	173	200	Claybound gravel
110	128	Gravel and sand	200	205	Clean gravel
128	130	Running sand and gravel	205	224	Clay
130	170	Clay and streaks gravel	224	226	Gravel
170	171	Rock and gravel	226	242	Clay
171	180	Sand and gravel	242	254	Gravel
180	182	Clay	254	260	Clay
182	185	Gravel	4-1-15bcc (I)		
185	198	Clay	Depth (ft)		Description
198	204	Good gravel	From	To	
204	213	Clay	0	4	Soils and clays
213	224	Gravel	4	40	Coarse gravels and boulders
224	245	Clay	40	42	Claybound gravels
			42	53	Coarse sand and gravels with boulders
			53	66	Claybound sand and gravels with cemented lenses

Continued on next page

Table 12. (continued)

4-1-15bcc, continued

Depth (ft)		Description
From	To	
66	70	Gritty clays
70	97	Sand and gravels with some clay lenses
97	100	Clean sand and gravels
100	112	Claybound sand and gravels
112	115	Clays
115	136	Fine to coarse sand and gravels, cemented and claybound lenses
136	142	Clay
142	144	Gravels
144	145	Clay
145	155	Coarse gravels, clean
155	158	Gritty clays
158	180	Claybound sand and gravels
180	181	Clay
181	212	Claybound gravels with some clean gravel lenses
212	213	Soft sandstone
213	221	Clays and gravels
221	226	Clays
226	352	Claybound sand and gravels with 1' to 3' thick lenses of clean gravel
352	355	Clay

4-1-15cdb (I)

Depth (ft)		Description
From	To	
0	14	Clays
14	18	Gravels and large boulders
18	24	Loose clean gravels
24	32	Hard cemented gravels
32	87	Claybound sand and gravels
87	134	As above with lenses of clay and cemented gravels
134	146	Clays. Dry
146	163	Gravels. Water
163	212	Lenses of gravels and clays. Wet
212	218	Hard cemented gravels
218	227	Claybound gravels
227	233	Clays
233	266	Cemented and claybound gravel with clay lenses. Water
266	267	Sandstone
267	313	Lenses of cemented and claybound gravels and clay. Water
313	330	Claybound gravels. Water
330	344	Clean coarse gravels. Water
344	360	Clays. Dry

4-1-16dad (I)

Depth (ft)		Description
From	To	
0	2	Topsoil
2	35	Sandy clay
35	85	Claybound gravel
85	167	Sandy clay
167	169	Sand. Water (10 gpm)
169	190	Claybound gravel
190	195	Sand. Water (30 gpm)
195	245	Cemented gravel, clay lenses
245	250	Gravel. Water
250	295	Clay and cemented gravel
295	297	Very fine sand. Water
297	300	Cemented sand, gravel, and clay
300	330	Sandy clay
330	348	Claybound gravel
348	380	Sand, gravel, and water.
380	415	Cemented gravel
415	430	Clay with some gravel. Dry
430	450	Cemented gravel with some clay

4-1-19ddd (S)

Depth (ft)		Description
From	To	
0	150	Gritty clays
150	182	Soft sandstone with clay binder

Continued on next column

4-1-19ddd, continued

Depth (ft)		Description
From	To	
182	200	Hard sandstone. Dry
200	230	Yellow clay
230	245	Soft sandstone
245	265	Red clays
265	270	Hard sandstone. Dry
270	291	Gritty clay

4-1-22 (Destroyed)

Depth (ft)		Description
From	To	
0	4	Clay
4	74	Clay and gravel streaks
74	74	Cement hard
74	110	Clay
110	115	Gravel and clay
115	152	Clay
152	170	Gravel and clay
170	172	Gravel. Water
172	218	Clay
218	230	Clay and gravel streaks
230	354	Clay
354	355	Gravel. Water
355	370	Cemented gravel
370	375	Rock
375	382	Gravel and rock
382	384	Cemented gravel
384	398	Gravel and lime
398	433	Rock, lime, gravel
433	435	Gravel and sand

4-1-23bac (I)

Depth (ft)		Description
From	To	
0	8	Soil, clay
8	13	Boulders and gravels
13	26	Yellow clays
26	30	Boulders and gravels
30	46	Clays with small gravels
46	50	Cemented gravels
50	52	Clays
52	58	Cemented boulders and gravels
58	60	Gritty clays
60	102	Lightly cemented boulders and gravels
102	104	Small cemented gravels and sandstone
104	107	Yellow clays
107	115	Small cemented gravels and sand
115	123	Small gravels embedded in clays
123	127	Yellow clays
127	131	Clays with few pebbles
131	154	Cemented small gravels
154	158	Gritty clays and sandstone
158	195	cemented sand and gravels
195	199	Gritty clays
199	238	Cemented sand and gravels
238	240	Gritty clays
240	244	Claybound gravels
244	248	Hardpan clays
248	345	Cemented gravels with clay lenses

4-2-16aaa (S)

Depth (ft)		Description
From	To	
0	225	Claybound broken rock
255	265	Yellow clay
265	325	Hard sandstone

4-2-18aca (S)

Depth (ft)		Description
From	To	
0	12	Topsoils
12	25	Shale ledge
25	87	Clay
87	91	Dirty gravels
91	110	Sand and fragmented shale

Table 12. (continued)

4-2-20dcd (S)			5-1-27acb (I)		
Depth (ft)		Description	Depth (ft)		Description
From	To		From	To	
0	282	Broken hard shale	0	77	Clay and fine gravel
282	301	Same as above but a little softer	77	83	Yellow clay
		4 gpm from 282' to 292'	83	143	Fine gravel
301	415	Buff shale	113	118	Yellow clay
415	425	Same as above but softer	118	182	Yellow clay and fine gravel
			182	190	Fine gravel
			190	331	Yellow clay and fine gravel
5-1-8bd (D)			5-1-27bbc (I)		
Depth (ft)		Description	Depth (ft)		Description
From	To		From	To	
0	1	Topsoil	0	305	Clay and gravel interbedded with clay
1	32	Soft clay, sand, gravel			
32	52	Sand and gravel			
52	56	Soft clay and sand. Water			
56	59	Coarse sand and gravel			
59	66	Soft clay and sand			
66	67.5	Coarse broken red shale			
5-1-17ac (S)			5-1-27ccb (I)		
Depth (ft)		Description	Depth (ft)		Description
From	To		From	To	
0	10	Dirty broken rock and sand	0	6	Clay
10	26	Buff clay	6	74	Large gravels and boulders, cemented
26	32	Fragmented buff shale and sand	74	87	Finer gravels, loose
32	52	Fragmented red shale and sand	87	115	Coarse gravels, boulders, cemented, porous
52	53	Soft buff shale	115	140	Loose gravels and boulders
53	57	Brown sandstone. Water	140	146	Small gravels embedded in porous sandstone
57	60	Soft buff shale	146	175	Large gravels and boulders, cemented and porous
			175	195	Small gravel in sandstone, porous
			195	211	Large boulders and gravels, cemented and loose layers
			211	219	Very large boulders, cemented
			219	221	Clay
5-1-22bba (S)			5-1-27cda (I)		
Depth (ft)		Description	Depth (ft)		Description
From	To		From	To	
0	24	Old well	0	2	Clay
24	30	Tan clay and sand. Water	2	10	Gravel
30	42	Tan clay and gravel	10	48	Claybound gravel
42	81	Brown clay and sand	48	64	Clay and rock
81	82	Coarse sand with water	64	80	Gravel and rock
			80	91	Gravel, clay
			91	99	Clean gravel
			99	110	Clay and gravel streaks
			110	125	Claybound gravel
			125	134	Clay streaked gravel
			134	136	Clean gravel
			136	142	Clay
			142	165	Gravel and clay streaks
			165	180	Gravel and rock
			180	186	Clean gravel
			186	192	Clay
			192	202	Gravel and clay
			202	207	Clean gravel
			207	220	Clay and gravel
			220	241	Clay, thin gravel streaks
			241	245	Gravel and rock, tight
			245	248	Clay
			248	258	Gravel, streaks clay
			258	270	Clay
			270	272	Gravel
			272	302	Clay and gravel streaks
5-1-24bdd (S)			5-1-33bac (I)		
Depth (ft)		Description	Depth (ft)		Description
From	To		From	To	
1	5	Topsoil	0	18	Clays and broken rock
5	35	Gravel, clay, and boulders	18	152	Sand, gravel, large boulders
35	43	Sand and gravel	152	156	Clean sand and gravel
			156	166	Gritty clay, hardpan
			166	168	Cemented gravel and boulders
			168	173	Hardpan and clay
			173	182	Coarse sand and gravel
			182	186	Red and buff clay
			186	190	Sand and claybound gravel
			190	192	Buff clay
5-1-26ccb (I)					
Depth (ft)		Description	Depth (ft)		Description
From	To		From	To	
0	3	Topsoil and clay			
3	34	Sand and gravels with some large boulders			
34	39	Hard cemented sand, gravels, and large boulders			
39	49	Loose sand and gravels			
49	51	Dry clay			
51	58	Large gravels and boulders, cemented			
58	59	Dry clay			
59	76	Sand, gravel, and boulders			
76	78	Dry clay			
78	80	Large gravels and boulders			
80	83	Dry clay			
83	87	Gravel			
87	89	Clay			
89	108	Sand and gravel			
108	109	Clay			
109	115	Sand and gravel			
115	117	Dry clay			
117	126	Sand and gravel			
126	128	Dry clay			
128	146	Sand and gravel			
146	154	Mixed clay and gravel			
154	165	Lightly cemented sand and gravel			

Continued on next page

Table 12. (continued)

5-1-33bac, continued

Depth (ft)		Description
From	To	
192	230	Sand and gravel, lightly cemented, claybound, few small boulders
230	234	Gritty clay
234	251	Large gravel and boulders, lightly cemented
251	255	Claybound sand and gravel

5-1-34ccc (I)

Depth (ft)		Description
From	To	
0	86	Clay, sand, and gravel
86	90	Gravel
90	100	Clay
100	117	Gravel
117	121	Sand
121	123	Gravel
123	129	Clay
129	135	Gravel
135	142	Clay
142	150	Gravel and clay mix
150	178	Gravel
178	184	Clay
184	217	Clay and gravel mix
217	229	Gravel
229	233	Clay
233	237	Gravel
237	241	Clay
241	249	Claybound gravel
249	253	Gravel and sand
253	265	Clay
265	269	Gravel
269	281	Clay
281	286	Gravel
286	287	Clay
287	292	Gravel
292	300	Clay
300	303	Gravel
303	310	Clay and gravel mix
310	320	Clay
320	325	Clay

5-2-35dab (D)

Depth (ft)		Description
From	To	
0	1	Topsoil
1	18	Sand, gravel, volcanic ash
18	24	Clay and ash
24	42	Sand and volcanic ash and some gravel
42	58	Coarse sand
58	62	Hardpan (CaCO ₃ cemented gravels)
62	66	Coarse gravel
66	72	Coarse sand and some gravel
72	102	Sand
102	134	Very sandy clay and pea-sized gravel
134	136	Large gravel
136	152	Very sandy clay and gravel

5-2-35d (D)

Depth (ft)		Description
From	To	
0	4	Topsoil
4	145	Clay and gravel
145	195	Gravel

Table 13. Specific Capacity Test Results

Well Number	Total Depth (ft)	Borehole Diameter (in)	Static Water Level (ft)	Pumping Water Level (ft)	Pumping Rate (gpm)	Test Duration (hr)	Specific Capacity (gpm/ft)	Estimated Transmissivity (gpd/ft)	Estimated Hydraulic Conductivity (gpd/ft ²)
Domestic, Stock, and Observation Wells in Basin-Fill Aquifer									
4-1-1ab	27	6	5	15	30	4	3.0	6000	860
4-1-1b	70	6	36	60	8	2	0.3	500	100
4-1-1cd	62	6	4.5	24	24	2	1.2	2000	---
4-1-2cdd	131	6	24	55	40	2	1.3	2000	440
4-1-2	133	6	19.5	80	60	4	1.0	1800	400
4-1-3bba1	220	6	68	73	50	4	10.0	20000	---
4-1-9aab	139	6	112	131	15	2	0.8	1500	---
4-1-9ca	253	6	174	179	30	4	6.0	11000	---
Do.	do.	do.	172.7	177.4	12	0.8	2.5(1)	5000	---
4-1-10bhc	447	7	100	125	5	1	0.2	300	---
4-1-12bad	40	6	5.5	6	20	1	40.0	100000	---
4-1-17add	220	6	190	200	7	2	0.7	1300	450
4-1-19ddd	291	6	120	225	8	3	0.08	150	30
4-1-23bbb3	na	6	66	73	6	na	<0.8	<1500	---
4-2-4bbb	40	7	12	35	20	2	0.9	1700	360
5-1-8bd	68	6	27	35	15	2.5	1.9	4000	---
5-1-8ca	40	7	20	35	20	2	1.3	2000	180
5-1-8cd	110	6	65	85	20	1	1.0	1800	---
5-1-13ddl	60	6	30	40	20	10	2.0	4000	---
5-1-17	66	6	42	57	20	1	1.3	2000	1000
5-1-22bba	82	6	15	57	17	4	0.4	700	---
5-1-24bdd	43	7	20	35	20	2	1.3	2000	20
5-1-24dbc	36	6	4	16	18	1	1.5	3000	---
5-1-33cbb	177	6	154	164	15	2	1.5	3000	760
5-1-34cbb	80	6	64	69	35	3	7.0	14000	1400
5-2-28cdb	148	6	127	138	8	1.5	0.7	1300	700
5-2-35d	195	6	100	185	25	1	0.3	500	40

Table 13. (continued)

Well Number	Total Depth (ft)	Borehole Diameter (in)	Static Water Level (ft)	Pumping Water Level (ft)	Pumping Rate (gpm)	Test Duration (hr)	Specific Capacity (gpm/ft)	Estimated Transmissivity (gpd/ft)	Estimated Hydraulic Conductivity (gpd/ft ²)
Irrigation Wells in Basin-Fill Aquifer									
4-1-2bbb	191	32	27	105	2000	8	25.6	50000	600
4-1-2ccb	275	16	54	140	1500	5	17.4	35000	260
4-1-2ccc	250	32	39.5	120	2200	10	27.3	55000	520
4-1-3bba2	220	16	68	120	2000	22	38.5	77000	1500
4-1-3dbb	313	32	55	143	2736	8	31.1	62000	580
4-1-9aac	349	16	121	180	2000	5	33.9	65000	360
4-1-10bcb	330	32	91	170	2250	na	28.5	57000	340
Do.	do.	do.	91	200	3000	35	27.5	55000	340
Do.	do.	do.	114	154.3	1600	40	40.0(2)	80000	480
4-1-10cbb	199	12	98	180	700	8	8.5	17000	200
4-1-11bcc	431	32	45	240	2400	8	12.3	25000	160
Do.	do.	do.	57	96	1170	20	30.0(3)	60000	320
4-1-11cbd	245	16	46	170	1000	5	8.1	16000	100
4-1-12acc	250	16	9	125	600	3	5.2	10000	60
4-1-13bbe	240	16	32	140	1350	5	12.5	25000	160
4-1-14bcc	260	16	43	180	1300	6	9.5	19000	100
4-1-15bcc	355	32	123	223.5	2000	8	19.9	39000	340
4-1-15cbd	342	32	125	216	2000	8	22.0	44000	340
4-1-23bac	345	32	59.5	140	3420	8	42.5	84000	800
Do.	do.	do.	69.9	139.8	1900	20	27.0(4)	55000	520
5-1-26ccb	172	32	22.5	72	2400	10	48.5	100000	1000
Do.	do.	do.	18	59.6	1750	>8	42.0(5)	85000	880
5-1-27acb	331	16	48	150	1500	1	14.7	30000	160
5-1-27bbe	305	16	81	138	1200	2	21.1	42000	220
5-1-27ccb	221	36	90	158	1300	16	19.1	38000	500
Do.	do.	do.	87	117.1	1100	>8	36.5(6)	75000	980
5-1-27cda	302	16	54	120	2000	5	30.3	60000	260
5-1-33bac	255	32	120	177	1020	8	17.9	36000	360
5-1-34ccc	325	16	80	145	1300	2	20.0	40000	180

Table 13. (continued)

Well Number	Total Depth (ft)	Borehole Diameter (in)	Static Water Level (ft)	Pumping Water Level (ft)	Pumping Rate (gpm)	Test Duration (hr)	Specific Capacity (gpm/ft)	Estimated Transmissivity (gpd/ft)	Estimated Hydraulic Conductivity (gpd/ft ²)
Domestic, Stock, and Observation Wells in Bedrock									
4-1-30cc	135	6	35	50	6	3	0.4	700	6
4-1-31a	45	6	12	18	60	1	10.0	20000	---
4-2-8bb	65	6	17	25	45	4	0.2	300	40
4-2-16aaa	325	6	248	313	4	2	0.06	120	2
4-2-17bb	154	6	92	150	3	2	0.05	100	---
4-2-18aca	110	6	70	85	30	3	2.0	4000	---
Do.	do.	do.	72.2	74.4	17	1.5	7.9(7)	15000	---
4-2-20dce	425	6	270	355	12	4	0.1	200	---
5-1-17ac	60	6	30	45	15	4	1.0	1800	100
Irrigation Test Well(8)									
4-1-22	435	16	34	180	150	2	1.0	2000	8

Notes: All data supplied from well logs with the following exceptions:

- (1) Measurements made 6-20-79. Recovery test indicated T of 12600 gpd/ft.
- (2) During aquifer test, May, 1980. Measured transmissivity was 300000 gpd/ft.
- (3) Based on discharge measurement and pumping water level on 7-9-79 and previous static water level.
- (4) Based on discharge measurement and pumping water level on 6-28-79 and previous static water level.
- (5) Based on discharge measurement and pumping water level on 7-12-79 and previous static water level.
- (6) Based on discharge measurement and pumping water level on 8-17-79 and previous static water level.
- (7) Test on 6-12-79
- (8) This well subsequently was abandoned by pulling casing

Table 14. Seasonal Discharge by Irrigation Wells

Well identification: 4-1-2bbb

Pump manufacturer: Floway Type: DOL Number of stages: 2

Motor horsepower: 60 RPM: 1800

Approximate pumping lift (ft): 92

Date	Power meter reading (kwhr x 10)	Remarks
5-26-79	8139	Pumping at 51 kw/hr
8-17-79	0925	Power meter reset to 0000
10-13-79	0368	before measurements
11-3-79	1042	
3-29-80	1042	No pumping since 11-3-79

Approximate kwhr used during irrigation season: 20000
 Estimated total number of hours pumped: 400
 Estimated volume pumped (gallons at 1500 gpm): 3.6×10^7

Well identification: 4-1-2ccb

Pump manufacturer: Floway Type: DOL Number of stages: 4

Motor horsepower: 100 RPM: 1770

Approximate pumping lift (ft): 137

Date	Power meter reading (kwhr x 160)	Remarks
5-23-79	2786	Pumping; assume rate of
8-17-79	3544	75 kw/hr
10-13-79	3544	
11-3-79	3627	
4-26-80	3627	

Approximate kwhr used during irrigation season: 130000
 Estimated total number of hours pumped: 1800
 Estimated volume pumped (gallons at 1500 gpm): 1.6×10^8

Well identification: 4-1-2ccc

Pump manufacturer: Floway Type: DKH Number of stages: 2

Motor horsepower: 125 RPM: 1770

Approximate pumping lift (ft): na

Date	Power meter reading (kwhr x 160)	Remarks
5-23-79	2838	Not used for irrigation this year

Table 14. (continued)

Well identification: 4-1-3bba2

Pump manufacturer: Johnston Type: na Number of stages: na

Motor horsepower: na RPM: na

Approximate pumping lift (ft): >80

Power meter

reading

Date	(kwhr x 1)	Remarks
5-26-79	7452	Assume rate of 70 kw/hr
9-15-79	2621	

Approximate kwhr used during irrigation season: 3000

Estimated total number of hours pumped: 50

Estimated volume pumped (gallons at 1500 gpm): 4.5×10^6

Well identification: 4-1-3dbb

Pump manufacturer: Floway Type: FKH Number of stages: 2

Motor horsepower: 125 RPM: 1770

Approximate pumping lift (ft): 127

Power meter

reading

Date	(kwhr x 160)	Remarks
5-26-79	3767	Pumping; assume rate of
11-3-79	4666	75 kw/h

Approximate kwhr used during irrigation season: 140000

Estimated total number of hours pumped: 1200

Estimated volume pumped (gallons at 1500 gpm): 1.0×10^8

Well identification: 4-1-4adb

Pump manufacturer: Aurora Type: 12RM Number of stages: na

Motor horsepower: na RPM: na

Approximate pumping lift (ft): 150

Power meter

reading

Date	(Kwhr x 40)	Remarks
6-20-79	2244	Not pumping
6-29-79	2261	Estimated power use rate
7-17-79	3123	of 75 kw/hr
8-17-79	4079	
9-15-79	4804	
3-29-80	4804	

Approximate kwhr used during irrigation season: 100000

Estimated total number of hours pumped: 1400

Estimated volume pumped (gallons at 1500 gpm): 1.2×10^8

Table 14. (continued)

Well identification: 4-1-9aac

Pump manufacturer: Floway Type: FKH Number of stages: 4

Motor horsepower: 200 RPM: 1770

Approximate pumping lift (ft): 160

Power meter

Date	reading (kwhr x 40)	Remarks
5-26-79	4649	Not pumping
6-20-79	5848	Estimated power use rate
7-17-79	8140	of 150 kw/hr
8-15-79	1080	
3-29-80	1080	
4-26-80	0000	Meter reset

Approximate kwhr used during irrigation season: 180000

Computed total number of hours pumped: 1100

Estimated volume pumped (gallons at 1500 gpm): 1.0×10^8

Well identification: 4-1-10bcb

Pump manufacturer: Floway Type: DOH Number of stages: 2

Motor horsepower: 100 RPM: 1800

Approximate pumping lift (ft): 150

Power meter

Date	reading (kwhr x 1)	Remarks
6-20-79	7689	Pumping; rate of 43 kw/hr
7-17-79	0111	
10-13-79	2664	
11-10-79	6433	
4-26-80	6433	
5-3-80	6506	At 0600 hrs during test
5-4-80	6622	At 0900 hrs during test

Approximate kwhr used during irrigation season: Unknown

Estimated total number of hours pumped: 1500

Estimated volume pumped (gallons at 2000 gpm): 1.8×10^8

(Note: Power meter multiplier uncertain)

Well identification: 4-1-10cbb

Pump manufacturer: Type: Number of stages: na

Motor horsepower: na RPM: na

Approximate pumping lift (ft): 150

Power meter

Date	reading (kwhr x 1)	Remarks
		Estimated power use rate
		of 50 kw/hr

Approximate kwhr used during irrigation season: 50000

Estimated total number of hours pumped: 1000

Estimated volume pumped (gallons at 1500 gpm): 9.0×10^7

Table 14. (continued)

Well identification: 4-1-11ac

Pump manufacturer: Aurora Type: 12RH Number of stages: na

Motor horsepower: na RPM: na

Approximate pumping lift (ft): >30

Power meter

reading

Date	(kwhr x 1)	Remarks
6-20-79	34594	
8-16-79	78905	Estimated power use rate
10-13-79	02522	of 50 kw/hr
4-26-80	02522	

Approximate kwhr used during irrigation season: 50000

Estimated total number of hours pumped: 1000

Estimated volume pumped (gallons at 1500 gpm): 9.0×10^7

Well identification: 4-1-11cbd

Pump manufacturer: Wel-Line Type: KH Number of stages: 5

Motor horsepower: na RPM: na

Approximate pumping lift (ft): 90

Power meter

reading

Date	(kwhr x 40)	Remarks
5-23-79	5006	
11-3-79	7704	Assume 60 kw/hr

Approximate kwhr used during irrigation season: 110000

Estimated total number of hours pumped: 1800

Estimated volume pumped (gallons at 1500 gpm): 1.6×10^8

Well identification: 4-1-12acc

Pump manufacturer: Johnston Type: na Number of stages: na

Motor horsepower: na RPM: na

Approximate pumping lift (ft): 52

Power meter

reading

Date	(kwhr x 10)	Remarks
6-20-79	8850	
8-17-79	3010	Pumping at 45.8 kw/hr
9-15-79	3455	(Assume meter reset after
11-3-79	3455	after 6-20-79)

Approximate kwhr used during irrigation season: 34550

Estimated total number of hours pumped: 754

Estimated volume pumped (gallons at 1500 gpm): 7.0×10^7

Table 14. (continued)

Well identification: 4-1-13bbc

Pump manufacturer: Johnston Type: na Number of stages: na

Motor horsepower: 150 RPM: na

Approximate pumping lift (ft): >40

Power meter
reading

Date	(kwhr x 40)	Remarks
------	-------------	---------

5-26-79	2672	
---------	------	--

11-3-79	4507	
---------	------	--

Assume 150 kw/hr

3-29-80	4664	
---------	------	--

Approximate kwhr used during irrigation season: 73000

Estimated total number of hours pumped: 500

Estimated volume pumped (gallons at 1500 gpm): 4.4×10^7

Well identification: 4-1-15bcc

Pump manufacturer: Floway Type: DOH Number of stages: 3

Motor horsepower: 125 RPM: 1800

Approximate pumping lift (ft): >300

Power meter
reading

Date	(kwhr x 40)	Remarks
------	-------------	---------

5-26-79	3137	
---------	------	--

7-24-79	5390	
---------	------	--

Pumping at 160 kw/hr

9-14-79	7202	
---------	------	--

3-29-80	7200	
---------	------	--

Approximate kwhr used during irrigation season: 160000

Estimated total number of hours pumped: 1000

Estimated volume pumped (gallons at 1500 gpm): 9.1×10^7

Well identification: 4-1-15cdb

Pump manufacturer: Johnston Type: na Number of stages: na

Motor horsepower: na RPM: na

Approximate pumping lift (ft): 52

Power meter
reading

Date	(kwhr x 40)	Remarks
------	-------------	---------

5-26-79	6630	
---------	------	--

6-20-79	8337	
---------	------	--

Pumping at 160 kw/hr

11-3-79	3486	
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Approximate kwhr used during irrigation season: 270000

Estimated total number of hours pumped: 1700

Estimated volume pumped (gallons at 1500 gpm): 1.5×10^8

Table 14. (continued)

Well identification: 4-1-16dad

Pump manufacturer: Johnston Type: na Number of stages: na

Motor horsepower: 60 RPM: na

Approximate pumping lift (ft): na

Power meter

reading

Date	(kwhr x 1)	Remarks
------	------------	---------

6-26-79	73953	
---------	-------	--

10-13-79	30403	Assume 40 kw/hr
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Approximate kwhr used during irrigation season: 60000

Estimated total number of hours pumped: 1500

Estimated volume pumped (gallons at 500 gpm): 4.5×10^7

Well identification: 4-1-23bac

Pump manufacturer: Floway Type: DKM Number of stages: 2

Motor horsepower: 75 RPM: 1760

Approximate pumping lift (ft): 140

Power meter

reading

Date	(kwhr x 160)	Remarks
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5-26-79	3708	
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6-28-79	3717	Pumping at 71.5 kw/hr
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11-2-79	3850	
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Approximate kwhr used during irrigation season: 23000

Estimated total number of hours pumped: 320

Estimated volume pumped (gallons at 2000 gpm): 3.8×10^7

Well identification: 5-1-26ccb

Pump manufacturer: Floway Type: DOH Number of stages: 1

Motor horsepower: 50 RPM: 1800

Approximate pumping lift (ft): 60

Power meter

reading

Date	(kwhr x 10)	Remarks
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5-23-79	4940	
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7-12-79	5435	Pumping at 43 kw/hr and
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8-17-79	7181	1500 to 2000 gpm
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11-3-79	7181	
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Approximate kwhr used during irrigation season: 22000

Estimated total number of hours pumped: 500

Estimated volume pumped (gallons at 1750 gpm): 5.3×10^7

Table 14. (continued)

Well identification: 5-1-27acb

Pump manufacturer: Floway Type: DOH Number of stages: 2

Motor horsepower: 100 RPM: 1800

Approximate pumping lift (ft): >50

Date	Power meter reading (kwhr x 160)	Remarks
6-16-79	2354	
9-23-79	2892	Assume 80 kw/hr

Approximate kwhr used during irrigation season: 86000
 Estimated total number of hours pumped: 1100
 Estimated volume pumped (gallons at 1500 gpm): 9.7×10^7

Well identification: 5-1-27bbc

Pump manufacturer: Floway Type: DOM Number of stages: 5

Motor horsepower: 75 RPM: 1760

Approximate pumping lift (ft): 105

Date	Power meter reading (kwhr x 1)	Remarks
6-1-79	28340	
10-26-79	78045	
4-26-80	78045	Assume 50 kw/hr

Approximate kwhr used during irrigation season: 78000
 Estimated total number of hours pumped: 1600
 Estimated volume pumped (gallons at 1000 gpm): 9.0×10^7

Well identification: 5-1-27ccb

Pump manufacturer: Floway Type: DKH Number of stages: 3

Motor horsepower: 60 RPM: 1800

Approximate pumping lift (ft): 117

Date	Power meter reading (kwhr x 1)	Remarks
6-1-79	31611	
7-18-79	81742	
8-17-79	18380	
10-26-79	76319	Assume 60 kw/hr

Approximate kwhr used during irrigation season: 110000
 Estimated total number of hours pumped: 1800
 Estimated volume pumped (gallons at 1100 gpm): 1.2×10^8

Table 14. (continued)

Well identification: 5-1-27cda

Pump manufacturer: Johnston Type: na Number of stages: na

Motor horsepower: na RPM: na

Approximate pumping lift (ft): >50

Power meter

reading

Date (kwhr x 1)

Remarks

6-28-79 59110

Meter was reset

9-23-79 17772

Assume 65 kw/hr

Assumed kwhr used during irrigation season: 75000

Estimated total number of hours pumped: 1200

Estimated volume pumped (gallons at 2200 gpm): 1.5×10^8

Well identification: 5-1-28bac

Pump manufacturer: Johnston Type: na Number of stages: na

Motor horsepower: na RPM: na

Approximate pumping lift (ft): 185

Power meter

reading

Date (kwhr x 40)

Remarks

6-20-79 494

Well installed in 1979

11-3-79 5255

Assume 100 kw/hr

Approximate kwhr used during irrigation season: 210000

Estimated total number of hours pumped: 2100

Estimated volume pumped (gallons at 1500 gpm): 1.9×10^8

Well identification: 5-1-33bac

Pump manufacturer: Floway Type: DOL Number of stages: 7

Motor horsepower: 100 RPM: 1800

Approximate pumping lift (ft): 168

Power meter

reading

Date (kwhr x 1)

Remarks

7-17-79 00202

Pumping at 81.5 kw/hr

10-13-79 70758

4-26-80 70758

Approximate kwhr used during irrigation season: 71000

Estimated total number of hours pumped: 870

Estimated volume pumped (gallons at 1500 gpm): 7.8×10^7

Table 14. (continued)

Well identification: 5-1-34ccc

Pump manufacturer: Floway Type: DOH Number of stages: 3

Motor horsepower: 100 RPM: 1800

Approximate pumping lift (ft): >100

Power meter

reading

Date	(kwhr x 1)	Remarks
5-26-79	41342	Meter was reset
8-17-79	05344	Assume 100 kw/hr

Assumed kwhr used during irrigation season: 5000

Estimated total number of hours pumped: 530

Estimated volume pumped (gallons at 1500 gpm): 4.8×10^7

Well identification: 5-1-34dcc

Pump manufacturer: Peerless Type: na Number of stages: na

Motor horsepower: na RPM: na

Approximate pumping lift (ft): na

Power meter

reading

Date	(kwhr x 10)	Remarks
5-26-79	2493	Not used during this
11-10-79	2493	irrigation season

Well identification: 5-2-34aac

Pump manufacturer: Aurora Type: na Number of stages: na

Motor horsepower: 75 RPM: na

Approximate pumping lift (ft): >80

Power meter

reading

Date	(kwhr x 80)	Remarks
9-12-79	2895	
10-26-79	4074	Assume 75 kw/hr

Approximate kwhr used during irrigation season: 94000

Estimated total number of hours pumped: 1300

Estimated volume pumped (gallons at 1000 gpm): 7.5×10^7

Note: na, information not available

Data missing from wells 4-1-11bcc and 4-1-14bcc

Pump not installed in well 4-1-2dbc

Table 15. Ground-Water Level Measurements

4-1-lcd (S) Elevation 4030 ft Date Depth to Water (ft)	4-1-2 (D) Elevation 4060 ft Date Depth to Water (ft)	4-1-9aac (I) Elevation 4170 ft Date Depth to Water (ft)	4-1-10bcb (I) Elevation 4155 ft Date Depth to Water (ft)
8-17-79 13.62	8-16-79 31.46	11-16-77 147.30	5-15-79 117.25*
9-15-79 10.91		5-26-79 126.44*	6-29-79 150.95rp
		6-20-79 146.38rp	7-17-79 154.06rp
		6-29-79 156p	8-15-79 120.12rp
		7-17-79 140.76rp	9-14-79 127.42rp
		8-15-79 137.67rp	10-13-79 161.25p
		9-14-79 134.87	11-10-79 119.84
		10-13-79 137.86	3-29-80 112.39
		10-26-79 139.56	4-26-80 112.27*
		11-3-79 140.44	
		11-10-79 135.49	
		3-29-80 128.86	
		4-26-80 128.66*	
			4-1-10cbb (I) Elevation 4160 UTM-no port
4-1-2bbb (I) Elevation 4075 ft Date Depth to Water (ft)	4-1-2dbc (I,U) Elevation 4060 ft Date Depth to Water (ft)	4-1-9abb (S,U) Elevation 4170 ft Date Depth to Water (ft)	4-1-11ab (D) Elevation 4060 ft Date Depth to Water (ft)
5-15-79 32.40*	6-23-79 24.32	5-26-79 125.05*	6-17-79 22.49
5-26-79 91.96p	8-16-79 24.34	6-1-79 125.20	
6-20-79 32.33	9-15-79 24.32	6-12-79 126.03	
6-29-79 UTM-p	10-13-79 24.35	6-20-79 127.29	
8-17-79 33.36	10-26-79 24.37	7-17-79 130.64	
9-15-79 32.35	11-3-79 24.40	8-17-79 132.97	
10-13-79 92.44p	3-29-80 24.58	9-14-79 130.39	
11-3-79 30.32	4-26-80 24.63	10-13-79 129.39	
3-29-80 32.81*		10-26-79 132.09	
		11-3-79 130.75	
		3-29-80 127.67	
		4-26-80 126.03*	
			4-1-11ac (I) Elevation 4060 ft Date Depth to Water (ft)
4-1-2ccb (I) Elevation 4085 ft Date Depth to Water (ft)	4-1-3bbal (OR) Elevation 4125 ft Date Depth to Water (ft)	4-1-9ca (S) Elevation 4200 ft Date Depth to Water (ft)	4-1-11bcc (I) Elevation 4090 ft Date Depth to Water (ft)
11-16-77 47.54	11-16-77 73.29	6-20-79 172.72*	11-16-77 56.30
6-20-78 52.50	6-20-78 82.16	7-17-79 174.24	6-20-78 55.96
5-15-79 46.16*	5-15-79 77.39	8-15-79 175.61	5-15-79 53.99*
5-23-79 136.98p	4-26-80 72.70	9-14-79 175.56	5-23-79 54.89
8-17-79 61.33		10-13-79 175.60	5-26-79 55.32
9-14-79 50.93	4-1-3bba2 (I) Elevation 4125 ft Date Depth to Water (ft)	11-3-79 175.56	6-1-79 55.26
10-13-79 55.48	5-26-79 69.02	11-10-79 175.43	6-12-79 56.80
11-3-79 51.49rp	9-15-79 73.92rp	3-29-80 174.39	6-20-79 96.34p
4-26-80 49.98*		4-26-80 174.12*	8-15-79 57.84
			9-14-79 56.01
			10-13-79 59.51rp
			10-26-79 58.74
			11-3-79 56.10
			4-26-80 56.17*
4-1-2ccc (I,U) Elevation 4085 ft Date Depth to Water (ft)	4-1-3dbb (I) Elevation 4105 ft Date Depth to Water (ft)	4-1-10bbc (O) Elevation 4155 ft Date Depth to Water (ft)	
11-16-77 50.32	6-20-79 117.85rp	11-16-77 108.27	
5-15-79 49.15*	6-29-79 153p	6-20-78 99.29	
5-23-79 56.06	7-17-79 126.13rp	5-15-79 111.27*	
6-20-79 56.67	8-17-79 117.65rp	6-20-79 118.59	
8-17-79 55.86	9-15-79 129.70rp	7-17-79 119.15	
9-14-79 51.54	10-13-79 116.10	8-15-79 114.03	
10-13-79 53.58	10-26-79 116.01	9-14-79 111.18	
11-2-79 53.29	11-3-79 116.46	10-13-79 115.68	
4-26-80 51.55*	3-29-80 112.59	11-2-79 115.03	
		11-10-79 112.48	
		4-26-80 108.81*	
4-1-2cd (D) Elevation 4070 ft Date Depth to Water (ft)	4-1-4adb (I) Elevation 4165 ft Date Depth to Water (ft)		
8-16-79 22.82	6-20-79 117.85rp		
	6-29-79 153p		
	7-17-79 126.13rp		
	8-17-79 117.65rp		
	9-15-79 129.70rp		
	10-13-79 116.10		
	10-26-79 116.01		
	11-3-79 116.46		
	3-29-80 112.59		
4-1-2cdd (D) Elevation 4065 ft Date Depth to Water (ft)	4-1-8dd (S,U) Elevation 4240 ft Dry well		
8-16-79 31.46			

Table 15. (continued)

4-1-11cbbd (I) Elevation 4085 ft Date Depth to Water (ft)	4-1-15bcc (I) Elevation 4185 ft Date Depth to Water (ft)	4-1-23bac (I) Elevation 4140 ft Date Depth to Water (ft)	4-2-18aca (S,U) Elevation 4100 ft Date Depth to Water (ft)
11-16-77 49.46	11-16-77 141.03	11-16-77 75.37	11-16-77 38.97
5-15-79 49.04*	6-20-78 139.55	5-15-79 71.53	6-20-78 32.27
5-23-79 49.75	5-15-79 139.45	5-26-79 70.02	6-12-79 72.24
6-17-79 89.44p	5-26-79 135.21*	6-17-79 69.69	6-17-79 75.70
8-15-79 51.01	6-20-79 136.70	6-26-79 69.90	8-16-79 69.99
9-14-79 49.85	7-17-79 UTM-p	6-28-79 139.76p	9-17-79 69.83
10-13-79 51.07rp	8-15-79 142.35	7-17-79 140.24p	11-2-79 69.20
10-26-79 51.13	9-14-79 139.08	8-15-79 71.14	3-29-80 72.74
11-3-79 50.92	10-13-79 138.63	9-14-79 70.05	
3-29-80 50.67*	10-26-79 139.16	10-13-79 69.86	
	11-3-79 138.53	11-2-79 70.06	
	11-10-79 138.27		4-2-20dcd (S,U) Elevation 4320 ft Date Depth to Water (ft)
	3-29-80 135.89		6-12-79 273.66*
	4-26-80 135.58*		6-20-79 273.60
4-1-12acc (I) Elevation 4040 ft Date Depth to Water (ft)	4-1-15cdb (I) Elevation 4180 ft Date Depth to Water (ft)	4-1-23bbb3 (D) Elevation 4150 ft Date Depth to Water (ft)	6-26-79 279.67(?)
6-20-79 10.63rp	11-16-77 140.95	5-26-79 66.56rp	7-17-79 271.01
8-16-79 UTM-p	5-15-79 122.09	6-28-79 67.32rp	8-17-79 270.83(?)
8-17-79 52.4p	5-26-79 141.01rp	7-17-79 73.18rp	9-12-79 273.45
9-15-79 10.41	6-20-79 UTM-p		11-2-79 273.19*
10-13-79 UTM-bc	6-26-79 UTM-p		
	7-17-79 UTM-rp	4-1-30cc (S) Elevation 4360 ft Date Depth to Water (ft)	5-1-11cdc (S) Elevation 4140 ft Date Depth to Water (ft)
4-1-12ad (S) Elevation 4030 ft Date Depth to Water (ft)	8-15-79 UTM-p	6-16-79 9.68	7-12-79 8.25rp
8-17-79 8.40	9-14-79 UTM	7-24-79 10.19	9-15-79 8.99p
9-15-79 8.52	10-13-79 128	9-14-79 10.45	
	10-26-79 UTM		
	11-3-79 128.07		
4-1-12bad (S) Elevation 4040 ft Date Depth to Water (ft)	4-1-16dad (I) Elevation 4200 ft UTM-no port	4-1-31a (S,U) Elevation 4360 ft Date Depth to Water (ft)	5-1-13ddd (S) Elevation 3995 ft Date Depth to Water (ft)
8-16-79 10.26		6-16-79 34.41	7-11-79 7.29rp
8-17-79 UTM-p		7-24-79 34.48	7-18-79 7.04rp
9-15-79 8.35	4-1-17add (S,U) Elevation 4265 ft Date Depth to Water (ft)	9-14-79 34.73	9-23-79 9.85
10-13-79 7.50	6-16-79 dry(?)		
11-2-79 8.53	9-14-79 196.87	4-2-4bbb (D) Elevation 3995 ft Date Depth to Water (ft)	5-1-22bba (S,U) Elevation 4140 ft Date Depth to Water (ft)
4-26-80 8.89	10-13-79 196.90	8-16-79 15.83	6-16-79 6.19
4-1-12dd (D) Elevation 4050 ft UTM-no port			7-18-79 6.20
			8-17-79 9.18
			9-23-79 13.23
			10-26-79 14.58
			11-10-79 16.08
			3-29-80 24.16
4-1-13bbc (I) Elevation 4080 ft Date Depth to Water (ft)	4-1-19ddd (S) Elevation 4340 ft Date Depth to Water (ft)	4-2-16aaa (S) Elevation 4235 ft Date Depth to Water (ft)	
5-26-79 34.37*	6-16-79 109.17	6-29-79 242rp	
6-17-79 33.59rp	7-24-79 109.21		5-1-24bdd (S,U) Elevation 4015 ft Date Depth to Water (ft)
8-15-79 33.62	9-14-79 109.21		6-17-79 8.64
9-14-79 32.54	10-13-79 120.57rp	4-2-17bb (S,U) Elevation 4110 ft Date Depth to Water (ft)	7-18-79 6.95
10-13-79 33.46rp	3-29-80 109.21	9-12-79 91.57	9-23-79 7.80
11-3-79 33.43rp		11-2-79 91.52	10-26-79 6.35
3-29-80 34.61*	4-1-22dcb (D,U) Elevation 4190 ft Date Depth to Water (ft)		
4-1-14bcc (I) Elevation 4120 ft UTM-no port	9-14-79 102.13		
	10-13-79 101.78		

Table 15. (continued)

5-1-24dbc (S,U) Elevation 4005 ft Date Depth to Water (ft)	5-1-27ccb (I) Elevation 4145 ft Date Depth to Water (ft)	5-1-33cbb (S) Elevation 4210 ft Date Depth to Water (ft)	5-2-28cd (S) Elevation 3960 ft UTM-no port
7-12-79 2.20	11-16-77 86.89	8-17-79 162.73	
9-23-79 2.17	5-15-79 78.50*	9-15-79 162.31	5-2-28cdd (S)
	6-1-79 UTM-p	11-3-79 162.11	Elevation 3960 ft
	6-20-79 86.96	3-29-80 161.40	Date Depth to Water (ft)
	7-18-79 UTM-p		9-12-79 5.34
5-1-26ccb (I) Elevation 4075 ft Date Depth to Water (ft)	8-17-79 117.11p		
5-23-79 20.75*	9-15-79 UTM-p	5-1-34ccc (I) Elevation 4135 ft Date Depth to Water (ft)	5-2-31dc (D)
6-1-79 19.61	10-26-79 84.84	11-16-77 87.85	Elevation 3995 ft
6-16-79 17.59	11-3-79 84.18	6-20-78 92.09	Flowing well
7-12-79 59.58p	11-10-79 84.00	5-15-79 86.00*	
7-18-79 61.37p	3-29-80 86.27	5-19-79 93.33	5-2-34aac (I)
8-17-79 18.08	4-26-80 86.78*	5-26-79 87.53	Elevation 3690 ft
9-23-79 17.34		6-20-79 UTM-p	Date Depth to Water (ft)
10-13-79 18.96	5-1-27cda (I) Elevation 4110 ft Date Depth to Water (ft)	8-17-79 91.35	9-12-79 UTM-p
10-26-79 19.83	6-28-79 44.02	9-15-79 90.25	9-23-79 73.88
11-3-79 20.20	7-18-79 UTM-p	10-13-79 92.65	10-26-79 UTM
3-29-80 22.73*	8-17-79 UTM-p	11-3-79 89.35	11-10-79 67.11
	9-23-79 49.75	11-10-79 88.78	
5-1-27acb (I) Elevation 4115 ft Date Depth to Water (ft)	10-26-79 51.89	3-29-80 86.76	
6-1-79 42.48	11-3-79 51.98	4-26-80 87.34*	5-2-35ad (U)
6-16-79 45.26	3-29-80 54.74		Unable to locate
6-28-79 UTM-p			
8-17-79 45.13	5-1-28bac (I) Elevation 4235 ft Date Depth to Water (ft)	5-1-34dcc (I,U) Elevation 4100 ft Date Depth to Water (ft)	5-2-35d (D)
9-23-79 47.43rp	6-20-79 160.30rp	11-16-77 53.36	Elevation 4080 ft
10-26-79 48.00	8-17-79 156.04rp	5-15-79 47.90*	Date Depth to Water (ft)
3-29-80 53.08	9-15-79 154.81rp	5-26-79 51.30	9-12-79 149.97rp
	10-13-79 185.20p	6-20-79 55.10	
5-1-27bbc (I) Elevation 4155 ft Date Depth to Water (ft)	10-26-79 156.07rp	8-17-79 51.80	
6-1-79 104.32p	11-3-79 156.11rp	9-15-79 49.79	
6-20-79 UTM-p		10-13-79 53.64	
6-29-79 UTM-p	5-1-33bac (I) Elevation 4180 ft Date Depth to Water (ft)	11-3-79 51.74	
8-17-79 UTM-p	11-16-77 122.46	11-10-79 51.29	
9-15-79 75.13rp	6-20-78 126.02	3-29-80 49.79	
10-26-79 78.14rp	5-15-79 121.63*	4-26-80 50.28*	
11-3-79 77.30	5-19-79 122.30rp		
11-10-79 77.23	7-17-79 127.56rp	5-1-35dc (S) Elevation 4040 ft UTM-no port	
3-29-80 81.93	7-24-79 UTM-p		
4-26-80 82.98	8-17-79 168.30p		
	9-15-79 122.57rp		
	10-13-79 124.13rp		
	10-26-79 122.69		
	11-3-79 122.43		
	3-29-80 122.42		
	4-26-80 122.73*		

Note: Asterisks show measurements used to determine change in ground-water storage during 1979-1980 irrigation season

Table 16. Discharge Measurements from Wells

Well Number	Date	Discharge Rate (gpm)	Method
Domestic and Stock Wells			
4-1-9cab	6-20-79	9	Bucket
4-1-19ddd	7-24-79	11	Do.
4-1-23bbb3	6-28-79	6	Do.
4-2-18aca	6-12-79	17	Do.
5-1-24bdd	6-17-79	13.5	Do.
5-1-33bac	7-12-79	7.5	Do.
Irrigation Wells			
4-1-10bcb	5-2-80	1609	Propeller Meter
4-1-11bcc	7-9-79	1174	Transducer Meter
4-1-23bac	6-28-79	1900	Do.
5-1-26bac	7-12-79	1750	Do.
5-1-27ccb	8-17-79	1113	Do.
5-1-27cda	8-17-79	2200	Do.

Table 17. Discharge Measurements from Crow Creek and Springs

Date	Distance from Bank (ft)	Water Depth (ft)	Velocity at 0.6 x Depth (fps)
Crow Creek (at Helena National Forest Boundary)			
6-28-79	0.6	0.2	0.5
	1.9	0.9	1.4
	4.0	1.3	2.6
	5.3	1.6	2.6
	6.9	1.8	4.0
	8.0	1.8	4.2
	9.5	1.8	3.7
	11.0	2.1	5.0
	12.5	2.0	5.2
	14.0	1.6	4.5
	15.4	1.7	5.0
	16.5	1.6	5.6
	17.4	1.4	5.5
	18.1	1.1	5.5
	19.5	1.3	2.6
	20.5	1.5	4.6
	21.5	1.0	4.0
	22.5	0.7	1.1
	24.5	0.3	1.2
	25.0	0.0	0.0

Table 17. (continued)

Date	Distance from Bank (ft)	Water Depth (ft)	Velocity at 0.6 x Depth (fps)
Crow Creek (at Helena National Forest Boundary)			
7-9-79	0.4	0.3	1.0
	0.9	0.6	1.5
	1.8	1.0	1.7
	2.7	1.1	2.1
	4.1	1.4	2.5
	5.1	1.5	2.9
	6.3	1.4	3.0
	7.7	1.4	2.6
	8.7	1.5	3.2
	9.9	1.5	3.5
	11.6	1.4	2.2
	13.3	1.4	3.2
	15.2	1.4	2.1
	17.0	1.1	2.0
	18.6	0.7	1.1
9-15-79	0.1	2.4	0.3
	1.3	0.4	1.0
	2.1	0.6	1.3
	2.6	0.7	1.3
	3.3	0.6	1.5
	3.7	0.7	1.7
	3.9	0.4	1.8
	4.8	0.7	1.9
	5.7	0.6	1.7
	6.3	0.7	1.7
	6.9	0.3	1.5
	7.8	0.8	2.0
	8.9	1.0	2.1
	10.2	1.0	1.6
	11.3	0.9	1.2
	12.6	0.9	2.1
	13.2	0.9	1.3
	14.2	0.8	2.3
	14.7	0.4	0.9
	16.1	0.4	0.6
	17.0	0.0	0.0

Table 17. (continued)

Date	Distance from Bank (ft)	Water Depth (ft)	Velocity at 0.6 x Depth (fps)
Crow Creek (1.5 miles north of Radersburg)			
7-9-79	1.6	0.4	0.5
	2.8	0.5	0.7
	4.2	0.6	1.0
	5.1	0.7	1.3
	7.1	1.1	1.6
	8.8	1.1	2.1
	10.1	1.1	2.4
	11.7	1.1	2.8
	13.4	1.1	2.5
	14.8	1.1	2.7
	16.2	1.1	2.4
	17.6	1.3	2.7
	19.1	1.1	3.3
	20.1	1.1	2.2
	22.1	0.6	1.2
	23.2	0.5	0.7
	23.4	0.4	0.7
	23.5	0.0	0.7
Plunket Spring (Southeast Spring)			
5-26-79	0.5	0.2	0.9
	1.0	0.2	0.7
	1.5	0.0	0.0
Plunket Spring (Culvert)			
5-26-79	0.5	0.1	1.0
	1.0	0.2	2.4
	1.5	0.1	1.1
	2.1	0.0	0.0
6-26-79	0.7	0.2	2.5
	1.3	0.3	3.6
	2.0	0.2	2.7
	2.6	0.0	0.0
10-13-79	1.0	0.6	3.5
	2.0	0.8	4.5
	3.0	0.6	4.2
	3.9	0.0	0.0

Table 17. (continued)

Date	Distance from Bank (ft)	Water Depth (ft)	Velocity at 0.6 x Depth (fps)
Plunket Spring (Culvert)			
11-10-79	1.0	0.7	3.4
	2.0	0.8	4.7
	3.0	0.7	3.7
	4.1	0.0	0.0
Kimpton Spring (150 Feet East of Spring)			
6-16-79	1.5	0.2	0.2
	2.5	0.2	0.3
	3.5	0.3	0.3
	4.5	0.3	0.4
	5.5	0.3	0.6
	7.0	0.3	0.2
	8.5	0.0	0.0

APPENDIX B

AQUIFER TEST ANALYSIS

Introduction

Hydraulic properties of the basin-fill aquifer were determined in the vicinities of wells 4-1-10bbc and 4-1-9ca using data from a pumping test and a recovery test. Results of the tests are summarized in Table 18.

Pumping Test

A pumping test was conducted from May 2 through May 4, 1980 to assist in the estimation of hydrologic characteristics of the basin's sediments which deliver water to high-capacity wells. Well 4-1-10bbc was pumped for approximately 44 hours at a discharge rate of 1,600 gpm. Drawdown was measured in the pumping well and in wells 4-1-9aac and 4-1-10bcb, 1,320 feet and 186 feet from the pumping well, respectively. Recovery water levels were measured in wells 4-1-10bbc and 4-1-9aac for approximately nine hours after pumping stopped.

The pumped well is normally used to irrigate portions of one square mile, using side-roll sprinklers. For the duration of this test, six side-roll lines were attached to the main delivery lines. A 6-inch McCrometer propeller flow meter was attached in turn at each junction of a side-roll line with the main delivery line. Well

discharge was computed by summing the discharge rate to each sprinkler line while water pressure approximately ten feet from the pump outlet was held constant. Figure 13 is a schematic diagram of the pumping test setup. Figure 14 shows lithologies, interpreted from well logs, in the vicinity of the pumped well. The pumped well and well 4-1-9aac were screened in gravels. The log of well 4-1-10bbc does not indicate the screened interval. The degree of interconnection and lenticularity of the gravel beds and total depth of the aquifer are not known.

At the beginning of the test and until about 15 minutes into the test, the discharge lines were partially full of air and one flush valve on a sprinkler line was left open. The pump was pumping against an effective head lift which was lower than the effective head of the fully pressurized system. Consequently, the discharge rate was much greater than the stabilized 1600 gpm. Figures 15 and 16 show that this initial discharge resulted in over 55 feet of drawdown in the pumped well. After the system became pressurized, the discharge rate and drawdown decreased.

The discharge rate of 1,600 gpm was held constant throughout the remainder of the test by maintaining constant pressure in the main delivery line. Some variations in discharge occurred as the side-roll sprinklers were moved periodically. At these times, rapid fluctuations in discharge rate were caused by the necessity of shutting down one or two side-roll lines to reposition them. No attempt was made to maintain constant discharge during these moves. Also, failure of the Fisher M-Scope electric water-level measuring tape which had been

used to measure water levels in the pumping well prevented rapid measurements of the pumping well's recovery after pumping ceased.

Data obtained during the course of the aquifer test (Tables 19 and 20, Figures 15 through 22) were analyzed using four different methods and various combinations of wells. Two methods which assume unsteady conditions were used to analyze data acquired during the pumping part of the test. Chow's (1952) nomogram method was used as it avoids the use of type curves. The Cooper-Jacob method (Cooper and Jacob, 1946) avoids the use of early time data which in this case is highly unreliable. The transmissivity (T) values obtained from the above were checked with Theis' (1935) recovery method. A method presented in Hantush (1956) for analyzing unsteady-state flow in semi-confined aquifers with at least two observation wells was also used. This method arrives at a value for T using all observation wells and uses this T to determine the storage coefficient at each observation well. The equations and limiting assumptions used in the above methods are summarized in Kruseman and de Ridder (1976). Analytical results are presented in Table 18.

Observation well data provide the best estimates for transmissivity and storage coefficient values because these wells are unaffected by well losses. Transmissivity of the aquifer determined by the above methods from the two observation wells is about 3×10^5 gallons per day per foot (Table 18). Drawdown in the pumping well is increased because of well losses (Todd, in Chow, 1964; see "Efficiency of the Pumped Well," below), resulting in the low transmissivity values. The

low T value for observation well 4-1-10bcb computed by Chow's method is caused by casing storage effects. The average storage coefficient (S) is 1.6×10^{-3} .

Hydraulic conductivity (K) of the aquifer was calculated by dividing the transmissivity of 3×10^5 gpd/ft by the pumping well's perforated length (166 ft). This results in a K of 1800 gpd/ft² which is representative of the beds which supply water to the well. This value may be higher than the K of the aquifer because the perforated length may be less than the aquifer thickness. This K is consistent with the estimated hydraulic conductivities calculated from specific capacity data.

The values of T, S, and K show that the aquifer is an excellent source of water and that it is confined.

Efficiency of the Pumped Well

The efficiency of the pumped well was determined using an equation presented in Walton (1970, p. 312). The theoretical specific capacity of a pumping well is:

$$\frac{Q}{s} = \frac{T}{264 \log \frac{Tt}{2693r_w^2s} - 65.5}$$

where $\frac{Q}{s}$ = specific capacity, in gpm/ft

Q = discharge, in gpm

s = drawdown, in feet

T = transmissivity, in gpd/ft

S = storage coefficient

r_w = nominal radius of the well, in feet

t = time after pumping started, in minutes

The equation assumes that the well is discharging water from an infinite, homogeneous, isotropic, nonleaky artesian aquifer, that the well is fully penetrating and is uncased throughout the saturated thickness of the aquifer, that well losses are negligible, and that the nominal well radius has not been affected by drilling or development and is equal to the casing radius. The degree to which the assumptions are met is impossible to assess. To maintain consistency with the previous methods used to determine transmissivity and storage coefficient, the effective radius of the well, 1.33 feet, was used here.

Using the values for T, S, t, Q, and r_w of 300,000 gpd/ft, 0.0016, 2640 minutes, 1600 gpm, and 1.33 ft, respectively, the theoretical specific capacity of 146.2 gpm/ft with 11.0 feet of drawdown was computed. The well was pumping at 27% efficiency, determined by

$$\text{Well efficiency} = \frac{\text{Measured specific capacity}}{\text{Theoretical specific capacity}} \times 100$$

using the drawdown measurement of 40.22 ft at 2640 minutes to arrive at the measured specific capacity value of 40.0 gpm/ft.

The poor efficiency of the well is caused by turbulence in and around the well. The well is constructed of 16-inch diameter steel pipe with 166 feet of perforations in the form of 0.188 by 1.25 inch machine-cut slots. The annulus between the 32-inch borehole and the casing is gravel packed. Fine-grained materials have been pulled out of the formation by the process of well development so that the local transmissivity of the formation has been increased, but the small surface area of the casing which is open to accept water to the pump causes such high well losses that the well is not very efficient. Eventually, as the depth to water in the basin increases, this and

similarly constructed wells may become prohibitively expensive to run for irrigation uses. A more efficient design would include the use of commercially available well screen instead of slotted pipe. The cost of the screen would be offset by the decrease in pump lift and power bills.

Recovery Test

The recovery methods of Theis (1935) and Cooper and Jacobs (1946) were used to analyze recovery measurements obtained from well 4-1-9ca on June 20, 1979, after a pumping period of 52 minutes. The discharge rate was 12 gpm. Table 21 lists measurements obtained during the test. Because data points were limited, non-linear regression methods were used to determine the slope of the line representing recovery versus time. The Cooper and Jacob (1946) method yielded a T of 12,600 gpd/ft. The T from Theis' (1935) method was 7,900 gpd/ft. The transmissivity of the aquifer determined by this test was approximately 10,000 gpd/ft.

Table 18. Results of Aquifer Tests

Method	Well Number	Transmissivity (gpd/ft)	Storage Coefficient
Pumping Test of Well 4-1-10bcb			
Chow (1952)	4-1-10bbc	89,700	---
	4-1-9aac	307,000	0.0017
Cooper and Jacob (1946)	4-1-10bcb	165,000	---
	4-1-10bbc	304,500	---
	4-1-9aac	317,000	0.0015
Theis Recovery (1935)	4-1-10bcb	149,000	---
	4-1-9aac	278,000	---
Hantush (1956)	4-1-10bbc & 4-1-9aac	302,000	---
	4-1-9aac	---	0.0016
Recovery Test of Well 4-1-9ca			
Cooper and Jacob (1946)	4-1-9ca	12,600	---
Theis Recovery (1935)	do.	7,900	---

Remarks:

Well 4-1-10bcb pumped at approximately 1,600 gpm for 44 hours.

Recovery measured for 9 hours

Well 4-1-10bbc 186 feet from well 4-1-10bcb

Well 4-1-9aac 1,320 feet from well 4-1-10bcb

Well 4-1-9ca pumped for 52 minutes at 12 gpm. Recovery
measured for 49 minutes

Table 19. Pump Test Data From Well 4-1-10bcb

PUMPING WELL NUMBER: 4-1-10BCB
WELL RADIUS IN FEET = 1.33

PUMPING RATE IN GPM = 1609.

DRAWDOWN DATA:

TIME	WATER LEVEL (FEET)	TIME SINCE PUMPING BEGAN (MINUTES)	DRAWDOWN (FEET)
13. 1. 0	115.38		
13. 1.38	170.30	.6	54.92
13. 3.18	171.10	2.3	55.72
13. 5. 0	171.45	4.0	56.07
13. 6. 0	171.40	5.0	56.02
13. 8. 0	171.53	7.0	56.15
13.10.15	171.77	9.2	56.39
13.15.15	171.78	14.2	56.40
13.20.15	165.01	19.2	49.63
13.25. 0	155.85	24.0	40.47
13.30. 0	155.67	29.0	40.29
13.40.30	152.05	39.5	36.67
13.50. 0	152.05	49.0	36.67
14. 2. 0	151.65	61.0	36.27
14.17. 0	151.95	76.0	36.57
14.38. 0	152.26	97.0	36.88
15. 0. 0	152.65	119.0	37.27
15.37. 0	153.03	156.0	37.65
16.17. 0	153.28	196.0	37.90
17. 6. 0	153.57	245.0	38.19
18. 2. 0	153.81	301.0	38.43
19.17. 0	151.27	376.0	35.89
20. 3. 0	155.73	422.0	40.35
22. 5. 0	156.12	544.0	40.74
2. 3. 0	155.33	782.0	39.95
2.33. 0	155.27	812.0	39.89
3. 0. 0	155.28	839.0	39.90
5.30. 0	155.38	989.0	40.00
6. 1. 0	155.50	1020.0	40.12
6. 9. 0	155.39	1028.0	40.01
6.13. 0	153.34	1032.0	37.96
6.16. 0	152.28	1035.0	36.90
7.35. 0	158.96	1114.0	43.58
8.22. 0	155.51	1161.0	40.13
8.51. 0	155.52	1190.0	40.14
11.11. 0	155.82	1330.0	40.44
13.31. 0	156.00	1470.0	40.62
15. 1. 0	156.09	1560.0	40.71
17.21. 0	156.18	1700.0	40.80
20.13. 0	155.50	1872.0	40.12
20.21. 0	155.53	1880.0	40.15
20.41. 0	155.53	1900.0	40.15
23.31. 0	155.70	2070.0	40.32
0. 1. 0	155.71	2100.0	40.33
1.47. 0	155.66	2206.0	40.28
6. 5. 0	155.52	2464.0	40.14
7. 1. 0	155.51	2520.0	40.13
9. 1. 0	155.60	2640.0	40.22
9. 2.20	155.60	2641.3	40.22

Table 19. (continued)

RECOVERY DATA:

TIME	WATER LEVEL (FEET)	TIME SINCE PUMPING BEGAN (MINUTES)	TIME SINCE PUMPING CEASED (MINUTES)	RECOVERY (FEET)	RESID DD (FEET)	RATIO T/T'
9. 2.20	155.60	2641.3	.0	.00	40.22	.0
9. 4.35	145.85	2643.6	2.2	9.75	30.47	1174.9
9.18.30	121.34	2657.5	16.2	34.26	5.96	164.4
9.20.15	121.01	2659.2	17.9	34.59	5.63	148.4
9.22.33	120.77	2661.5	20.2	34.83	5.39	131.7
9.24.55	120.49	2663.9	22.6	35.11	5.11	118.0
9.25.40	120.44	2664.7	23.3	35.16	5.06	114.2
9.26.35	120.33	2665.6	24.2	35.27	4.95	109.9
9.27.29	120.27	2666.5	25.1	35.33	4.89	106.0
9.28.35	120.16	2667.6	26.2	35.44	4.78	101.6
9.30. 0	120.05	2669.0	27.7	35.55	4.67	96.5
9.30.15	119.95	2669.2	27.9	35.65	4.57	95.6
9.35.10	119.72	2674.2	32.8	35.88	4.34	81.4
9.39.15	119.51	2678.2	36.9	36.09	4.13	72.5
9.53.15	118.96	2692.2	50.9	36.64	3.58	52.9
10. 1.20	118.72	2700.3	59.0	36.88	3.34	45.8
10.11.20	118.46	2710.3	69.0	37.14	3.08	39.3
10.27.20	118.17	2726.3	85.0	37.43	2.79	32.1
11. 3.20	117.70	2762.3	121.0	37.90	2.32	22.8
11.35.20	117.39	2794.3	153.0	38.21	2.01	18.3
11.42.40	117.34	2801.7	160.3	38.26	1.96	17.5
12.34.20	117.00	2853.3	212.0	38.60	1.62	13.5
13.37.20	116.72	2916.3	275.0	38.88	1.34	10.6
15.23.20	116.37	3022.3	381.0	39.23	.99	7.9
18. 2. 0	116.04	3181.0	539.7	39.56	.66	5.9

Table 20. Pump Test Data From Wells 4-1-10bbc and 4-1-9aac

OBSERVATION WELL 4-1-10BBC 186 FEET FROM PUMPING WELL

OBSERVATION WELL NUMBER: 4-1-10BBC

PUMPING RATE IN GPM = 1609.

RADIAL DISTANCE FROM PUMPING WELL IN FEET = 186.0

DRAWDOWN DATA:

TIME	WATER LEVEL (FEET)	TIME SINCE PUMPING BEGAN (MINUTES)	DRAWDOWN (FEET)
13. 1. 0	109.14		
14.33. 0	109.14	92.0	.00
16.37. 0	109.16	216.0	.02
18. 1. 0	109.18	300.0	.03
20. 1. 0	109.21	420.0	.07
22. 1. 0	109.24	540.0	.10
0. 1. 0	109.30	660.0	.15
2. 1. 0	109.35	780.0	.21
4. 1. 0	109.41	900.0	.27
6. 1. 0	109.46	1020.0	.32
8. 1. 0	109.52	1140.0	.38
10. 1. 0	109.57	1260.0	.43
13. 1. 0	109.66	1440.0	.52
16. 1. 0	109.73	1620.0	.59
19. 1. 0	109.79	1800.0	.65
22. 1. 0	109.85	1980.0	.71
1. 1. 0	109.90	2160.0	.76
4. 1. 0	109.95	2340.0	.81
7. 1. 0	110.00	2520.0	.86
9. 1. 0	110.03	2640.0	.89

OBSERVATION WELL 4-1-9AAC 1320 FEET FROM PUMPING WELL

OBSERVATION WELL NUMBER: 4-1-9AAC

PUMPING RATE IN GPM = 1609.

RADIAL DISTANCE FROM PUMPING WELL IN FEET = 1320.0

DRAWDOWN DATA:

TIME	WATER LEVEL (FEET)	TIME SINCE PUMPING BEGAN (MINUTES)	DRAWDOWN (FEET)
13. 1. 0	131.00		
18.33. 0	132.23	332.0	1.23
18.38. 0	132.23	337.0	1.23
8.39. 0	133.01	1178.0	2.01
18. 1. 0	133.28	1740.0	2.28
6.43. 0	133.33	2502.0	2.33
9. 2.20	133.50	2641.3	2.50

RECOVERY DATA:

TIME	WATER LEVEL (FEET)	TIME SINCE PUMPING BEGAN (MINUTES)	TIME SINCE PUMPING CEASED (MINUTES)	RECOVERY (FEET)	RESID DD (FEET)	RATIO T/T'
9. 2.20	133.50	2641.3	.0	.00	2.50	.0
10.55. 0	132.01	2754.0	112.7	1.49	1.01	24.4
13. 1. 0	131.54	2880.0	238.7	1.96	.54	12.1
18.10. 0	131.06	3189.0	547.7	2.44	.06	5.8

Table 21. Recovery Test Data From Well 4-1-9ca, Pumping at 12 gpm

Time Since Pumping Started, t (min)	Time Since Pumping Ceased, t' (min)	t/t'	Water Level (ft)	Drawdown (ft)	Recovery (ft)	Residual Drawdown (ft)
0.0	---	---	176.74	0.00	---	---
50.5	---	---	181.45	4.71	---	---
52.2	0.25	209.0	180.35	---	1.10	3.61
53.5	1.50	35.7	177.21	---	4.24	0.47
64.0	12.00	5.3	176.75	---	4.70	0.02
101.0	49.00	2.1	176.74	---	4.71	0.00

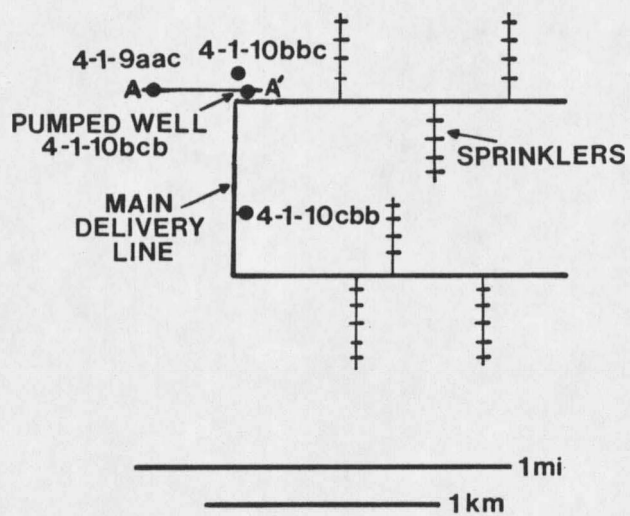


Figure 13. Location of Wells Used During Pumping Test

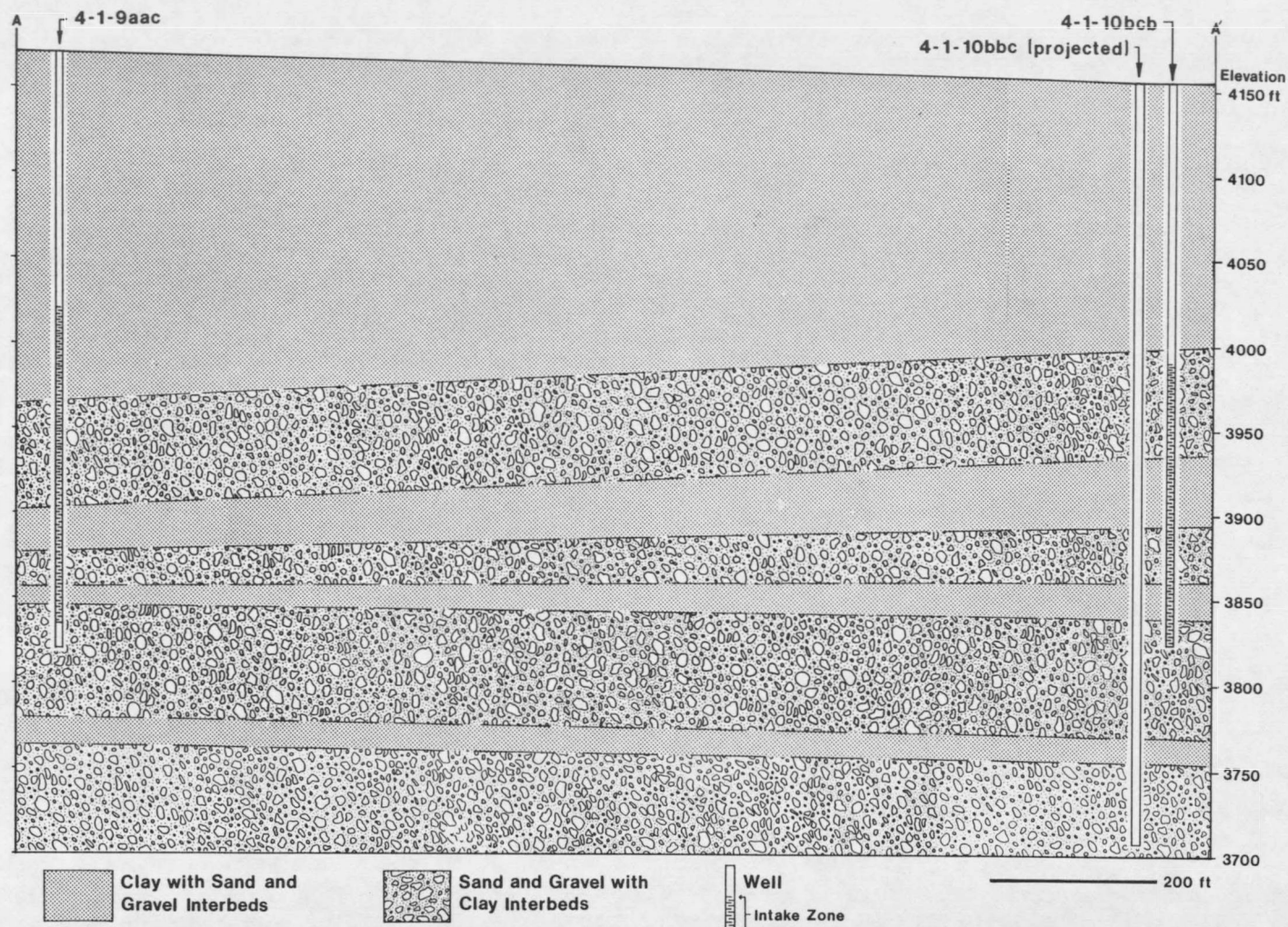


Figure 14. West-East Cross-Section Through Pumping Test Area

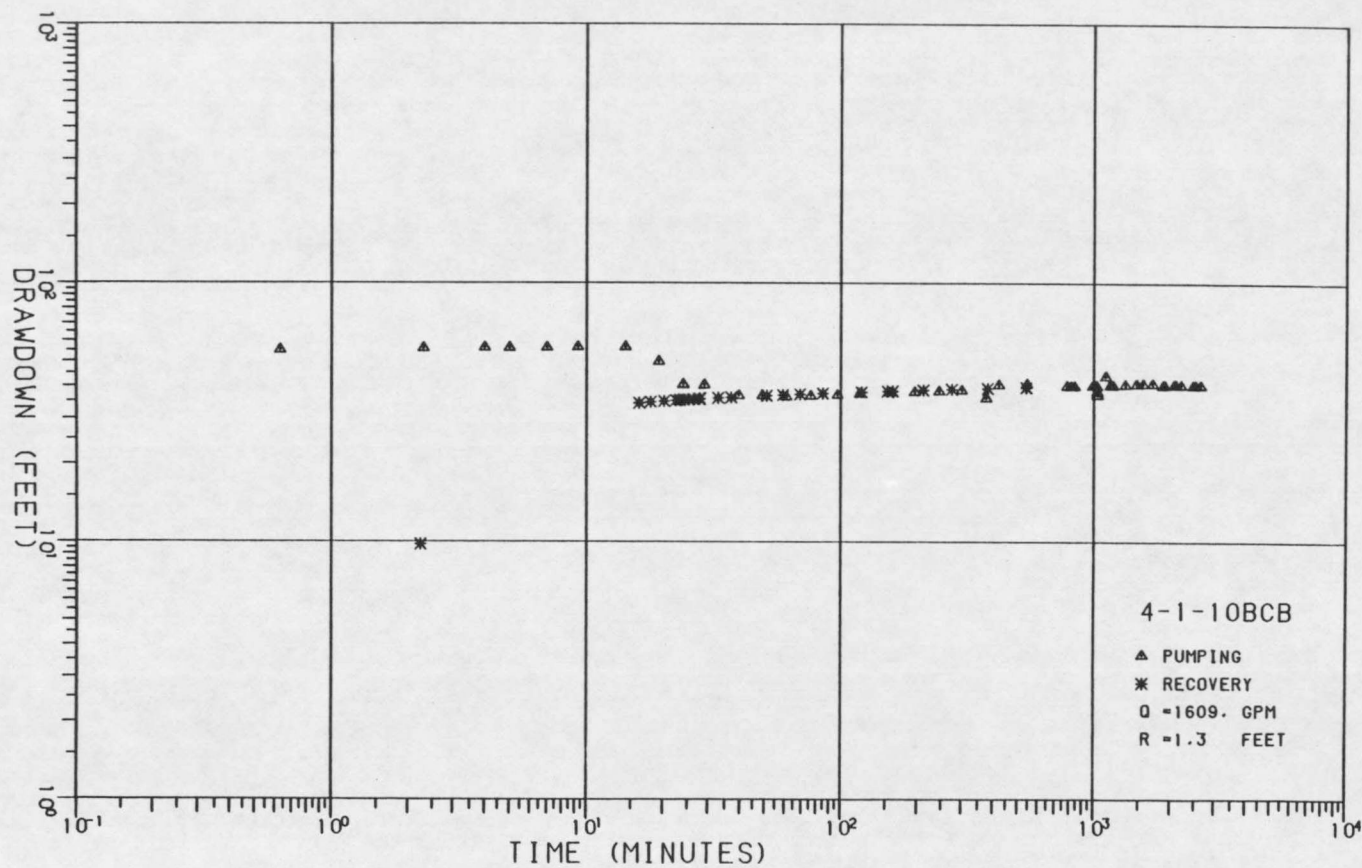


Figure 15. Log-Log Plot of Pumping and Recovery Data From Pumping Well 4-1-10bcb

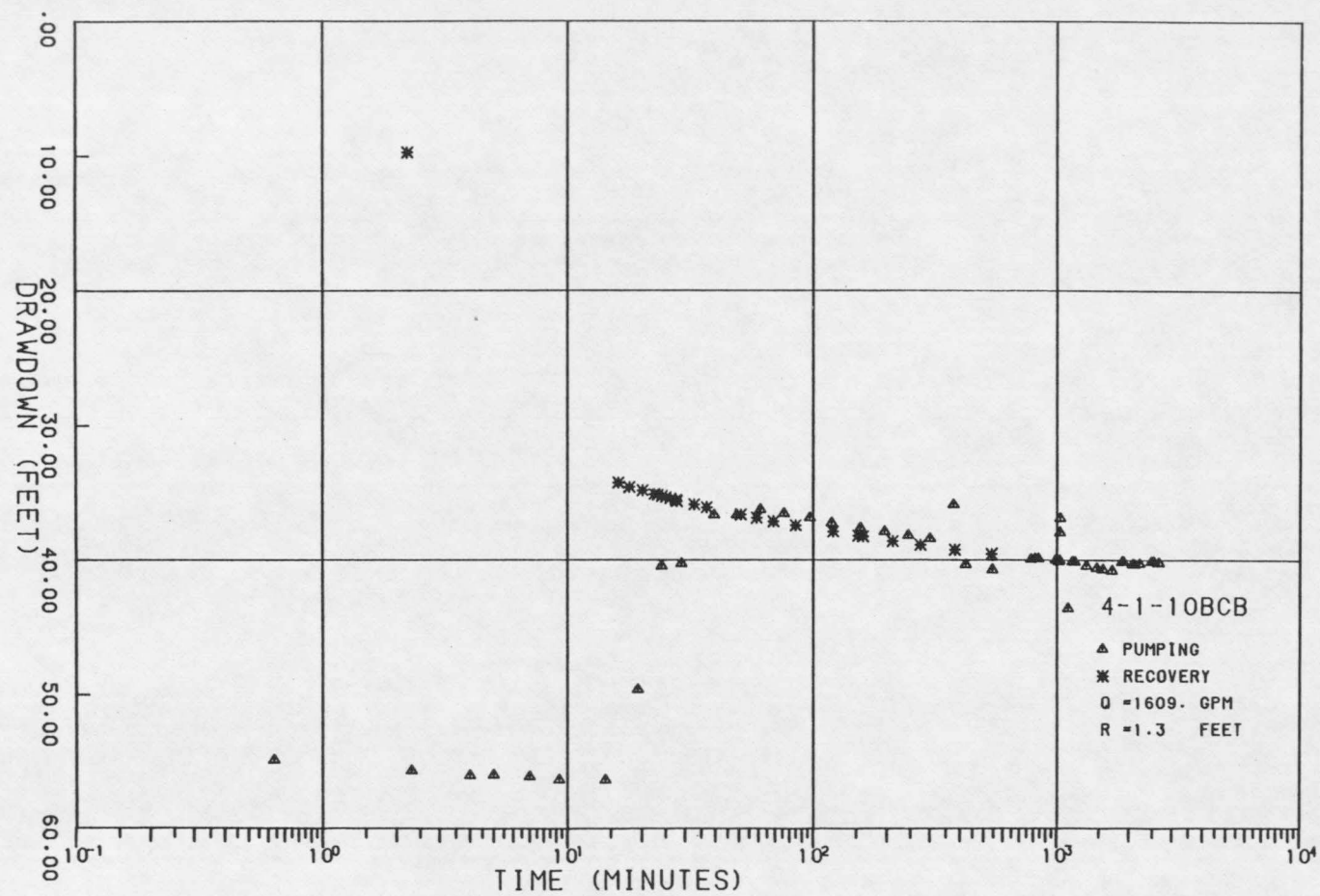


Figure 16. Semi-Log Plot of Pumping and Recovery Data From Pumping Well 4-1-10bcb

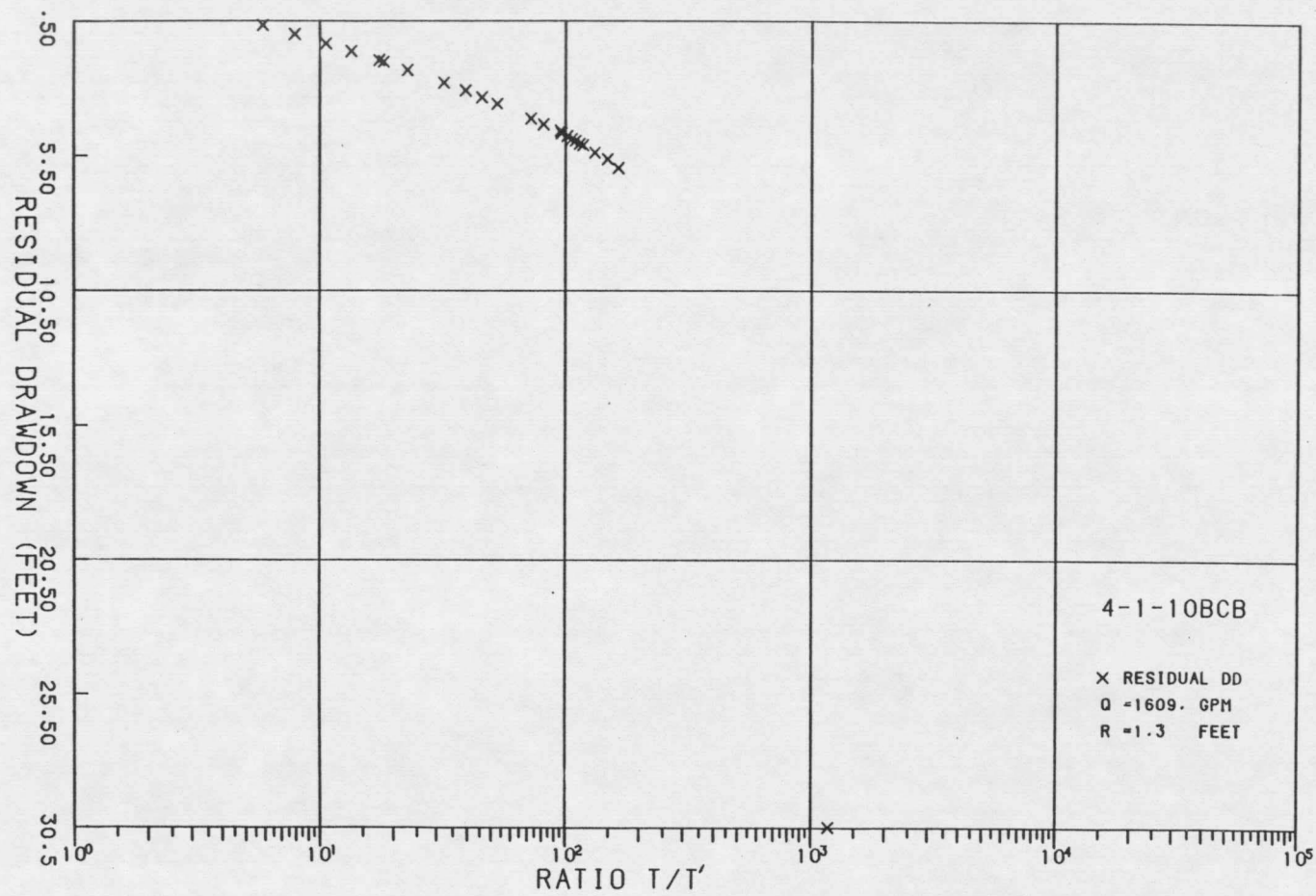


Figure 17. Plot of Residual Drawdown in Pumped Well 4-1-10bcb
After Pumping Ceased

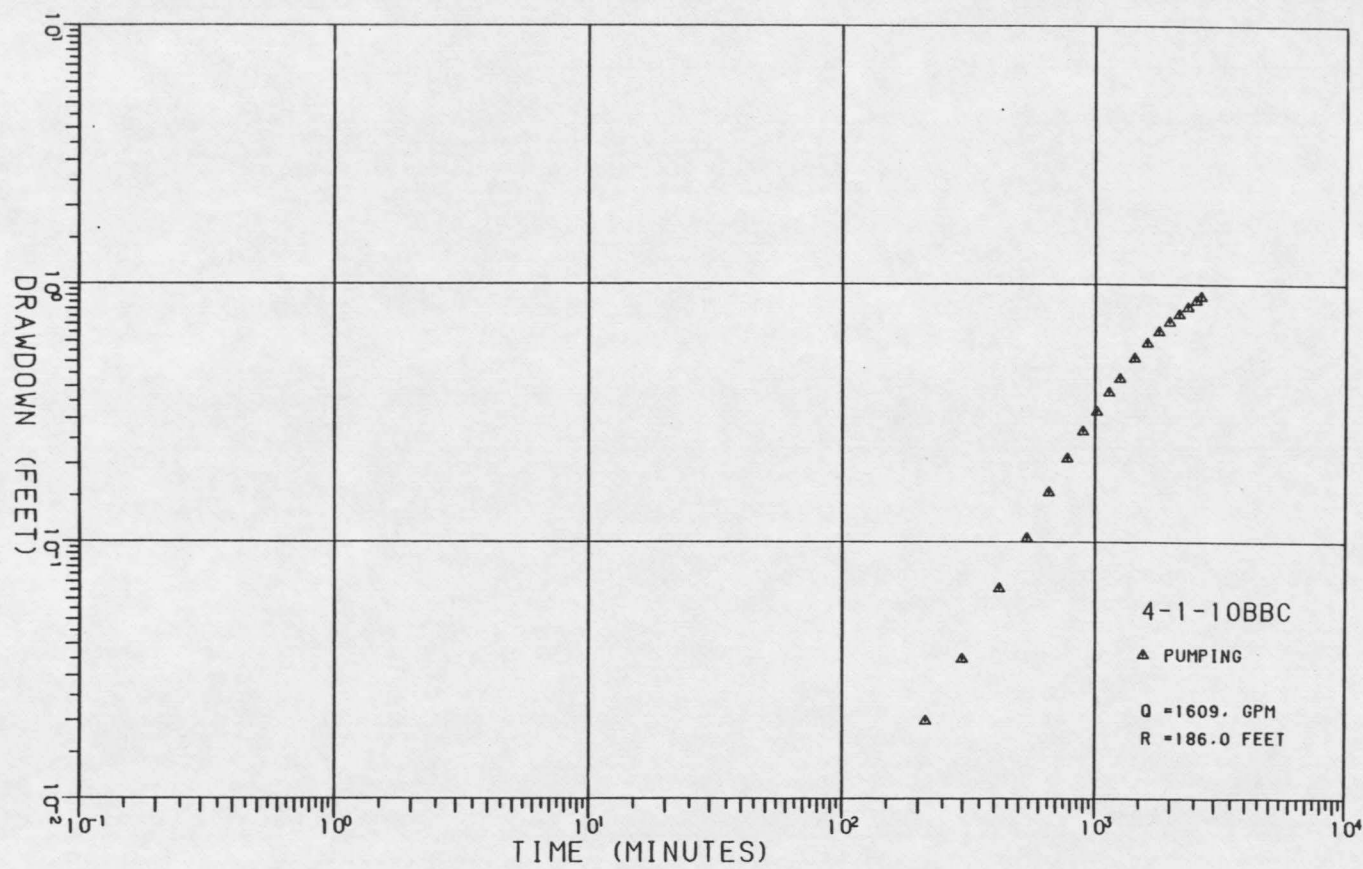


Figure 18. Log-Log Plot of Drawdown in Observation Well 4-1-10bbc, 186 Feet From Pumping Well

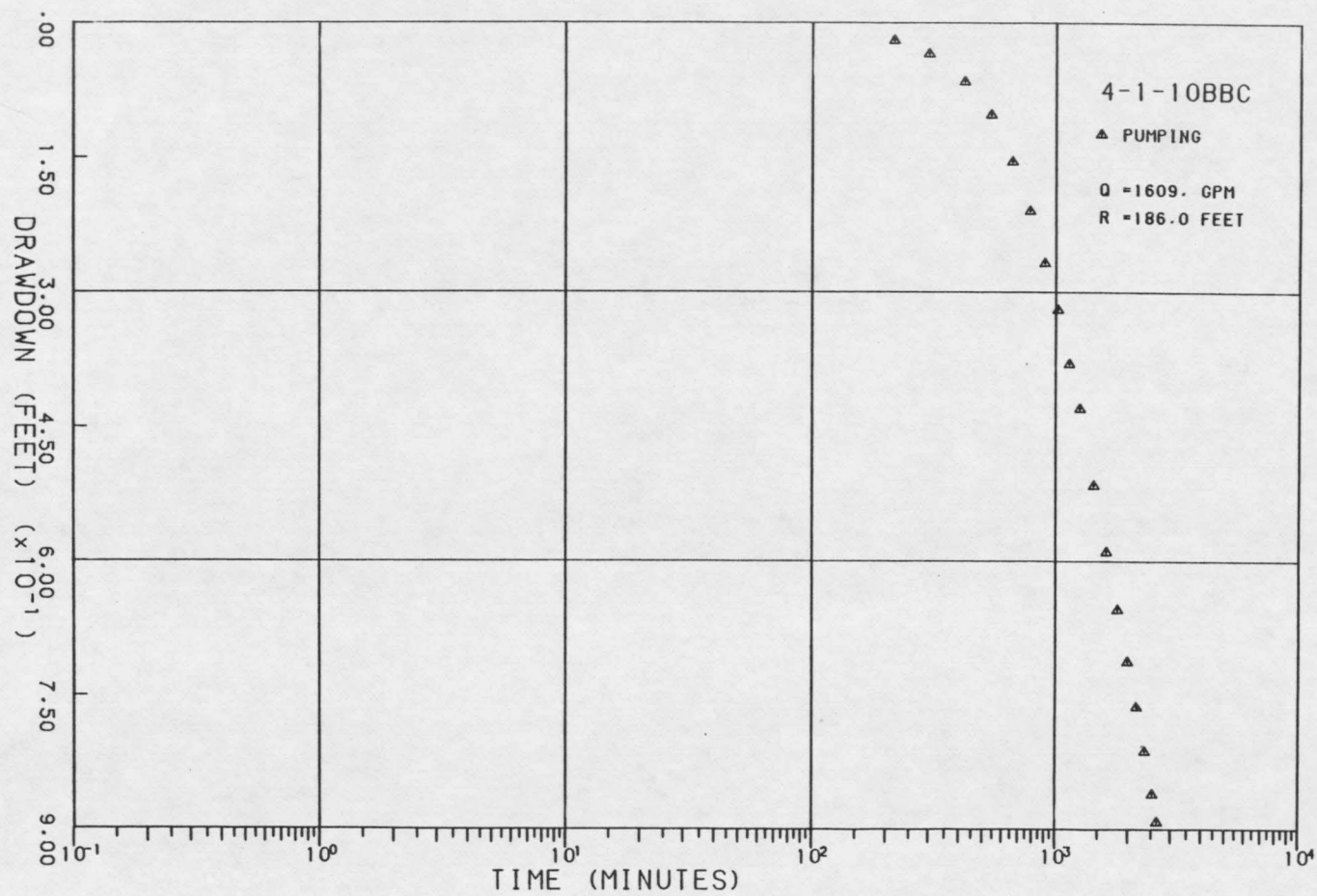


Figure 19. Semi-Log Plot of Drawdown in Observation Well 4-1-10bbc,
186 Feet From Pumping Well

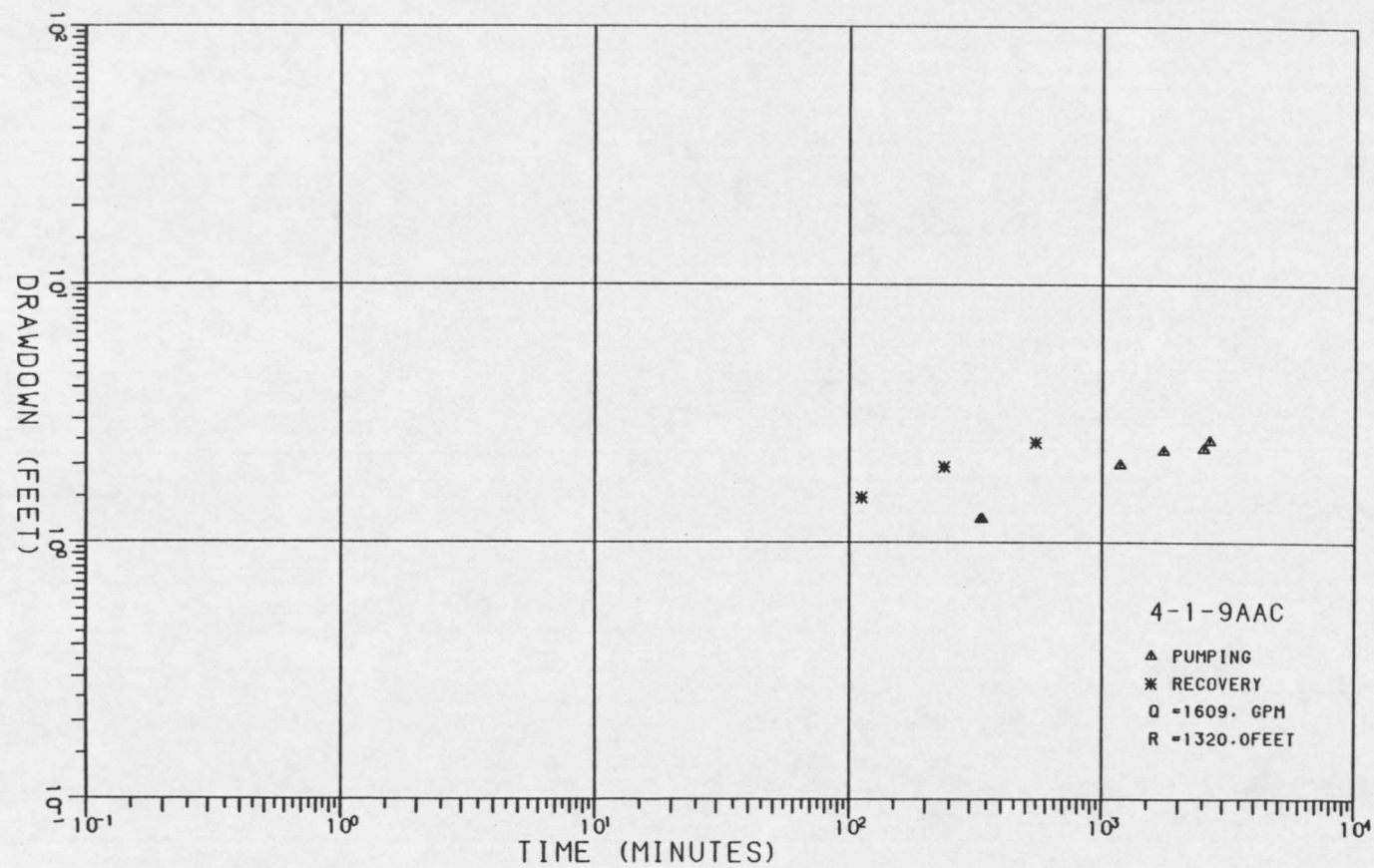


Figure 20. Log-Log Plot of Drawdown and Recovery in Observation Well 4-1-9aac, 1320 Feet From Pumping Well

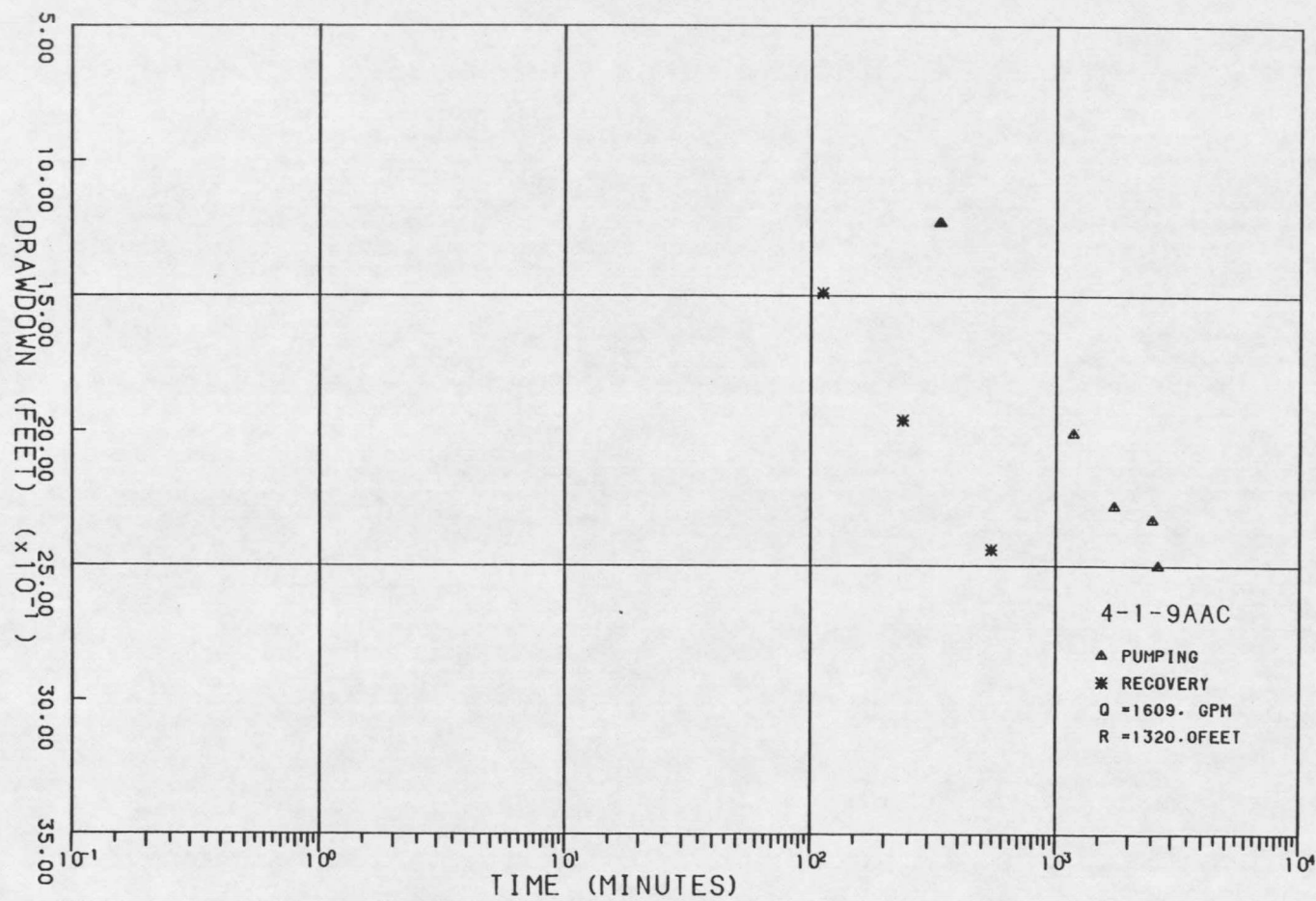


Figure 21. Semi-Log Plot of Drawdown and Recovery in Observation Well 4-1-9aac, 1320 Feet From Pumping Well

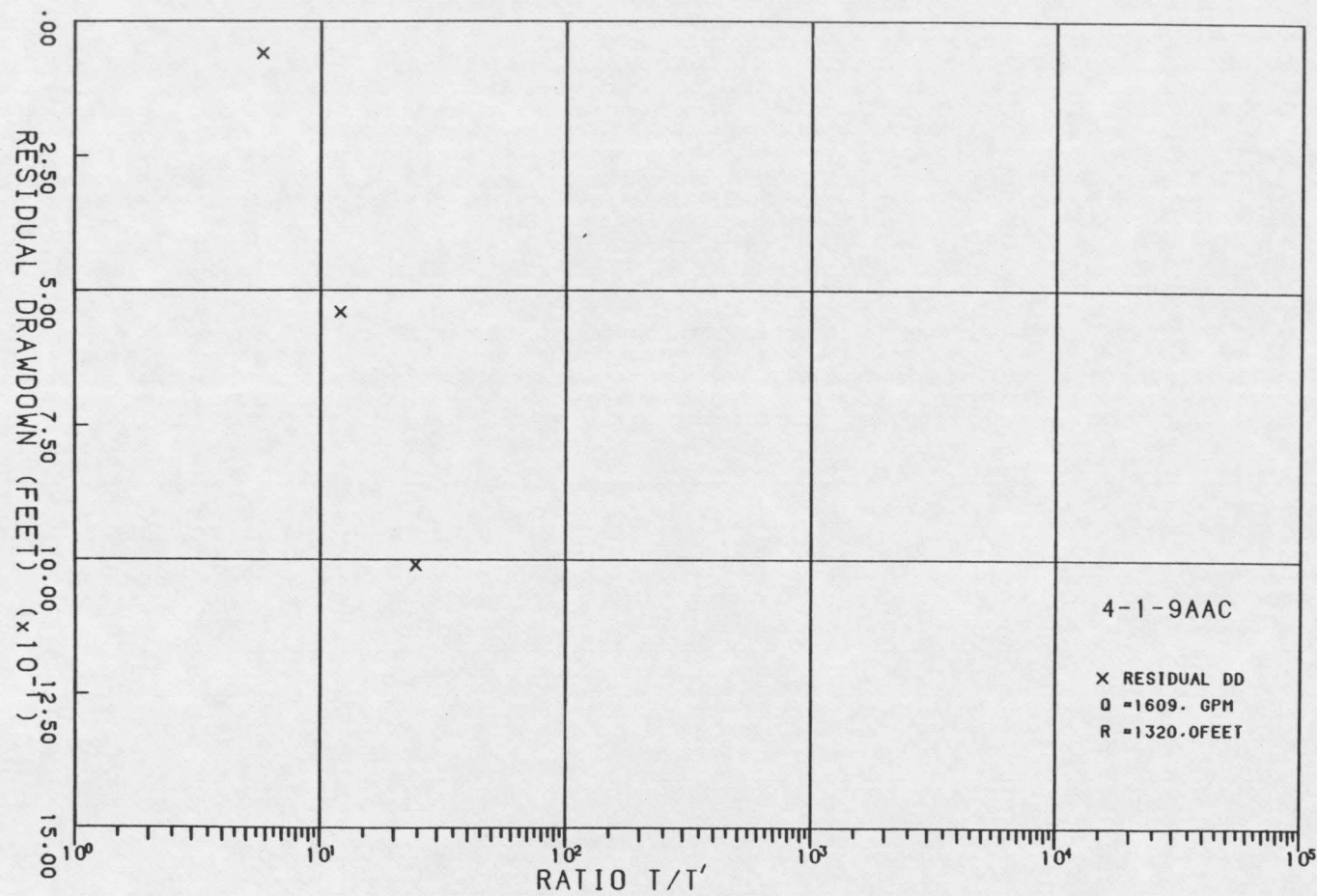


Figure 22. Plot of Residual Drawdown in Observation Well 4-1-9aac, 1320 Feet From Pumped Well After Pumping Ceased

APPENDIX C

WATER QUALITY

Introduction

Ground-water and surface-water samples were obtained in the Radersburg valley to detail differences in water which recharges the basin-fill aquifer. Tables 22, 23, and 24 report field and laboratory water-quality data for samples from wells, springs and Crow Creek, and from the aquifer test, respectively. Table 25 lists additional field specific conductance measurements.

Water-Quality Sampling

Twenty-nine water-quality samples were obtained from 24 sampling locations (Figure 23). Spring water was obtained from Plunket (or Mockel) Spring (4-1-27ada), Big Spring (4-3-6dad), Kimpton Spring (5-1-22dbb), and Hunsaker Spring (4-2-32dbd). Water obtained from Crow Creek near the Helena National Forest Boundary in the northeast quarter of section 26, T. 6N., R. 1 W. northwest of Radersburg provided a sample of surface water.

Wells were chosen for sampling on the basis of position and water temperature. Kimpton Spring is thought to flow from Tertiary or Quaternary sediments (Lorenz and McMurtrey, 1956; Pardee, 1925), and Plunket Spring flows from the Mississippian Madison Group. These springs are on a line trending approximately north-south. Wells

were sampled between these springs to determine if changes in water chemistry occur between these springs.

Wells were also sampled to determine if variations in chemistry exist from the topographically and hydraulically high part of the study area in the west, downgradient to the low area in the east.

Four samples were collected from well 4-1-10bcb during the pumping test to determine if significant changes in water chemistry occurred during the test. Concentrations of parameters in samples 26 through 29 (Table 24) generally varied by less than 15 percent. The nitrate concentrations of these samples tripled during the test, from 6.6 mg/l, 44 minutes after the test began, to 19.5 mg/l about 37 hours into the test. The cause of the nitrate increase is not known, but could be related to fertilizer pollution of recharge water.

Field Measurements

Field water quality measurements were taken and water samples were collected using procedures discussed in Wood (1976). Specific conductance (SC), pH, and temperature were measured in the field using a temperature-compensated Lab-Line Lectro Mho-Meter, an Orion 407 pH meter and gell-filled electrode calibrated with pH 4, 7, and 10 buffers prior to each use, and a Taylor mercury-filled thermometer, respectively.

Bicarbonate-ion content of each sample was determined by titration of 50 milliliters (ml) of sample to pH 4.5 endpoint using 0.01639N H_2SO_4 . Titration for bicarbonate ion content was done at the time of

collection for all samples except numbers 1, 10, 14, 15, 21, and 22, which were done within 24 hours of collection.

Two and one-half liters of water were collected in four sample bottles at each sampling site. One liter was of raw (unfiltered) water, one liter was vacuum filtered through a 0.45 micrometer Millipore ashless filter paper, 250 ml was filtered as above and preserved with 10 milligrams (mg) of HgCl_2 to stabilize nitrate, and 250 ml was filtered as above and acidified to pH 2 with HNO_3 to complex metal ions. The bottles were stored at room temperature until they were transported to the MBMG water quality laboratory.

Laboratory Analyses

Laboratory water-quality analyses were performed by the MBMG. This laboratory is routinely checked for analytical accuracy by the USGS.

In the accompanying tables, chemical analyses are reported in milligrams per liter (mg/l) and milliequivalents per liter (meq/l) where appropriate. An asterisk denotes that the amount of a constituent was below detection limits, less than 0.01 mg/l for iron or manganese and less than 0.02 mg/l for boron. Arsenic was only analyzed if ground water temperature was at least 15°C, at the request of the MBMG. Negative numbers in parentheses are exponents to base ten. Specific conductances are reported in micromhos per centimeter (umhos/cm) at 25°C. The sodium-adsorption ratio (SAR) is defined as:

$$\text{SAR} = \frac{(\text{Na}^+)}{\sqrt{\frac{(\text{Ca}^{+2}) + (\text{Mg}^{+2})}{2}}}$$

with ion concentrations expressed in meq/l. High values of the ratio imply that sodium may be replacing adsorbed calcium and magnesium on clays (Hem, 1970).

Table 22. Water-Quality Analyses From Wells

Sample Number	1		2		3		4		5	
Location	4-1-4adb		4-1-9cab		4-1-11bcc		4-1-12bad		4-1-15bcc	
Units	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l
Calcium (Ca^{+2})	279.0	13.92	44.4	2.22	68.6	3.42	59.4	2.96	81.8	4.08
Magnesium (Mg^{+2})	3.0	0.25	13.0	1.07	24.4	2.01	23.6	1.94	11.0	0.90
Sodium (Na^+)	129.0	5.61	58.0	2.52	58.2	2.53	40.7	1.77	98.4	4.28
Potassium (K^+)	5.5	0.14	4.9	0.13	3.6	0.09	2.7	0.07	3.8	0.10
Bicarbonate (HCO_3^-)										
Field	28.0	0.46	206.0	3.38	203.3	3.33	250.6	4.11	138.2	2.27
Laboratory	30.7	0.50	206.0	3.38	180.0	3.11	249.0	4.08	138.0	2.26
Chloride (Cl^-)	59.2	1.67	20.1	0.57	30.5	0.86	10.5	0.30	41.3	1.16
Sulfate (SO_4^{-2})	850.0	17.70	86.0	1.79	178.0	3.71	103.0	2.14	282.0	5.87
Nitrate (NO_3^-)	1.1	0.02	7.35	0.12	14.2	0.23	4.15	0.07	6.1	0.10
Fluoride (F^-)	1.2	0.06	0.5	0.03	0.6	0.03	0.58	0.03	1.04	0.05
Iron (Fe^{+3})	0.034	0.002	0.028	0.002	*		*		*	
Manganese (Mn^{+2})	0.012	0.001	0.012	0.001	*		*		*	
Boron (B)	0.38		0.11		0.14		0.16		0.22	
Lithium (Li^+)	0.07	0.01	0.017	0.002	0.027	0.004	0.028	0.004	0.02	0.003
Strontium (Sr^{+2})	2.4	0.055	0.94	0.021	1.18	0.027	0.55	0.013	1.22	0.028
Arsenic (As)	1.3(-4)		--		--		--		--	
Silica (SiO_2)	31.9		56.8		42.0		28.0		43.9	
pH, Field	8.21		7.75		7.89		7.66		7.71	
Laboratory	7.05		7.93		8.53		7.92		7.74	
Field Temperature, $^{\circ}\text{C}$	18.0		13.5		11.5		7.0		13.5	
SC, $\mu\text{mhos/cm}$ @ 25°C	2540		795		761		588		641	
TDS, mg/l	1391		498		625		524		709	
Sodium Adsorption Ratio	2.11		1.97		1.54		1.13		2.71	
Date of Collection	6-29-79		6-20-79		7-9-79		9-15-79		7-24-79	

Table 22. (continued)

Sample Number	6		7		8		9		10	
Location	4-1-15cdb		4-1-19ddd		4-1-23bac		4-1-23bbb3		4-2-16aaa	
Units	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l
Calcium (Ca^{+2})	94.8	4.73	45.8	2.29	58.1	2.90	55.1	2.75	41.6	2.08
Magnesium (Mg^{+2})	20.5	1.69	5.1	0.42	27.6	2.27	21.7	1.79	12.1	1.00
Sodium (Na^{+})	92.0	4.00	103.6	4.51	26.9	1.17	25.0	1.09	60.4	2.63
Potassium (K^{+})	3.4	0.04	3.4	0.09	3.0	0.08	2.3	0.06	5.4	0.14
Bicarbonate (HCO_3^{-})										
Field	162.0	2.66	277.8	4.55	210.3	3.44	190.4	3.12	189.4	3.10
Laboratory	151.0	2.47	277.0	4.54	209.0	3.43	190.0	3.11	190.0	3.11
Chloride (Cl^{-})	38.2	1.08	33.5	0.94	11.4	0.32	11.0	0.31	28.5	0.80
Sulfate (SO_4^{-2})	323.0	6.72	86.0	1.79	127.0	2.64	96.4	2.01	82.0	1.71
Nitrate (NO_3^{-})	3.18	0.05	4.0	0.06	4.7	0.08	4.30	0.07	11.8	0.19
Fluoride (F^{-})	0.96	0.05	0.64	0.03	0.61	0.03	0.60	0.03	1.0	0.05
Iron (Fe^{+3})	*		0.028	0.002	*		*		*	
Manganese (Mn^{+2})	*		0.032	0.001	*		*		*	
Boron (B)	0.19		0.17		0.14		0.10		0.23	
Lithium (Li^{+})	0.032	0.005	0.025	0.004	0.031	0.004	0.026	0.004	0.025	0.004
Strontium (Sr^{+2})	1.33	0.03	0.63	0.014	0.61	0.014	0.48	0.011	0.38	0.009
Arsenic (As)	--		--		--		--		--	
Silica (SiO_2)	28.0		42.6		20.8		22.8		24.8	
pH, Field	7.71		7.81		7.43		7.64		7.76	
Laboratory	7.90		8.04		8.11		7.84		7.93	
Field Temperature, $^{\circ}\text{C}$	13.0		10.5		12.4		10.5		12.5	
SC, $\mu\text{mhos/cm}$ @ 25°C	909		505		572		583		830	
TDS, mg/l	768		603		491		430		458	
Sodium Adsorption Ratio	2.23		3.88		0.73		0.72		2.12	
Date of Collection	6-29-79		7-24-79		6-28-79		6-28-79		6-29-79	

Table 22. (continued)

Sample Number	11		12		13		14		15	
Location	4-2-18aca		5-1-22bba		5-1-24bdd		5-1-27acb		5-1-28bac	
Units	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l
Calcium (Ca ⁺²)	21.6	1.08	19.0	0.95	41.0	2.05	70.0	3.49	75.2	3.75
Magnesium (Mg ⁺²)	12.5	1.03	4.8	0.39	5.6	0.46	11.0	0.90	14.0	1.15
Sodium (Na ⁺)	44.4	1.93	4.7	0.20	5.9	0.26	17.5	0.76	27.4	1.19
Potassium (K ⁺)	2.5	0.06	0.85	0.02	1.1	0.03	1.3	0.03	2.6	0.07
Bicarbonate (HCO ₃ ⁻)										
Field	182.0	2.98	84.9	1.47	138.7	2.27	182.6	2.99	250.6	4.11
Laboratory	179.0	2.93	75.6	1.24	139.0	2.28	181.3	2.97	185.0	3.03
Chloride (Cl ⁻)	9.6	0.27	0.8	0.02	1.7	0.05	35.6	1.00	8.7	0.25
Sulfate (SO ₄ ⁻²)	34.1	0.71	14.5	0.30	17.0	0.35	49.0	1.02	128.0	2.66
Nitrate (NO ₃ ⁻)	1.57	0.03	0.08	0.001	1.38	0.02	4.4	0.07	2.66	0.04
Fluoride (F ⁻)	1.5	0.08	0.11	0.01	0.10	0.01	0.10	0.01	0.20	0.01
Iron (Fe ⁺³)	0.013	0.001	0.77	0.04	0.013	0.001	*	*	*	*
Manganese (Mn ⁺²)	*	*	0.29	0.01	*	*	*	*	*	*
Boron (B)	0.18		*		0.05		*		0.12	
Lithium (Li ⁺)	0.025	0.004	0.005	0.001	0.012	0.002	0.005	0.001	0.01	0.001
Strontium (Sr ⁺²)	0.27	0.006	0.14	0.003	0.18	0.004	0.32	0.007	0.42	0.010
Arsenic (As)	--		--		--		--		1.2(-3)	
Silica (SiO ₂)	29.9		1.3		19.2		21.9		32.0	
pH, Field	8.17		7.65		7.80		7.70		7.64	
Laboratory	8.21		7.51		8.00		7.70		7.97	
Field Temperature, °C	15.0		12.0		9.5		10.5		16.0	
SC, µmhos/cm @ 25°C	405		135		255		652		538	
TDS, mg/l	340		132		232		394		542	
Sodium Adsorption Ratio	1.88		0.25		0.23		0.51		0.76	
Date of Collection	6-12-79		6-16-79		6-17-79		6-28-79		10-13-79	

Table 22. (continued)

Sample Number Location	16		17		18	
	5-2-31dcc		5-2-33dab		5-2-35dab	
Units	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l
Calcium (Ca^{+2})	63.1	3.15	56.8	2.83	47.5	2.37
Magnesium (Mg^{+2})	25.3	2.08	30.3	2.49	13.8	1.14
Sodium (Na^{+})	51.2	2.23	58.7	2.55	30.7	1.34
Potassium (K^{+})	3.5	0.09	3.9	0.10	3.9	0.01
Bicarbonate (HCO_3^{-})						
Field	175.0	2.87	222.0	3.62	172.5	2.83
Laboratory	176.0	2.88	221.0	3.62	171.0	2.80
Chloride (Cl^{-})	46.1	1.30	29.4	0.83	20.1	0.57
Sulfate (SO_4^{-2})	167.0	3.48	160.0	3.33	64.5	1.34
Nitrate (NO_3^{-})	6.90	0.11	18.8	0.30	3.1	0.05
Fluoride (F^{-})	0.70	0.04	0.8	0.04	0.8	0.04
Iron (Fe^{+3})	*		*		*	
Manganese (Mn^{+2})	*		*		*	
Boron (B)	0.20		0.24		0.15	
Lithium (Li^{+})	0.03	0.004	0.04	0.006	0.034	0.005
Strontium (Sr^{+2})	0.69	0.016	0.68	0.016	0.34	0.008
Arsenic (As)	--		--		--	
Silica (SiO_2)	23.3		28.6		20.7	
pH, Field	7.85		7.91		7.68	
Laboratory	7.76		8.21		7.70	
Field Temperature, $^{\circ}\text{C}$	11.0		12.0		12.5	
SC, $\mu\text{mhos/cm @ } 25^{\circ}\text{C}$	659		1359		437	
TDS, mg/l	563		610		378	
Sodium Adsorption Ratio			1.56		1.01	
Date of Collection	11-2-79		11-2-79		9-12-79	

Table 23. Results of Water-Quality Analyses From Plunket Spring (19,20), Hunsaker Spring (21), Big Spring (22), Kimpton Spring (23,24), and Crow Creek (25)

Sample Number	19		20		21		22	
Location	Plunket Spring (4-1-27ada)				4-2-32dbd		4-3-6dad	
Units	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l
Calcium (Ca ⁺²)	38.5	1.92	48.0	2.40	71.2	3.55	48.7	2.43
Magnesium (Mg ⁺²)	23.5	1.93	23.0	1.89	18.8	1.55	20.2	1.66
Sodium (Na ⁺)	22.4	0.97	22.7	0.99	22.3	0.97	13.6	0.59
Potassium (K ⁺)	2.4	0.06	2.7	0.07	11.4	0.29	3.6	0.09
Bicarbonate (HCO ₃ ⁻)								
Field	188.0	3.08	184.6	3.03	332.0	5.44	192.5	3.16
Laboratory	159.0	2.61	183.0	3.00	325.0	5.33	193.0	3.16
Chloride (Cl ⁻)	9.0	0.25	8.9	0.25	11.0	0.31	6.8	0.19
Sulfate (SO ₄ ⁻²)	87.0	1.81	86.9	1.81	30.0	0.62	56.6	1.18
Nitrate (NO ₃ ⁻)	3.0	0.05	3.1	0.05	0.16	0.003	1.7	0.03
Fluoride (F ⁻)	0.7	0.04	0.7	0.04	0.75	0.04	0.70	0.04
Iron (Fe ⁺³)	*		*		0.59		*	
Manganese (Mn ⁺²)	*		*		0.20		*	
Boron (B)	0.11		0.12		0.10		0.12	
Lithium (Li ⁺)	0.032	0.005	0.020	0.003	0.019	0.003	0.047	0.007
Strontium (Sr ⁺²)	0.45	0.010	0.44	0.010	0.30	0.007	0.35	0.008
Arsenic (As)	1.7(-3)		1.4(-3)		3.4(-3)		--	
Silica (SiO ₂)	15.5		14.1		23.3		19.8	
pH, Field	7.93		7.78		6.90		7.51	
Laboratory	8.64		8.48		7.78		8.00	
Field Temperature, °C	17.0		17.0		24.5		15.5	
SC, µmhos/cm @ 25°C	490		498		571		781	
TDS, mg/l	391		395		522		365	
Sodium Adsorption Ratio	0.70		0.67		0.61		0.41	
Date of Collection	7-17-79		11-10-79		6-26-79		6-29-79	

Table 23. (continued)

Sample Number	23		24		25	
Location	Kimpton Spring (5-1-22dbc)				Crow Creek	
Units	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l
Calcium (Ca ⁺²)	25.8	1.29	26.5	1.32	14.3	0.7
Magnesium (Mg ⁺²)	7.2	0.59	7.1	0.58	3.3	0.27
Sodium (Na ⁺)	5.3	0.23	5.1	0.22	3.5	0.15
Potassium (K ⁺)	0.84	0.02	1.1	0.03	1.6	0.04
Bicarbonate (HCO ₃ ⁻)						
Field	102.8	1.68	102.5	1.68	56.3	0.92
Laboratory	101.0	1.66	104.0	1.70	30.2	0.49
Chloride (Cl ⁻)	1.8	0.05	1.7	0.05	0.6	0.02
Sulfate (SO ₄ ⁻²)	16.4	0.34	16.7	0.35	10.6	0.22
Nitrate (NO ₃ ⁻)	0.99	0.02	0.89	0.01	0.06	0.001
Fluoride (F ⁻)	0.20	0.01	0.20	0.01	1.0	0.05
Iron (Fe ⁺³)	*		*		0.05	
Manganese (Mn ⁺²)	*		*		0.01	
Boron (B)	*		0.06		0.02	
Lithium (Li ⁺)	0.005	0.001	0.03	0.004	0.007	0.001
Strontium (Sr ⁺²)	0.15	0.003	0.15	0.003	0.10	0.002
Arsenic (As)	9.0(-4)		7.0(-4)		--	
Silica (SiO ₂)	17.1		15.4		15.5	
pH, Field	8.07		8.04		8.05	
Laboratory	8.43		7.51		9.50	
Field Temperature, °C	18.0		17.8		17.0	
SC, μmhos/cm @ 25°C	195		182		123	
TDS, mg/l	179		178		107	
Sodium Adsorption Ratio	0.24		0.23		0.22	
Date of Collection	6-16-79		11-10-79		7-9-79	

Table 24. Water-Quality Analyses From Samples Collected During the Pumping Test of Well 4-1-10bcb

Sample Number	26		27		28		29		30	
Minutes after start of aquifer test	44		484		1361		2189		Average	
Units	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l
Calcium (Ca ⁺²)	56.5	2.82	53.8	2.68	52.3	2.61	51.8	2.58	53.6	2.67
Magnesium (Mg ⁺²)	16.8	1.38	18.5	1.52	19.0	1.56	19.4	1.60	18.4	1.52
Sodium (Na ⁺)	57.4	2.50	55.7	2.42	54.7	2.38	54.7	2.38	55.6	2.42
Potassium (K ⁺)	5.3	0.14	4.7	0.12	4.7	0.12	4.6	0.12	4.8	0.13
Bicarbonate (HCO ₃ ⁻)										
Field	196.8	3.23	193.6	3.17	193.6	3.17	191.0	3.13	193.6	3.17
Laboratory	198.0	3.25	194.0	3.18	196.0	3.21	195.0	3.20	195.8	3.21
Chloride (Cl ⁻)	21.7	0.61	21.7	0.61	19.7	0.56	20.3	0.57	20.9	0.59
Sulfate (SO ₄ ⁻²)	142.0	2.96	133.0	2.77	136.0	2.83	132.0	2.75	135.8	2.83
Nitrate (NO ₃ ⁻)	6.6	0.11	12.0	0.19	18.1	0.29	19.5	0.31	14.1	0.23
Fluoride (F ⁻)	0.5	0.03	0.5	0.03	0.5	0.03	0.5	0.03	0.5	0.03
Boron (B)	0.19		0.18		0.18		0.18		0.18	
Lithium (Li ⁺)	0.02	0.003	0.02	0.003	0.02	0.003	0.02	0.003	0.02	0.003
Strontium (Sr ⁺²)	1.13	0.026	1.13	0.026	1.13	0.026	1.14	0.026	1.13	0.026
Arsenic (As)	5.2(-3)		6.0(-3)		--		--			
Silica (SiO ₂)	50.7		48.4		47.8		47.3		48.6	
pH, Field	7.70		7.69		7.65		7.45		7.63	
Laboratory	7.80		7.86		8.02		7.69		7.84	
SC, μ mhos/cm @ 25°C	725		662		656		656		675	
TDS, mg/l	550		533		535		530		537	
Field Temperature, °C	15.5		15.0		14.0		13.5		14.5	
Sodium Adsorption Ratio	1.72		1.67		1.65		1.65		1.67	
Date of collection	5-2-80		5-2-80		5-3-80		5-4-80			

Table 25. Additional Temperature and Specific Conductance Measurements

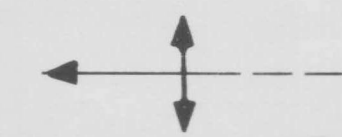
Site	Temperature °C	Specific Conductance μmhos/cm @ 25°C	Date
Plunket Spring	16.0	---	5-26-79
	16.5	---	8-15-79
	16.5	455	9-14-79
	16.5	---	10-13-79
Wells			
4-1-1abc(S)	8.5	1880	6-29-79
4-1-1cd(S)	9.5	520	8-17-79
4-1-2bbb(I)	11.5	1420	6-29-79
4-1-3dbb(I)	15.0	830	8-17-79
4-1-4adb(I)	22.5	900	7-24-79
4-1-9aac(I)	15.0	590	6-29-79
4-1-12acc(I)	11.9	610	8-17-79
4-1-12ad(S)	9.2	780	8-17-79
4-1-12bad(S)	5.5	590	8-12-79
4-1-15cdb(I)	12.5	967	6-20-79
	13.5	641	7-24-79
4-1-23bac(I)	12.0	---	7-17-79
4-1-31a(S)	9.5	665	7-24-79
5-1-24dbc(S)	8.0	263	7-12-79
5-1-26ccb(I)	11.0	345	7-12-79
5-1-27acb(I)	11.0	399	7-24-79
5-1-27bbc(I)	10.0	752	6-29-79
5-1-27ccb(I)	10.0	300	8-17-79
5-1-27cda(I)	10.0	400	8-17-79
5-1-33cbb(S)	12.0	485	7-12-79
5-2-31dc (D)	12.0	650	8-16-79

GENERALIZED GEOLOGIC MAP OF THE
RADERSBURG DRAINAGE BASIN AND VICINITY
BROADWATER AND JEFFERSON COUNTIES, MONTANA

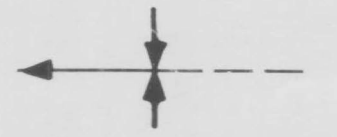
BY
GLEN M. WYATT
1984

EXPLANATION

- QTs UNDIFFERENTIATED QUATERNARY AND TERTIARY SEDIMENTARY ROCKS AND SEDIMENTS
- TKi TERTIARY TO CRETACEOUS INTRUSIVE ROCKS
- Kv CRETACEOUS VOLCANIC ROCKS
- KMs CRETACEOUS TO MISSISSIPPIAN SEDIMENTARY ROCKS ABOVE THE MADISON GROUP
- Mm MISSISSIPPIAN MADISON GROUP LIMESTONE
- Dcs DEVONIAN TO CAMBRIAN SEDIMENTARY ROCKS
- d PRECAMBRIAN BELT SUPERGROUP SEDIMENTARY ROCKS, INCLUDES DIABASE SILL



ANTICLINE, SHOWING DIRECTION OF PLUNGE
DASHED WHERE CONCEALED
DFD: DEVILS FENCE DOME
LHA: LIMESTONE HILLS ANTICLINE
HHA: HOSSFELDT HILLS ANTICLINE



SYNCLINE, SHOWING DIRECTION OF PLUNGE
DASHED WHERE CONCEALED
EMS: ELKHORN MOUNTAINS SYNCLINE
RS: RADERSBURG SYNCLINE



OVERTURNED ANTICLINE
DASHED WHERE CONCEALED



OVERTURNED SYNCLINE
DASHED WHERE CONCEALED

CONTACT
DASHED WHERE CONCEALED

FAULT
DASHED WHERE CONCEALED
U ON UPTHROWN SIDE
D ON DOWNTOWN SIDE
CCF: CROW CREEK FAULT

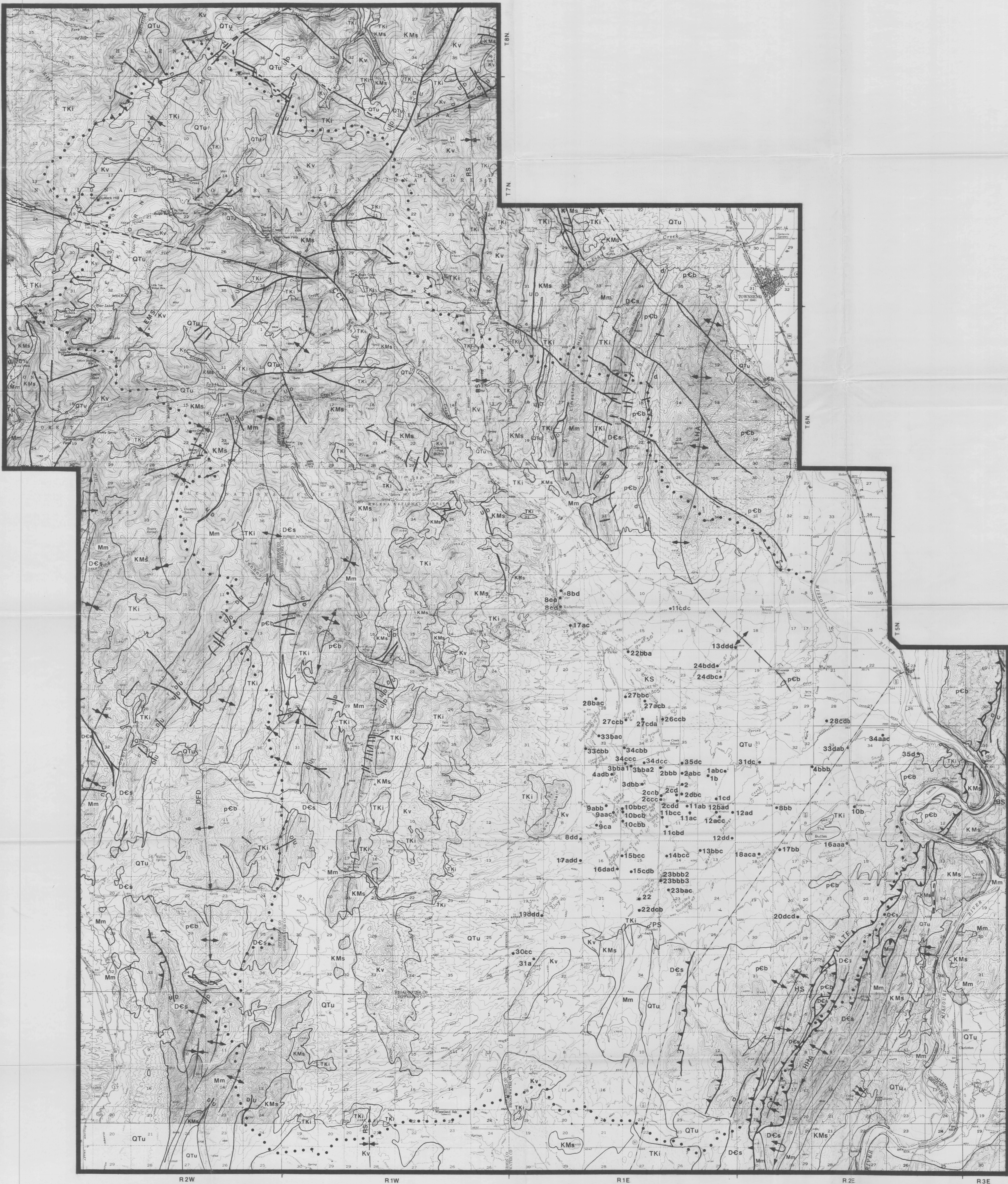
THRUST FAULT
TEETH ON UPPER PLATE
LTF: LOMBARD THRUST

OUTLINE OF RADERSBURG DRAINAGE BASIN

WELL

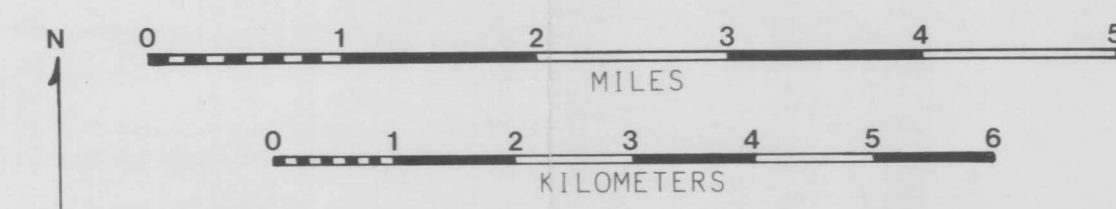
SPRING

PS: PLUNKET SPRING
KS: KIMPTON SPRING
HS: HUNSAKER SPRING
BS: BIG SPRING



BASE MAP COMPILED FROM USGS 15-MINUTE QUADRANGLES:

CLANDY (1950).
DEVILS FENCE (1950).
JEFFERSON ISLAND (1950).
MANHATTAN (1949).
RADERSBURG (1949).
THREE FORKS (1950).
TOSTON (1949). AND
TOWNSEND (1950).



CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL

GEOLOGY COMPILED FROM:

KLEPPER AND OTHERS (1957).
FREEMAN AND OTHERS (1958).
ROBINSON (1963, 1967).
DAVIS AND OTHERS (1965).
KINOSHITA AND OTHERS (1965).
SMEDES (1966). AND
KLEPPER AND OTHERS (1971).

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