

CHEMICAL CHARACTERISTICS, INCLUDING STABLE-ISOTOPE RATIOS, OF  
SURFACE WATER AND GROUND WATER FROM SELECTED SOURCES IN AND  
NEAR EAST FORK ARMELLS CREEK BASIN, SOUTHEASTERN MONTANA, 1985

by Rodger F. Ferreira, John H. Lambing, and Robert E. Davis

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CONVERSION FACTORS

The following factors can be used to convert inch-pound units to metric (International System) units.

<u>Multiply inch-pound unit</u>	<u>By</u>	<u>To obtain metric unit</u>
acre	4,047	square meter
cubic foot per second (ft <sup>3</sup> /s)	0.028317	cubic meter per second
foot (ft)	0.3048	meter
gallon per minute (gal/min)	3.785	liter per minute
inch (in.)	25.40	millimeter
mile (mi)	1.609	kilometer

Temperature can be converted to degrees Celsius (°C) or degrees Fahrenheit (°F) by the equations:

$$^{\circ}\text{C} = 5/9 (^{\circ}\text{F} - 32)$$

$$^{\circ}\text{F} = 9/5 (^{\circ}\text{C}) + 32$$

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929."

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ABSTRACT

Twenty-nine water samples were collected from surface-water and ground-water sites to provide synoptic chemical data, including stable-isotope ratios, for an area of active surface coal mining and to explore the effectiveness of using the data to chemically distinguish water from different aquifers. Surface-water samples were collected from one spring, four sites on East Fork Armells Creek, one site on Stocker Creek, and two fly-ash ponds. Streamflows in East Fork Armells Creek ranged from no flow in several upstream reaches to 2.11 cubic feet per second downstream from Colstrip, Montana. Only one tributary, Stocker Creek, was observed to contribute surface flow in the study area. Ground-water samples were collected from wells completed in either Quaternary alluvium or mine spoils, Rosebud overburden, Rosebud coal bed, McKay coal bed, and sub-McKay deposits of the Tongue River Member of the Paleocene Fort Union Formation.

Dissolved-solids concentration, in milligrams per liter, was 840 at the spring and ranged from 3,100 to 5,000 in the streams, 13,000 to 22,000 in the ash ponds, and 690 to 4,100 in the aquifers. With few exceptions, water from the sampled spring, streams, and wells had similar concentrations of major constituents and trace elements and had similar stable-isotope ratios. Water from the fly-ash ponds had larger concentrations of dissolved solids, boron, and manganese and were isotopically more enriched in deuterium and oxygen-18 than water from other sources.

Water from individual aquifers could not be distinguished by either ion-composition diagrams or statistical cluster analyses based on chemical and stable-isotope characteristics. Variability of water quality in samples from the same aquifer was equal to or greater than the variability between different aquifers.

INTRODUCTION

Development of coal resources in the Paleocene Fort Union Formation of the northern Great Plains has fostered several water-quality studies related to mining. These studies were designed to describe baseline conditions, delineate areas affected by mining, document water-quality changes at existing mines, and predict water-quality changes for potential mine areas.

Surface mining of coal involves removal of overburden and coal aquifers, followed by replacement of disturbed overburden (mine spoils) into the mine cut. Several studies have indicated that exposure of overburden to air and subsequent

contact with water after replacement can result in increased dissolved-constituent concentrations in water (Davis, 1984; Van Voast and others, 1978a,b). The degree of water-quality change depends on several factors including initial constituent composition of water entering the spoils, contact time of water with the spoils, mineralogy of the spoils and downgradient aquifers, contact time in downgradient aquifers, and degree of mixing with water derived from non-spoils sources. In addition to these physical and chemical factors, substantial water-quality changes can result from bacteriological activity in the spoils or receiving aquifers.

Because of the large number of factors that can affect the chemical composition of water downgradient from mined areas, identification of hydrochemical relations is difficult. The ability to uniquely identify water originating from specific aquifer sources would help in understanding the hydrology and geochemistry in areas affected by surface coal mining. Statistical cluster analyses of various chemical characteristics of water, including stable-isotope ratios, may provide a means to chemically distinguish ground-water sources.

### Purpose and Scope

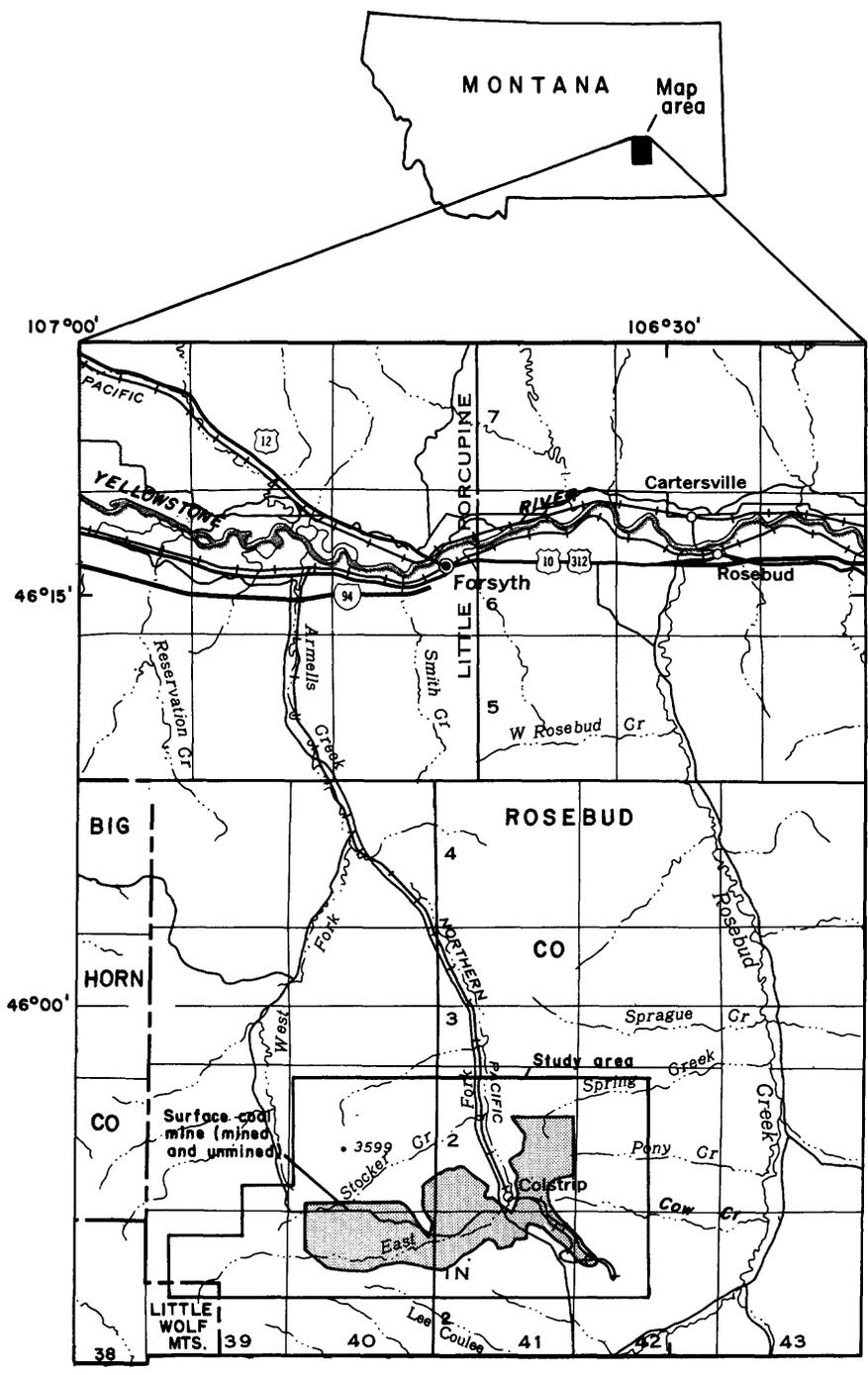
To help assess the usability of stable-isotope data, the U.S. Bureau of Land Management and the Montana Department of State Lands developed a cooperative study with the U.S. Geological Survey. The purpose of the study was to obtain synoptic chemical data, including stable-isotope ratios, for stream base flow and ground water from an area of active surface coal mining and to explore the effectiveness of using the data to chemically distinguish water from different aquifers. This report describes the data collected and the result of using the data to identify aquifers.

Data collection was conducted in and near the East Fork Armells Creek basin (fig. 1). Surface-water samples were collected from one spring, four sites on East Fork Armells Creek, and one site on Stocker Creek, a tributary to East Fork Armells Creek. In addition, surface samples were collected from two fly-ash ponds associated with a coal-fired electric-power generating plant. Ground-water samples were collected from 21 wells completed in Quaternary alluvium and the Tongue River Member of the Paleocene Fort Union Formation. Specific zones within the Tongue River Member from which samples were collected include mine spoils, Rosebud overburden, Rosebud coal bed, McKay coal bed, and sub-McKay deposits.

### Description of Study Area

#### Physical Setting

The study area (fig. 1) is located in Rosebud County in southeastern Montana and includes primarily the headwaters of East Fork Armells Creek, Stocker Creek, and parts of several tributaries to Rosebud Creek. A surface coal mine is entirely within the study area, near the town of Colstrip. The topography of the area is characterized by rolling hills of low to moderate relief. Altitudes range from about 3,120 ft above sea level at the most downstream reach of East Fork Armells Creek to about 4,750 ft in the Little Wolf Mountains to the southwest. Vegetation is primarily grasses in areas of flat and gently sloping terrain, with shrubs and coniferous trees growing on ridges and steep slopes. Average annual precipitation in the area is about 16 in. (U.S. Department of Commerce, 1973). Average daily temperatures range from 21.0 °F in January to 71.5 °F in July.



Base modified from U.S. Geological Survey  
 State base map, 1:500,000, 1968

Figure 1.--Location of study area.

## Geology

The study area is located on the gently dipping northwest flank of the Powder River structural basin. Geologic formations exposed in the area are Quaternary deposits and the Tongue River Member of the Tertiary Fort Union Formation. A generalized section showing geologic units is presented as table 1.

Quaternary deposits are generally alluvium consisting of clay, silt, and sand. Alluvial gravels are present in the East Fork Armells and Stocker Creek valleys.

The Tongue River Member is predominantly a fine- to medium-grained sandstone with interbedded siltstone, shale, localized clinker and baked shale, and coal beds. The Rosebud, McKay, and Stocker, in descending order, are the major coal seams in the Tongue River Member in the study area. The coal seams generally dip 1-2° in a southerly direction, with local variations resulting from small-scale folding and faulting. Only the uppermost two coal seams, Rosebud and McKay, are mineable by surface-mining technology and, of these, only the Rosebud coal bed has been mined extensively in the area.

Table 1.--Generalized section of geologic units exposed in study area<sup>1</sup>

System	Series	Geologic unit		Thick-ness (feet)	General description	Water-yielding characteristics
Quater-nary	Holocene and Pleisto-cene	Alluvium		0-100	Sand, silt, clay, and local lenses of gravel. Gravel consists predominantly of clinker fragments on many smaller streams. Deposits commonly are less than 40 feet thick along smaller streams.	Yields commonly are 30 gallons per minute or less to stock and domestic wells. Larger yields may be possible.
Ter-tiary	Paleo-cene	Fort Union For-ma-tion	Tongue River Member	0-2,500	Light-yellow to light-gray fine- to medium-grained thick-bedded to massive locally crossbedded and lenticular sandstone and siltstone; weathers to a buff color. Commonly contains light-buff to light-gray shaly siltstone and shale, and brown to black carbonaceous shale. Contains numerous coal beds; as much as 80 feet thick. Burning of the coal along outcrops has formed thick red and lavender clinker and baked shale beds. Base of unit is mapped as the change from predominantly siltstone and sandstone to predominantly shale of underlying unit. Entire thickness not present in study area.	Sandstone and coal beds are the aquifers; the shale does not yield significant quantities of water to wells. Unit contains major aquifers in much of the study area; yields of as much as 160 gallons per minute may be possible from wells penetrating large saturated thicknesses of aquifer material. Fractured clinker beds are very permeable and may yield as much as 65 gallons per minute. Many aquifers are under artesian pressure. Sediments disturbed and replaced (mine spoils) as a result of surface mining of coal can also function as aquifers.

<sup>1</sup>Modified from Lewis and Roberts (1978).

## Hydrology

Streams within the study area are ephemeral or intermittent. East Fork Armells Creek flows east across the southern part of the area, then flows north, eventually joining the Yellowstone River (fig. 1). Stocker Creek is the largest tributary to East Fork Armells Creek. In the eastern part of the study area, Cow, Pony, and Spring Creeks flow east to Rosebud Creek. Rosebud Creek is a north-flowing tributary to the Yellowstone River.

Major near-surface geologic units that store and transmit water in the study area include alluvium, mine spoils, Rosebud overburden, Rosebud coal bed, McKay coal bed, and sub-McKay deposits. Only aquifers below the McKay coal seam are not subject to physical disturbance by mining activities.

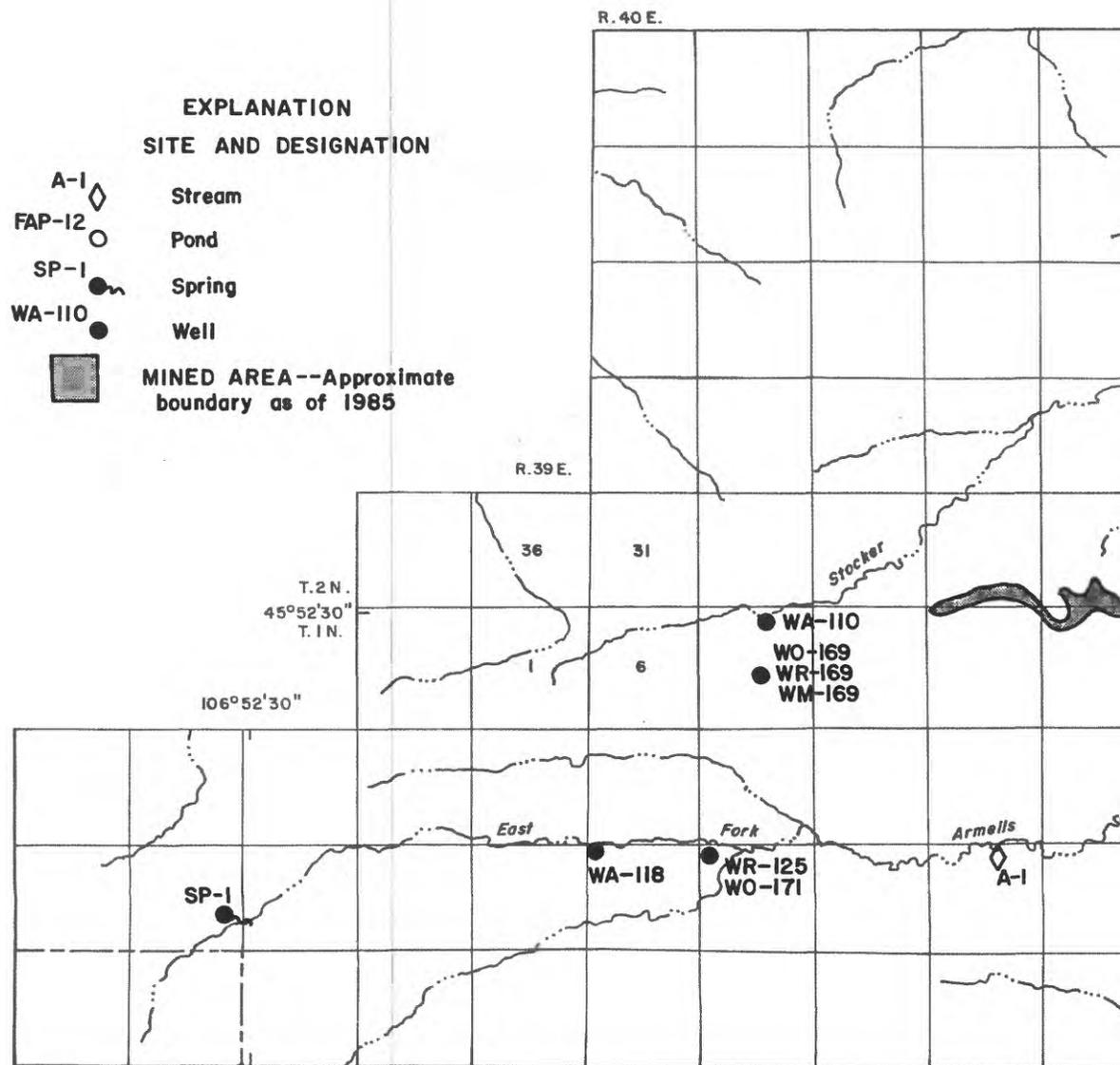
Both confined and unconfined conditions exist in near-surface aquifers in the study area. Directions of flow in the aquifers are variable. Water in aquifers of regional extent, such as the Rosebud and McKay coal beds, generally flows south-eastward. Flow directions in less-extensive aquifers, such as alluvium, mine spoils, and overburden, generally parallel the surface topography. Deviations in flow patterns occur in the vicinity of open mine pits.

Water from bedrock aquifers discharges to the alluvium and subsequently to short reaches of East Fork Armells Creek upstream from Colstrip. In the reach of East Fork Armells Creek near Colstrip, the stream and alluvium recharge the bedrock aquifers. Downstream from Colstrip, water from a surge pond or a ground-water source discharges to East Fork Armells Creek. Stocker Creek is the main tributary source of surface and alluvial water to East Fork Armells Creek in the study area.

## SAMPLE COLLECTION

Water samples collected from 29 surface- and ground-water sites (fig. 2) were analyzed for major constituents, selected trace elements, and selected stable-isotope ratios. Surface-water sites (table 2) were selected to provide areal coverage of East Fork Armells Creek upstream and downstream from mined areas and near selected tributary basins. Sampling at stream sites in the upstream part of the basin was limited to a short reach where streamflow was present. A spring in the headwaters of East Fork Armells Creek was also sampled. A sample from each of two fly-ash ponds was collected to provide baseline water-quality data for potential sources of leakage into the alluvial aquifer. Ground-water sites (table 3) were chosen to provide several samples from each of six major near-surface aquifers in the area (alluvium, mine spoils, Rosebud overburden, Rosebud coal bed, McKay coal bed, and sub-McKay deposits).

Streamflow was measured at all stream sampling sites to identify gaining and losing reaches along the channel. Because the area had received no significant precipitation for 20 days prior to the study, and surface runoff was absent, streamflow during the April sampling period was considered to represent base flow contributed primarily by ground-water sources. Streamflow was stable during the measurement period, owing to a lack of freezing temperatures and negligible evapotranspiration by riparian vegetation. Depth-integrated samples for chemical analysis were obtained by a standard U.S. Geological Survey DH-48 sampler at one or more points across the stream, depending on stream width.

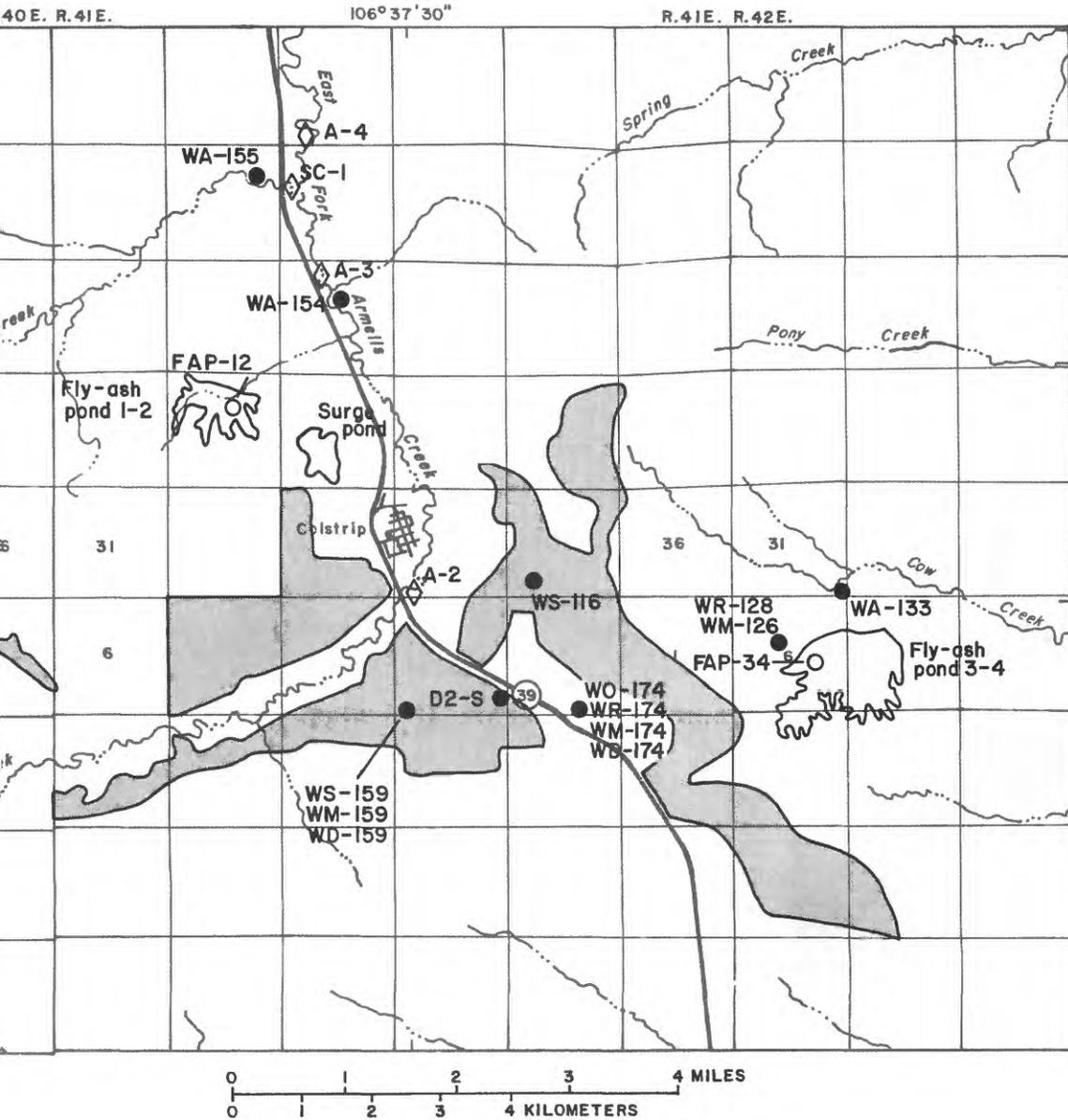


Base modified from U.S. Geological Survey  
Lame Deer, 1:100,000, 1980

Figure 2.--Location of surface-water and

Ground-water samples were collected from existing wells in the study area. Each well was completed in only one of the six designated aquifers. Most samples were obtained after bailing or pumping until at least three well-volumes of water had been removed and specific conductance and temperature had stabilized. However, for some small-yield wells, water in the casing was removed until the well was essentially dry and the sample was collected after the water level in the well had recovered.

All surface-water and ground-water samples were pretreated onsite according to methods of the U.S. Geological Survey (Friedman, 1979). Chemical constituents in water samples were analyzed at the U.S. Geological Survey National Water-Quality Laboratory in Denver, Colo., using methods described by Fishman and Friedman (1985).



ground-water sampling sites.

## METHODS OF ANALYSIS

### Stable-Isotope Ratios

Isotopes are atoms of the same element whose nuclei contain the same number of protons but a different number of neutrons. The difference in neutrons results in what are termed "heavy" and "light" isotopes of the element. Classification of an isotope as stable is related to its rate of radioactive decay. Only 21 elements are pure elements in that they have only one stable isotope. All other elements are a mixture of at least two isotopes.

Table 2.--Site identification and sampling dates for surface-water sites

Site number <sup>1</sup>	Site name	Site designation <sup>2</sup> (fig. 2)	Date (month- day- year)	Time (hours)
455009106524201	Spring	SP-1	04-16-85	1730
455043106442401	East Fork Armells Creek above Rosebud Mine, near Colstrip	A-1	04-15-85	1300
455239106373101	East Fork Armells Creek at Highway 39 bridge, at Colstrip	A-2	04-15-85	1530
455503106382401	East Fork Armells Creek below fly-ash pond 1-2, near Colstrip	A-3	04-15-85	1730
455544106384401	Stocker Creek at mouth, near Colstrip	SC-1	04-16-85	0800
455608106383801	East Fork Armells Creek below Stocker Creek	A-4	04-16-85	1000
455410106391701	Fly-ash pond 1-2, near Colstrip	FAP-12	06-10-85	1045
455218106325301	Fly-ash pond 3-4, near Colstrip	FAP-34	06-10-85	0945

<sup>1</sup>Site number consists of latitude, longitude, and two-digit sequence number to differentiate proximate sites.

<sup>2</sup>Site designation consists of abbreviation of type of site and number.

Differences exist in the physiochemical properties of isotopes of a given element. Because of these differences, certain phenomena, mainly isotope-exchange reactions and kinetic processes, result in natural substances containing varying quantities of heavy and light isotopes (Hoefs, 1980).

The absolute concentration of isotopes in water is difficult to determine precisely (T.B. Coplen, U.S. Geological Survey, written commun., 1987). In addition, variations in the absolute abundances of stable isotopes of elements such as hydrogen, carbon, nitrogen, oxygen, silicon, and sulfur are small. For most studies the ratio of the rare (heavy) isotope to the common (light) isotope is determined because the ratio can be determined far more accurately than the absolute abundance. Stable-isotope ratios are reported relative to a standard ratio as the  $\delta$  (delta) value, in units of parts per thousand or per mil (‰). The general equation for calculating  $\delta$  is:

$$\delta_x = \left( \frac{R_x}{R_s} - 1 \right) \cdot 1,000 \quad (1)$$

where

$\delta_x$  (delta value) is the isotope ratio of an element (x) in a sample relative to a standard ratio for that element,

$R_x$  is the isotope ratio of an element in a sample (x), and

$R_s$  is the isotope ratio of an element in a standard (s).

Table 3.--Site identification and sampling dates for ground-water sites

[Aquifer: AL, alluvium; MS, mine spoils; RO, Rosebud overburden; RC, Rosebud coal bed; MC, McKay coal bed; SM, sub-McKay deposits. Depth of well: in feet below land surface]

Site number <sup>1</sup>	Well number <sup>2</sup>	Site designation <sup>3</sup> (fig. 2)	Aquifer	Depth of well (feet)	Date (month-day-year)	Time (hours)
455230106465701	01N40E05ABBB01	WA-110	AL	19	06-12-85	1100
455020106484701	01N40E07CCCD01	WA-118	AL	15	06-12-85	1830
455235106324201	02N42E31DDDD01	WA-133	AL	15	06-14-85	1400
455458106382501	02N41E21BADB01	WA-154	AL	24	06-14-85	1530
455549106392601	02N41E17ABCD01	WA-155	AL	28	06-14-85	1730
455242106360601	02N41E35CCAD01	WS-116	MS	109	06-14-85	1300
455142106373103	01N41E03CCDC03	WS-159	MS	150	06-13-85	1700
455152106364801	01N41E03DBDD01	D2-S	MS	85	06-14-85	1200
455202106470002	01N40E05DBBB02	WO-169	RO	48	06-12-85	1500
455041106473401	01N40E17BBBC01	WO-171	RO	195	06-12-85	2000
455142106354203	01N41E02DCCD03	WO-174	RO	190	06-11-85	1400
455041106473402	01N40E17BBBC02	WR-125	RC	228	06-13-85	1030
455209106332302	01N42E06BDDD02	WR-128	RC	65	06-11-85	2000
455202106470003	01N40E05DBBB03	WR-169	RC	71	06-12-85	1400
455142106354204	01N41E02DCCD04	WR-174	RC	249	06-12-85	0900
455209106332301	01N42E06BDDD01	WM-126	MC	81	06-11-85	1930
455142106373102	01N41E03CCDC02	WM-159	MC	184	06-13-85	1530
455202106470001	01N40E05DBBB01	WM-169	MC	190	06-12-85	2100
455142106354202	01N41E02DCCD02	WM-174	MC	274	06-12-85	0830
455142106373101	01N41E03CCDC01	WD-159	SM	280	06-13-85	1830
455142106354201	01N41E02DCCD01	WD-174	SM	501	06-11-85	1730

<sup>1</sup> Site number consists of latitude, longitude, and two-digit sequence number to differentiate proximate sites.

<sup>2</sup> Well number consists of 14 characters. The first three characters specify the township and its location north (N) of the Montana Base Line. The next three characters specify the range and its position east (E) of the Montana Principal Meridian. The next two characters are the section number. The next four characters designate the quarter section (160-acre tract), quarter-quarter section (40-acre tract), quarter-quarter-quarter section (10-acre tract), and quarter-quarter-quarter-quarter section (2.5-acre tract) in which the well is located. The subdivisions of the section are designated A, B, C, and D in a counterclockwise direction, beginning in the northeast quadrant. The final two digits form a sequence number to differentiate proximate sites.

<sup>3</sup> Site designation consists of abbreviation of type of site and number.

Stable-isotope ratios determined in this study are  $^2\text{H}/^1\text{H}$  (or  $\text{D}/^1\text{H}$ ),  $^{13}\text{C}/^{12}\text{C}$ ,  $^{18}\text{O}/^{16}\text{O}$ , and  $^{34}\text{S}/^{32}\text{S}$ , where the letters H, C, O, and S represent the elements hydrogen, carbon, oxygen, and sulfur, respectively, and the superscript numeral refers to the atomic mass. Deuterium ( $^2\text{H}$ ) commonly is represented by the letter D. Isotope ratios measured in the water were compared to standard ratios for each element. Isotope ratios of hydrogen and oxygen were compared to ratios obtained from Standard Mean Ocean Water (SMOW) to calculate delta values. Carbon ratios were compared to that of the fossil of the extinct cephalopod *Belemnitella americana* from the Cretaceous Peedee Formation (PDB) in South Carolina. Sulfur ratios were compared to troilite, a ferrous sulfide mineral, from the Canyon Diablo iron meteorite (CDT). For example, a sample that had a delta value of +25.0 per mil for  $^{18}\text{O}$  would be enriched in  $^{18}\text{O}$  by 2.5 percent relative to the standard and would be isotopically "heavy." A sample with a delta value of -25.0 per mil for  $^{18}\text{O}$  would be depleted in  $^{18}\text{O}$  by 2.5 percent relative to the standard and would be isotopically "light."

Stable-isotope ratios of many elements are different for waters of different history and origin. For example, the ratios  $\text{D}/^1\text{H}$  and  $^{18}\text{O}/^{16}\text{O}$  of precipitation vary as a function of temperature and orographic effects. In surface- and ground-water systems, some of the processes that can modify the isotopic composition of water are evaporation, heating in geothermal systems, and bacteriological activity.

### Cluster Analysis

A statistical cluster analysis was used to group the well sites into "clusters" having similar hydrochemical characteristics. Various combinations of major dissolved constituents, trace elements, and stable-isotope ratios were used in the cluster analysis as a basis for forming groups of wells with similar water quality.

The average-linkage method of the cluster procedure (SAS Institute, Inc., 1985) was used to determine agglomerative hierarchical clusters based on the similarity of Euclidean distances between pairs of observations. The average distance between two clusters is the average distance between pairs of observations, one in each cluster (SAS Institute, Inc., 1985; Steinhorst and Williams, 1985). During the analysis, each well observation begins in a cluster by itself. The two closest clusters are merged to form a single cluster. Merging of the two closest clusters is repeated until all observations are included in one cluster. Cluster pairs with the smallest average distance between observations are more strongly associated with each other than pairs with larger distances between observations. The cluster that includes all observations has the weakest association among its members.

Prior to using cluster analysis, frequency histograms, box plots, and normal-probability plots of the water-quality data were used to determine variables requiring transformations to be normally distributed. In this study, calcium, potassium, alkalinity, chloride, fluoride, boron, iron, manganese, and strontium were transformed to the natural logarithm of their values. Isotope ratios for hydrogen, oxygen, and sulfur were transformed to the inverse of their values. Other variables used in the cluster analysis did not require transformations.

To give equal weight to each variable in the cluster analysis, the variables were standardized. The following equation was used to calculate a standard value, or z score, for each data value:

$$z = \frac{x - \bar{x}}{s} \quad (2)$$

where

- z = the standard value, or z score,
- x = a water-quality value,
- $\bar{x}$  = the average of water-quality values, and
- s = the standard deviation of water-quality values.

### STREAM BASE-FLOW CHARACTERISTICS

Measured streamflow and net gain or loss of streamflow between sites on East Fork Armells Creek during April 15-16, 1985, are presented in table 4. The streamflow profile (fig. 3) indicates that base flow is small and interrupted by reaches of no flow in East Fork Armells Creek upstream from site A-2 near Colstrip. Flow was observed in a 1.4-mi reach near site A-1. No flow was observed upstream from this reach. About 0.3 mi downstream from site A-1, all surface flow infiltrated into the alluvial channel. Surface coal mining along the sides of the valley between sites A-1 and A-2 probably has disrupted natural ground- and surface-water flow patterns.

Table 4.--Measured streamflow and gains or losses of streamflow between measurement sites, April 1985

[ft<sup>3</sup>/s, cubic foot per second. --, no data]

Site designation (fig. 2)	Stream	Date (month-day)	Measured streamflow (ft <sup>3</sup> /s)	Gain (+) or loss (-) of streamflow between East Fork Armells Creek sites (ft <sup>3</sup> /s)	Sum of tributary inflow between East Fork Armells Creek sites (ft <sup>3</sup> /s)	Net gain (+) or loss (-) of ground water or loss (-) of surface water between East Fork Armells Creek sites (ft <sup>3</sup> /s)
A-1	East Fork Armells Creek	04-15	0.22	--	--	--
A-2	East Fork Armells Creek	04-15	.06	-0.16	0	-0.16
A-3	East Fork Armells Creek	04-15	1.68	+1.62	0	+1.62
SC-1	Stocker Creek	04-16	.06	--	--	--
A-4	East Fork Armells Creek	04-16	2.11	+ .43	.06	+ .37

Downstream from site A-2, flow was present in all observed reaches. Streamflow increased by 1.62 ft<sup>3</sup>/s from site A-2 to site A-3, probably as a result of seepage from a surge pond and mine spoils, sewage plant effluent, and natural ground-water sources. Additional ground-water discharge and surface inflow from Stocker Creek contributed 0.43 ft<sup>3</sup>/s between sites A-3 and A-4. No other tributaries were observed to contribute surface flow to East Fork Armells Creek in the study area.

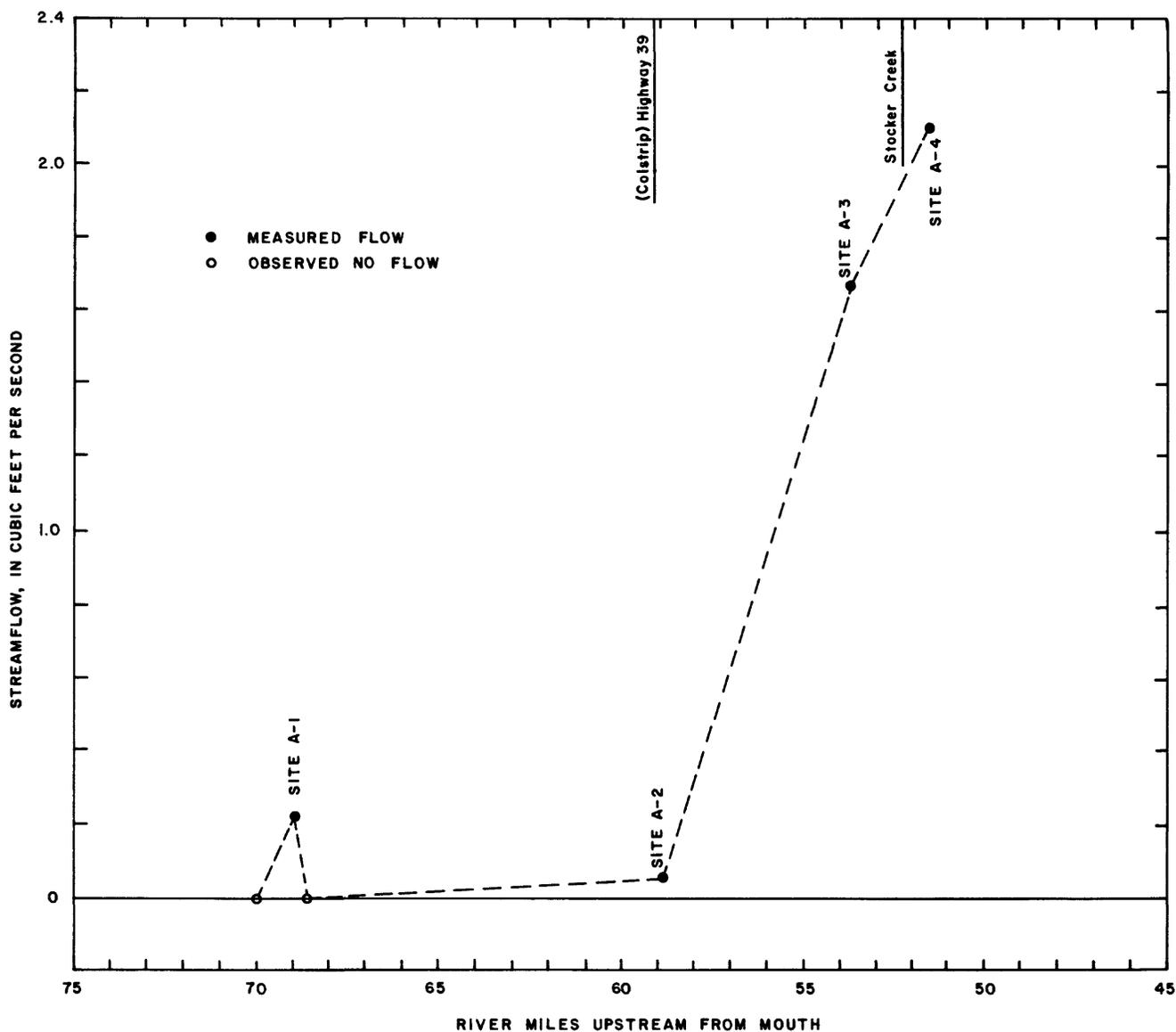


Figure 3.--Profile of base flow in East Fork Armells Creek, April 15-16, 1985.

CHEMICAL CHARACTERISTICS OF SURFACE WATER

Onsite Water Quality and Major Dissolved Constituents

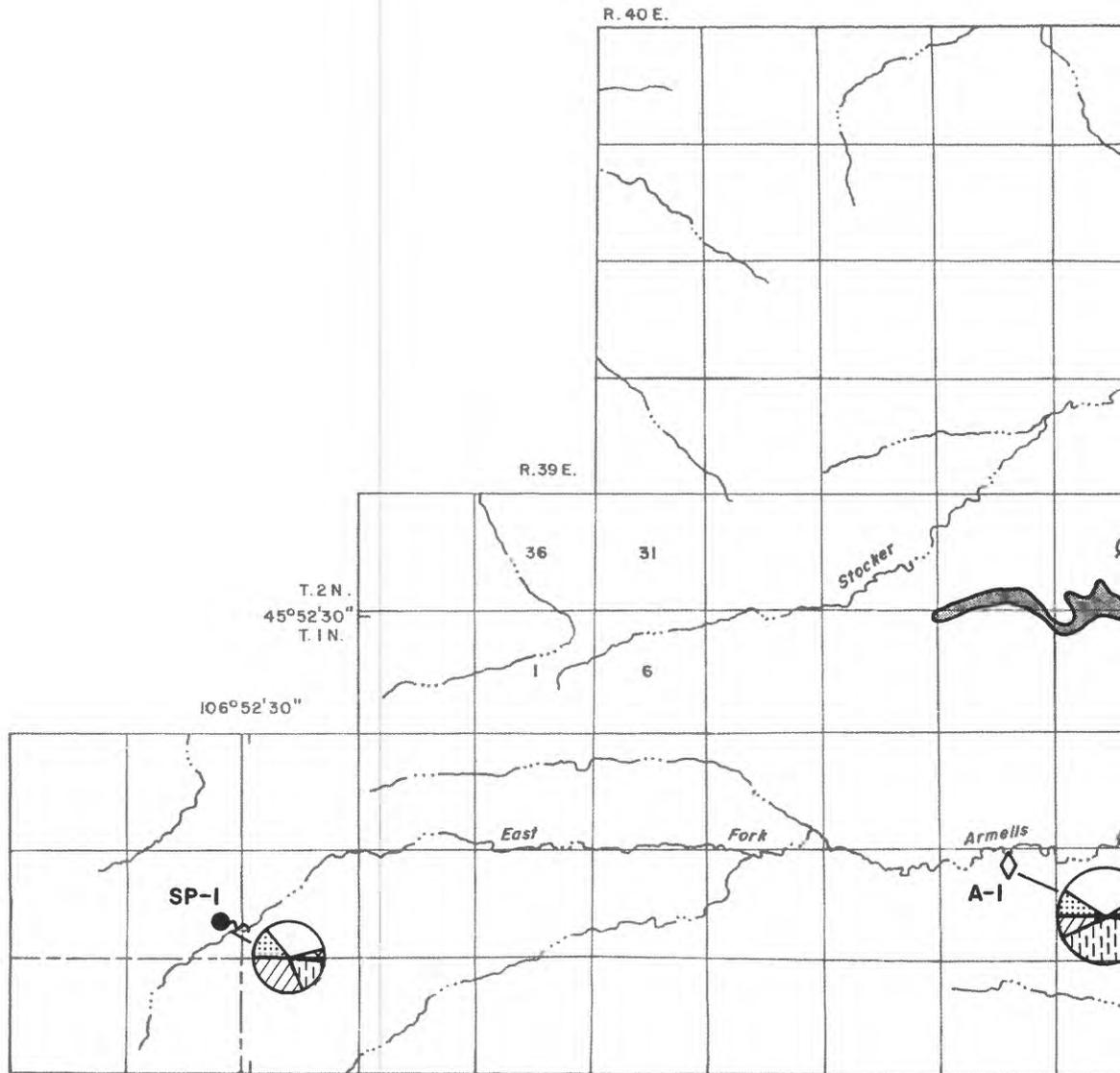
Onsite water-quality data and major-dissolved-constituent concentrations for the surface-water sites are presented in table 5. Dissolved-solids concentrations and water type at surface-water sites are presented graphically in figure 4. Bicarbonate plus carbonate concentrations shown in figure 4 and subsequent graphs were calculated from measured values of onsite alkalinity.

Table 5.--Onsite water-quality data and major-dissolved-constituent concentrations for surface-water sites, April and June 1985

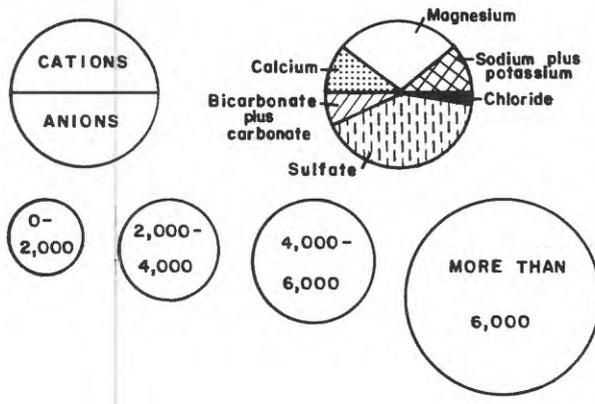
[Analyses by U.S. Geological Survey. Abbreviations: ft<sup>3</sup>/s, cubic foot per second;  $\mu$ S/cm, microsiemens per centimeter at 25 °C; °C, degrees Celsius; mg/L, milligrams per liter; NA, not applicable]

Site designation (fig. 2)	Sample date (month-day)	Stream-flow, instantaneous (ft <sup>3</sup> /s)	Specific conductance ( $\mu$ S/cm)	pH (standard units)	Temperature, air (°C)	Temperature, water (°C)	Oxygen, dissolved (mg/L)	Oxygen, dissolved (percent saturation)	Calcium, dissolved (mg/L)
SP-1	04-16	0.01	1,280	7.5	21.5	6.0	4.8	45	92
A-1	04-15	.22	4,100	8.2	20.0	13.5	9.0	100	210
A-2	04-15	.06	5,100	7.8	18.0	15.0	10.8	123	310
A-3	04-15	1.68	3,700	8.8	18.0	14.0	12.4	137	230
SC-1	04-16	.06	3,790	7.9	13.0	8.5	9.0	88	230
A-4	04-16	2.11	3,700	8.3	17.0	10.0	13.2	134	220
FAP-12	06-10	NA	11,000	7.7	17.0	18.0	8.9	110	400
FAP-34	06-10	NA	15,000	8.1	18.0	15.0	9.4	110	500

Site designation (fig. 2)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Alkalinity, onsite (mg/L as CaCO <sub>3</sub> )	Sulfate, dissolved (mg/L)	Chloride, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Silica, dissolved (mg/L)	Solids, sum of constituents, dissolved (mg/L)
SP-1	120	23	4.8	458	300	5.5	0.3	14	840
A-1	410	300	12	457	2,300	20	.3	14	3,500
A-2	530	340	19	491	3,400	62	.2	4.7	5,000
A-3	300	270	14	362	2,100	52	.5	11	3,200
SC-1	330	290	24	500	2,100	28	.3	4.5	3,300
A-4	300	280	14	392	2,000	54	.5	10	3,100
FAP-12	2,300	280	13	36	10,000	6.7	2.5	33	13,000
FAP-34	3,200	900	45	95	17,000	210	13	30	22,000



Base modified from U.S. Geological Survey  
Lame Deer, 1:100,000, 1980

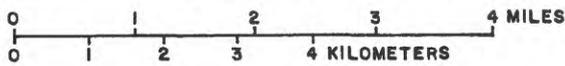
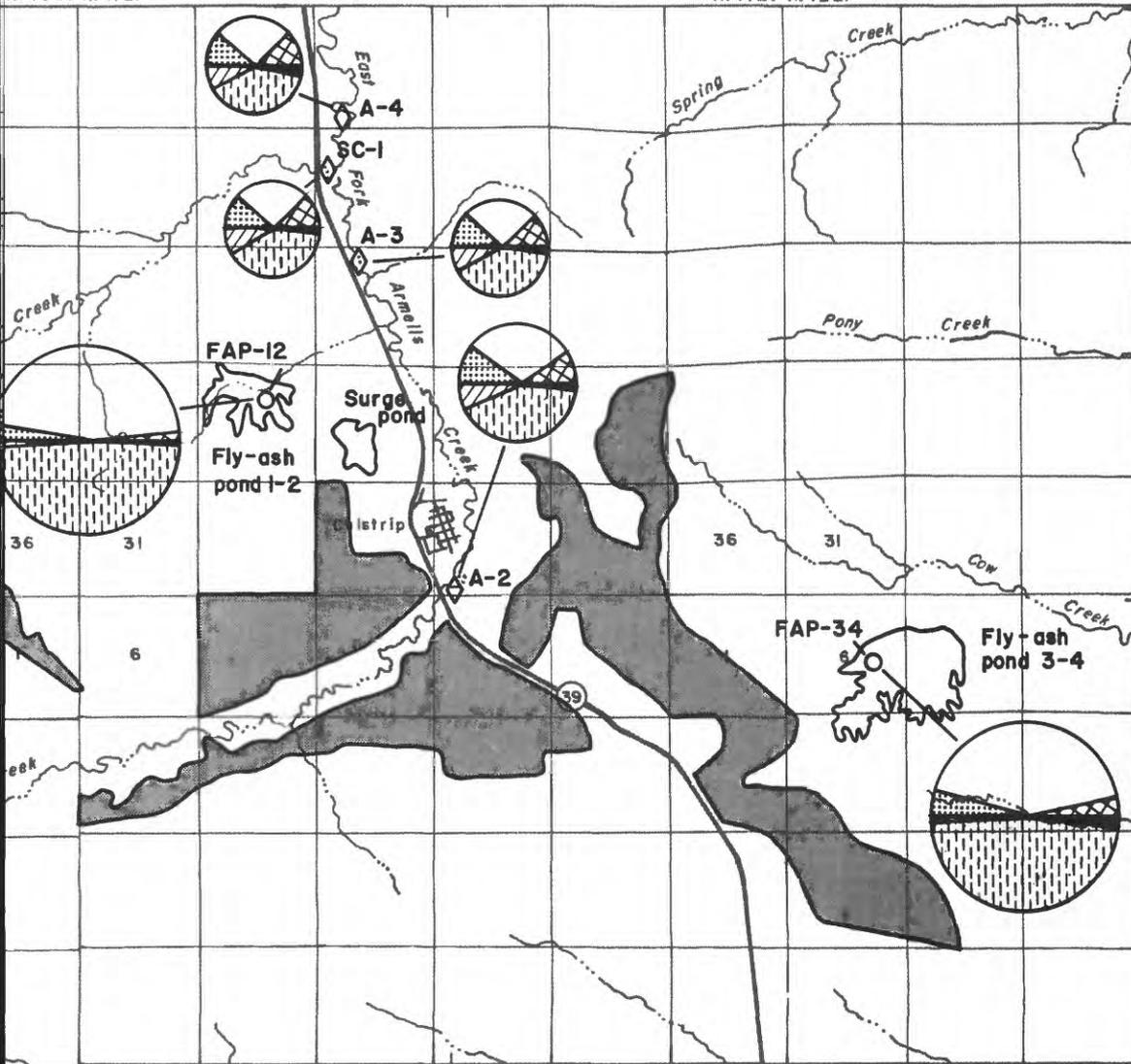


**EXPLANATION**

RELATIVE PERCENTAGE OF MAJOR IONS, BASED ON MILLIEQUIVALENTS PER LITER

DISSOLVED-SOLIDS CONCENTRATION, IN MILLIGRAMS PER LITER

Figure 4.--Water-quality diagrams for surface-water



**SITE AND DESIGNATION**

- A-1 ◊ Stream
- FAP-12 ○ Pond
- SP-1 ● Spring
- MINED AREA-- Approximate boundary as of 1985

sites, April and June 1985.

The smallest concentration of dissolved solids at the surface-water sites was 840 mg/L (milligrams per liter) measured at spring SP-1 in the headwaters of East Fork Armells Creek. Water from this spring infiltrates back into surficial deposits within a few feet of discharge before entering the alluvium of East Fork Armells Creek and probably is representative of recharge waters having short residence time in overburden materials. Water quality of base flow in East Fork Armells Creek varied only slightly from site A-1 to site A-4. Dissolved-solids concentrations among the four mainstem sites and Stocker Creek ranged from 3,100 mg/L at site A-4 to 5,000 mg/L at site A-2 (table 5). At site A-1, located within the most upstream reach of flow in the stream channel, the dissolved-solids concentration was 3,500 mg/L, which is more than four times the concentration at SP-1 about 7 mi upstream. The increased concentration of 5,000 mg/L at site A-2 near Colstrip may be, in part, the result of inflow of water from mine spoils. Downstream from Colstrip at sites A-3, SC-1, and A-4, dissolved-solids concentrations decreased to about 3,200 mg/L, possibly as a result of dilution due to inflow of surge-pond seepage, sewage-plant effluent, and natural ground water.

Fly-ash pond 1-2 and pond 3-4 (fig. 2) were constructed to allow evaporation of water discharged from coal-fired electric-power generating units at Colstrip. Units 1 and 2 discharge to pond 1-2; units 3 and 4 discharge to pond 3-4. Dissolved-solids concentrations measured in samples collected from the surface of the ponds were 13,000 mg/L in fly-ash pond 1-2 (site FAP-12) and 22,000 mg/L in fly-ash pond 3-4 (site FAP-34).

Major-ion composition of water from spring SP-1 was a magnesium bicarbonate type (fig. 4). Water collected at the stream sites was a magnesium sulfate type, with very little difference in relative percentages of major ions among sites. Water from the fly-ash ponds also was a magnesium sulfate type; however, magnesium and sulfate comprised almost 90 percent of the dissolved constituents compared to about 60 percent at the stream sites.

#### Trace Elements

The concentrations of trace elements in water from the spring SP-1 and the five stream sites (table 6) are typical of southeastern Montana waters and generally were within the range of values measured at the U.S. Geological Survey streamflow-gaging station (No. 06294980) on East Fork Armells Creek about 7 mi north of Colstrip (Knapton and Ferreira, 1980). Trace-element concentrations were smallest in water from spring SP-1. Total recoverable boron and iron increased downstream from site A-1 to site A-4. Conversely, strontium concentrations were large at upstream sites A-1 and A-2 and decreased downstream to site A-4. Concentrations of trace elements in Stocker Creek (site SC-1) generally were intermediate to values measured at sites on East Fork Armells Creek. Concentrations of boron and manganese were large in water from the fly-ash ponds (sites FAP-12 and FAP-34).

#### Stable-Isotope Ratios

Stable-isotope ratios for deuterium, carbon-13, oxygen-18, and sulfur-34 in water from the headwaters spring, five stream sites, and the fly-ash ponds are given in table 7. Samples from the spring and stream sites had similar isotopic

Table 6.--Trace-element concentrations for surface-water sites, April and June 1985

[Concentrations are in micrograms per liter. &lt;, less than]

Site designation (fig. 2)	Sample date (month-day)	Aluminum, dissolved	Boron, total recoverable	Boron, dissolved	Cadmium, total recoverable	Cadmium, dissolved	Iron, total recoverable
SP-1	04-16	<10	160	150	<1	<1	130
A-1	04-15	10	360	340	<1	2	290
A-2	04-15	20	940	940	<1	<1	360
A-3	04-15	10	1,000	1,000	<1	<1	1,300
SC-1	04-16	10	730	700	<1	<1	470
A-4	04-16	<10	1,000	950	<1	1	2,100
FAP-12	06-10	50	77,000	77,000	3	2	1,100
FAP-34	06-10	40	81,000	81,000	5	5	180

Site designation (fig. 2)	Iron, dissolved	Manganese, total recoverable	Manganese, dissolved	Strontium, total recoverable	Strontium, dissolved
SP-1	6	10	2	1,200	1,700
A-1	40	470	410	6,500	6,500
A-2	50	1,400	1,000	6,600	6,600
A-3	40	690	540	5,400	5,400
SC-1	60	460	400	5,000	5,000
A-4	40	850	660	5,300	5,200
FAP-12	90	14,000	14,000	2,900	2,500
FAP-34	110	16,000	16,000	2,900	2,900

ratios for each element analyzed. The negative ratios indicate depletion of the heavy isotope relative to the standards for each element. Samples from the fly-ash ponds were isotopically more enriched in deuterium and oxygen-18 than samples from the spring and stream sites, probably as a result of evaporation. Only the oxygen-18 sample from site FAP-12 and the oxygen-18 and sulfur-34 samples from site FAP-34 had positive ratios, indicating isotopically "heavy" composition relative to a standard ratio.

Stable-isotope ratios for deuterium and oxygen-18 for the surface-water samples are graphically compared (fig. 5) to the isotopic composition of North American continental precipitation as reported by Gat (1980). Except for the samples from the fly-ash ponds, which probably are affected by evaporation, the

Table 7.--Stable-isotope ratios for surface-water sites, April and June 1985

[--, no data]

Site designation (fig. 2)	Sample date (month-day)	Stable-isotope ratio, per mil			
		Deuterium (D/ <sup>1</sup> H)	Carbon-13 ( <sup>13</sup> C/ <sup>12</sup> C)	Oxygen-18 ( <sup>18</sup> O/ <sup>16</sup> O)	Sulfur-34 ( <sup>34</sup> S/ <sup>32</sup> S)
SP-1	04-16	-139	-10.5	-17.9	--
A-1	04-15	-142	-10.3	-17.9	--
A-2	04-15	-137	-10.0	-16.8	--
A-3	04-15	-132	-8.4	-16.2	--
SC-1	04-16	-136	-9.2	-16.7	--
A-4	04-16	-133	-9.6	-16.3	--
FAP-12	06-10	-92.5	--	3.0	-7.2
FAP-34	06-10	-102	--	2.0	1.4

isotopic compositions of the surface-water samples approximately correspond to the composition of North American continental precipitation, indicating the presence of present-day meteoric water.

#### CHEMICAL CHARACTERISTICS OF GROUND WATER

##### Onsite Water Quality and Major Dissolved Constituents

Onsite water-quality data and major-dissolved-constituent concentrations for the ground-water sites are presented in table 8. Quality of water from the six major near-surface aquifers in the study area is illustrated by bar graphs in figure 6.

Dissolved-solids concentrations ranged from 690 mg/L in water from a well completed in the Rosebud coal bed to 4,100 mg/L in a well completed in alluvium. Median dissolved-solids concentrations of water sampled from each of the aquifers were: alluvium, 2,300 mg/L; mine spoils, 2,800 mg/L; Rosebud overburden, 1,300 mg/L; Rosebud coal bed, 1,520 mg/L; McKay coal bed, 2,000 mg/L; and sub-McKay deposits, 1,750 mg/L. Concentrations of dissolved solids within individual aquifers were variable, indicating possible local differences in mineralogy, source of recharge, or interaquifer leakage. All dissolved-solids concentrations measured in this study were within the range of values reported by the Montana Department of State Lands and U.S. Office of Surface Mining (1983).

Major-ion composition of water from the aquifers ranged from a magnesium-calcium sulfate type in the mine spoils to a sodium sulfate type in the McKay coal bed and sub-McKay deposits. Water from wells completed in alluvium and Rosebud overburden was a magnesium sulfate type. Water sampled from the Rosebud coal bed was variable in ionic composition.

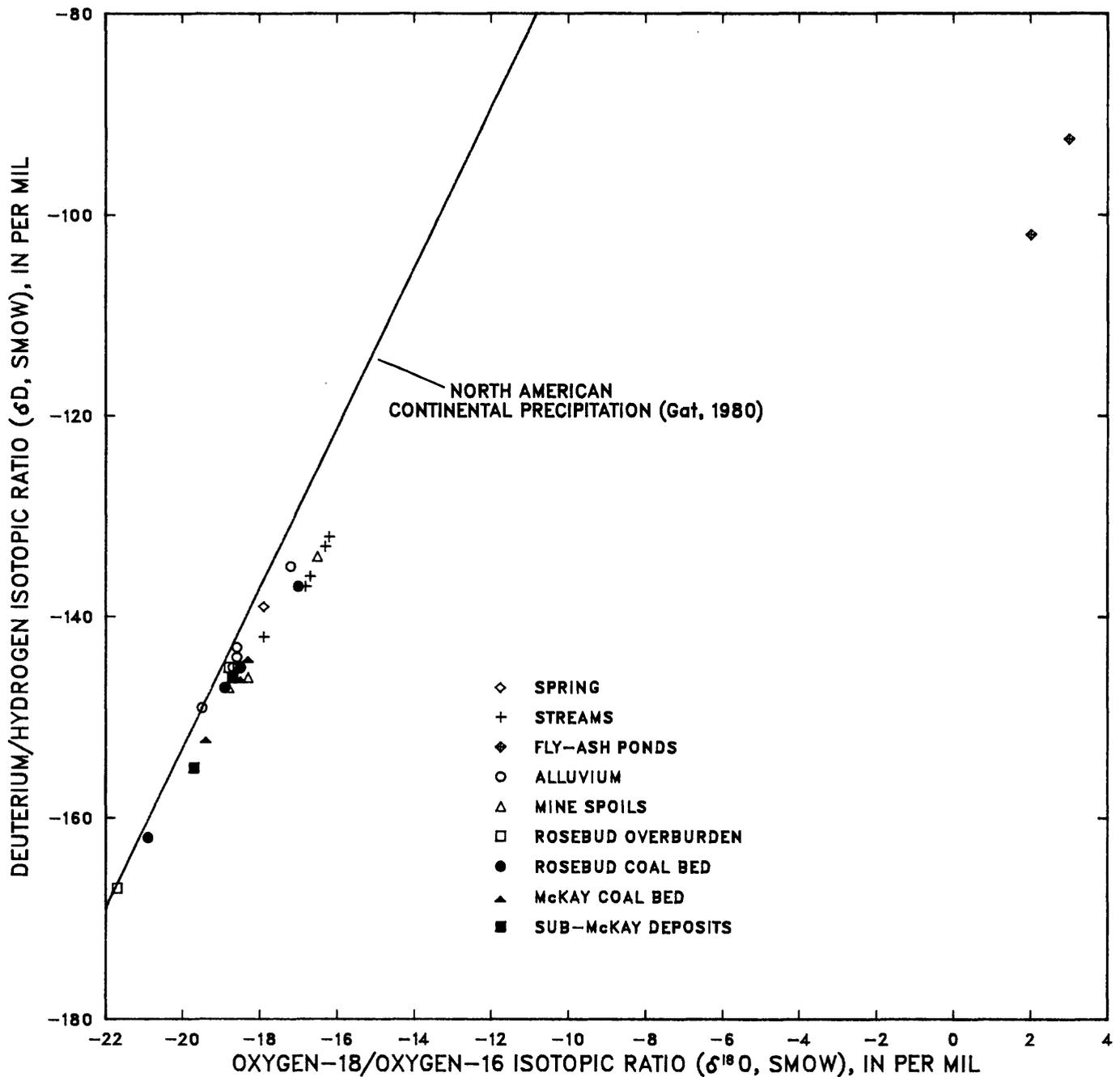


Figure 5.--Comparison of the isotopic composition of surface-water and ground-water samples to the isotopic composition of North American continental precipitation. SMOW, standard mean ocean water.

Concentrations of major dissolved constituents in the ground-water samples generally were of the same magnitude as concentrations for the spring and stream samples. However, concentrations of most constituents in the ground-water samples were considerably different from those in samples from the fly-ash ponds.

Table 8.--Onsite water-quality data and major-dissolved-constituent concentrations for ground-water sites, June 1985

[Analyses by U.S. Geological Survey. Aquifer: AL, alluvium; MS, mine spoils; RO, Rosebud overburden; RC, Rosebud coal bed; MC, McKay coal bed; SM, sub-McKay deposits; <, less than. Abbreviations:  $\mu\text{S}/\text{cm}$ , microsiemens per centimeter at 25 °C; °C, degrees Celsius; mg/L, milligrams per liter]

Site designation (fig. 2)	Aquifer	Sample date (month, day)	Specific conductance ( $\mu\text{S}/\text{cm}$ )	pH (standard units)	Temperature, air (°C)	Temperature, water (°C)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)
WA-110	AL	06-12	2,590	7.7	20.5	13.5	90	290
WA-118	AL	06-12	2,450	7.5	26.0	9.5	130	250
WA-133	AL	06-14	2,750	7.5	26.5	10.5	190	200
WA-154	AL	06-14	4,800	7.4	24.5	10.0	310	470
WA-155	AL	06-14	2,900	7.4	24.5	11.0	240	220
WS-116	MS	06-14	3,230	6.9	24.0	13.5	360	290
WS-159	MS	06-13	3,290	7.2	25.0	13.5	360	260
D2-S	MS	06-14	3,410	7.1	22.0	10.5	350	300
WO-169	RO	06-12	1,720	7.6	26.0	15.0	120	120
WO-171	RO	06-12	2,500	7.5	26.0	13.0	120	250
WO-174	RO	06-11	1,470	7.5	18.0	12.0	99	130
WR-125	RC	06-13	2,650	7.2	24.5	11.5	230	200
WR-128	RC	06-11	1,110	7.2	17.0	14.5	110	62
WR-169	RC	06-12	3,500	7.3	26.0	11.5	240	190
WR-174	RC	06-12	1,210	7.5	18.5	13.0	88	89
WM-126	MC	06-11	2,680	7.2	18.0	16.5	230	240
WM-159	MC	06-13	2,500	7.6	25.0	14.5	170	82
WM-169	MC	06-12	2,220	8.1	26.0	15.0	46	29
WM-174	MC	06-12	2,780	7.7	18.0	12.0	87	50
WD-159	SM	06-13	2,040	7.7	24.5	13.5	80	40
WD-174	SM	06-11	2,910	7.7	18.0	14.0	77	55

Site designation (fig. 2)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Alkalinity, onsite (mg/L) as $\text{CaCO}_3$	Sulfate, dissolved (mg/L)	Chloride, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Silica, dissolved (mg/L)	Solids, sum of constituents, dissolved (mg/L)
WA-110	150	3.5	416	1,200	25	0.1	10	2,000
WA-118	120	9.0	607	990	9.7	.3	15	1,900
WA-133	210	13	340	1,400	9.4	.7	16	2,300
WA-154	370	15	508	2,600	31	.3	19	4,100
WA-155	230	6.8	396	1,500	33	.3	18	2,500
WS-116	82	9.9	690	1,400	17	<.1	12	2,600
WS-159	300	15	943	1,300	12	<.1	20	2,800
D2-S	170	11	335	2,000	25	.1	11	3,100
WO-169	120	5.7	376	660	14	.3	18	1,300
WO-171	130	8.9	555	1,100	19	.3	13	2,000
WO-174	54	4.1	364	510	2.0	.2	12	1,000
WR-125	170	9.5	588	1,200	14	.2	15	2,200
WR-128	60	7.1	553	92	5.6	.1	14	690
WR-169	370	12	376	1,900	12	.3	11	3,000
WR-174	70	4.7	391	330	2.1	.3	13	840
WM-126	64	31	214	1,600	10	.1	15	2,300
WM-159	330	13	472	1,100	7.5	.2	14	2,000
WM-169	410	6.6	432	720	6.4	.3	9.5	1,500
WM-174	530	10	578	970	6.6	.4	10	2,000
WD-159	370	8.4	412	650	4.8	.2	.3	1,400
WD-174	570	7.0	492	1,100	12	1.2	8.4	2,100

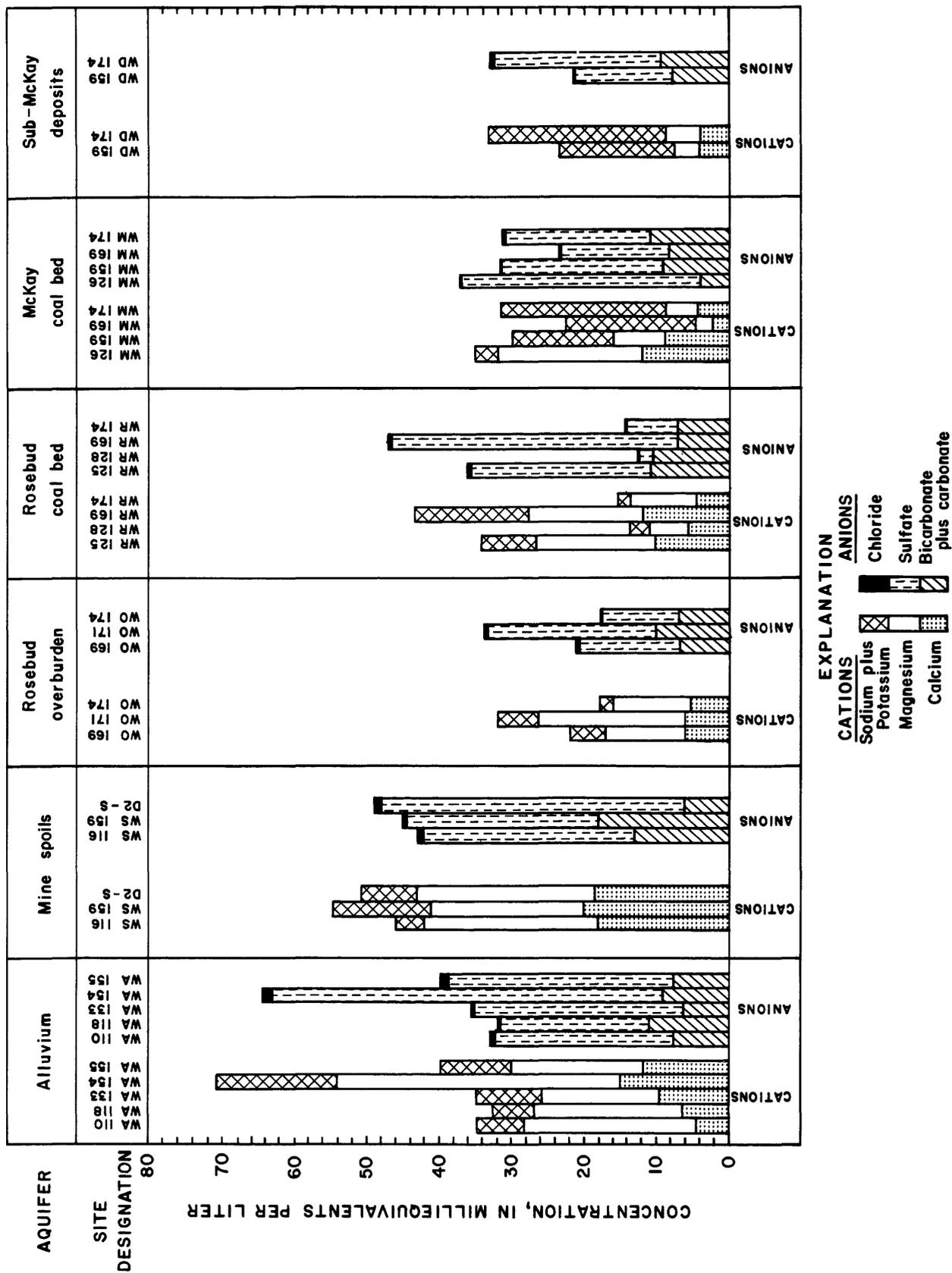


Figure 6.--Quality of water from ground-water sites, June 1985.

## Trace Elements

Trace-element concentrations in water from wells sampled in this study are presented in table 9. Concentrations of most trace elements in ground water were similar to concentrations measured in stream samples, although dissolved-manganese concentrations, in general, were slightly smaller. Water from the Rosebud overburden commonly had the smallest concentrations of trace elements, whereas water from the McKay coal bed commonly had the largest concentrations. A notable exception was the large strontium concentration in water from mine spoils and two wells completed in the Rosebud coal bed. The median dissolved-strontium concentration in spoils water was 15,000 µg/L (micrograms per liter), compared to median dissolved-strontium concentrations that ranged from 3,500 µg/L in the alluvium and Rosebud overburden to 9,000 µg/L in the Rosebud coal bed. Two of the four samples from the Rosebud coal bed had strontium concentrations of 13,000 µg/L. Both water samples from the Rosebud coal bed having large strontium concentrations were collected from wells located in the western part of the study area near the headwaters of East Fork Armells and Stocker Creeks. Boron concentrations were relatively large in a sample from alluvium (1,400 µg/L) and the McKay coal bed (3,800 µg/L).

Table 9.--Trace-element concentrations for ground-water sites, June 1985

[Analyses by U.S. Geological Survey. Concentrations are in micrograms per liter. Aquifer: AL, alluvium; MS, mine spoils; RO, Rosebud overburden; RC, Rosebud coal bed; MC, McKay coal bed; SM, sub-McKay deposits. <, less than]

Site designation (fig. 2)	Aquifer	Sample date (month-day)	Aluminum, dissolved	Boron, dissolved	Cadmium, dissolved	Iron, dissolved	Manganese, dissolved	Strontium, dissolved
WA-110	AL	06-12	20	330	1	290	50	2,800
WA-118	AL	06-12	<10	340	<1	280	380	2,800
WA-133	AL	06-14	<10	1,400	<1	60	160	4,500
WA-154	AL	06-14	<10	<10	<1	30	40	6,000
WA-155	AL	06-14	<10	270	<1	30	20	3,500
WS-116	MS	06-14	<10	630	1	30	340	15,000
WS-159	MS	06-13	<10	490	1	190	690	12,000
D2-S	MS	06-14	<10	350	<1	70	430	15,000
WO-169	RO	06-12	<10	150	<1	<3	120	4,300
WO-171	RO	06-12	<10	340	<1	20	80	3,500
WO-174	RO	06-11	40	60	<1	5	27	1,800
WR-125	RC	06-13	<10	410	<1	190	300	13,000
WR-128	RC	06-11	<10	900	<1	9	200	4,900
WR-169	RC	06-12	<10	260	<1	40	80	13,000
WR-174	RC	06-12	<10	150	<1	5	40	3,000
WM-126	MC	06-11	10	3,800	2	30	1,100	8,000
WM-159	MC	06-13	<10	320	1	900	740	9,500
WM-169	MC	06-12	<10	150	<1	30	30	2,900
WM-174	MC	06-12	20	320	<1	30	90	4,300
WD-159	SM	06-13	<10	330	<1	70	390	4,700
WD-174	SM	06-11	<10	350	<1	20	80	3,800

### Stable-Isotope Ratios

Stable-isotope ratios for deuterium, carbon-13, oxygen-18, and sulfur-34 in water from wells are given in table 10. Ratios for deuterium range from -167 to -134 per mil, ratios for carbon-13 range from -13.0 to 0.4 per mil, ratios for oxygen-18 range from -21.7 to -16.5 per mil, and ratios for sulfur-34 range from -9.3 to 6.2 per mil. No pattern is obvious among the individual isotopes to uniquely distinguish between ground-water sources, either because of variability within aquifers (carbon-13, sulfur-34) or similarity between aquifers (deuterium, oxygen-18). The ratios for ground-water samples are of the same general magnitude as ratios for the spring and stream samples, but are considerably different from the ratios for deuterium and oxygen-18 for samples from the fly-ash ponds.

Table 10.--Stable-isotope ratios for ground-water sites, June 1985

[Analyses by U.S. Geological Survey. Aquifer: AL, alluvium; MS, mine spoils; RO, Rosebud overburden; RC, Rosebud coal bed; MC, McKay coal bed; SM, sub-McKay deposits. --, no data]

Site designation (fig. 2)	Aquifer	Sample date (month-day)	Stable-isotope ratio, per mil			
			Deuterium (D/ <sup>1</sup> H)	Carbon-13 ( <sup>13</sup> C/ <sup>12</sup> C)	Oxygen-18 ( <sup>18</sup> O/ <sup>16</sup> O)	Sulfur-34 ( <sup>34</sup> S/ <sup>32</sup> S)
WA-110	AL	06-12	-144	-9.6	-18.6	0.6
WA-118	AL	06-12	-143	-11.6	-18.6	1.4
WA-133	AL	06-14	-149	-9.7	-19.5	-9.3
WA-154	AL	06-14	-135	-11.6	-17.2	-3.2
WA-155	AL	06-14	-145	-12.2	-18.7	-2.1
WS-116	MS	06-14	-134	--	-16.5	.5
WS-159	MS	06-13	-146	.4	-18.3	4.0
D2-S	MS	06-14	-147	-8.3	-18.8	-2.0
WO-169	RO	06-12	-146	-4.9	-18.7	-1.1
WO-171	RO	06-12	-145	-8.6	-18.8	2.0
WO-174	RO	06-11	-167	-5.3	-21.7	3.3
WR-125	RC	06-13	-147	-6.8	-18.9	1.8
WR-128	RC	06-11	-137	-13.0	-17.0	-4.1
WR-169	RC	06-12	-145	-4.7	-18.5	1.7
WR-174	RC	06-12	-162	-4.8	-20.9	2.6
WM-126	MC	06-11	-144	-6.2	-18.3	-8.3
WM-159	MC	06-13	-146	-4.5	-18.5	5.0
WM-169	MC	06-12	-145	-9.0	-18.6	2.6
WM-174	MC	06-12	-152	-3.8	-19.4	3.4
WD-159	SM	06-13	-146	-5.2	-18.7	6.2
WD-174	SM	06-11	-155	-4.5	-19.7	1.9

Stable-isotope ratios for deuterium and oxygen-18 for the ground-water samples are graphically compared (fig. 5) to the isotopic composition of North American continental precipitation as reported by Gat (1980). The isotopic compositions of all the ground-water samples approximately correspond to the composition of North American continental precipitation, indicating the presence of present-day meteoric water in the aquifers.

#### IDENTIFICATION OF GROUND-WATER SOURCES

The chemical characteristics of ground water can be used to identify the aquifer source if those characteristics are relatively uniform within the aquifer but are substantially different for water from separate aquifers. Two methods of determining chemical relations are to analyze the chemical data graphically and statistically. To explore the effectiveness of using synoptic chemical data for distinguishing ground-water sources, the data were analyzed graphically using major-ion-composition diagrams and statistically using cluster analysis.

The major-ion composition of water sampled from the six near-surface aquifers is shown graphically in figure 7. Based on major-ion composition, distinct groupings of aquifers by water type are not evident. However, waters from the alluvium, mine spoils, and Rosebud overburden can be generally grouped. These waters are primarily a magnesium sulfate type, with calcium being a significant component in water from the mine spoils. Water from the sub-McKay deposits also can be grouped as a sodium sulfate type. Two of the four water samples from the McKay coal bed had major-ion composition similar to that for the sub-McKay deposits, but the other two samples were notably different. Water from the Rosebud coal bed was variable in composition.

Cluster analysis was used to form sample groups in a more quantitative manner than the ion-composition diagram. Cluster analysis also provides a means of forming sample groups having similar attributes using combinations of variables. A matrix of observations for combinations of variables can be analyzed to cluster the observations, variables, or both into similar groups. If groups having similar hydrochemical characteristics can be defined, other multivariate statistical analyses can be used to allot variables to the groups (Steinhorst and Williams, 1985). In this study, the cluster pattern for the spring and ground-water sites was compared for several arbitrarily selected combinations of chemical variables.

Cluster analysis of the spring and ground-water samples based on specific conductance and dissolved-solids concentration indicates four groups at the base of the cluster hierarchy (fig. 8). No single aquifer is represented solely in one group. One sample, from site WA-154, is not clearly part of any of the other sample groups.

Cluster diagrams based on major dissolved cations and major dissolved anions are shown in figures 9 and 10, respectively. By cations, the samples form three major groups, with two samples, from sites WM-126 and WA-154, not clearly part of any group. By anions, the samples form several groups, with samples from sites WA-154 and WM-126 weakly clustered with sites D2-S, WA-110, and WA-155. As with specific conductance and dissolved-solids concentration, no single aquifer is represented solely in one group.

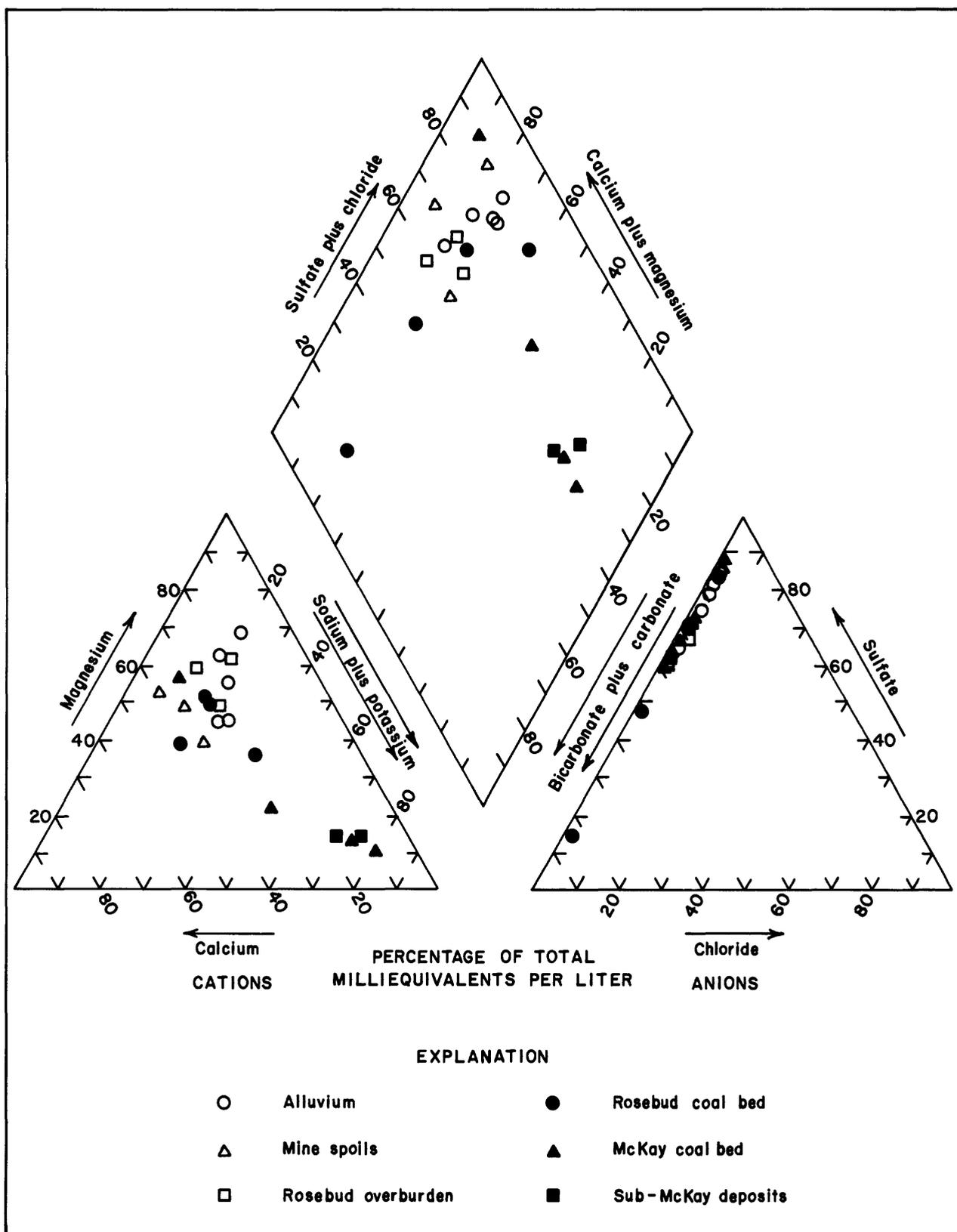


Figure 7.--Major-ion composition of water from ground-water sites, June 1985.

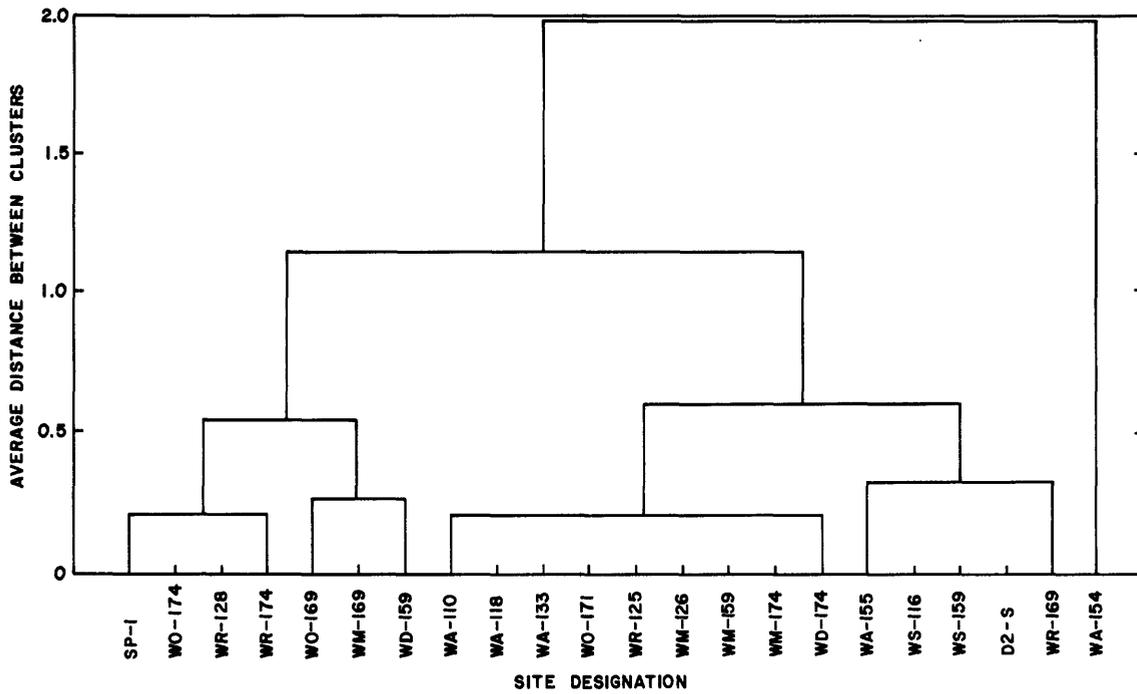


Figure 8.--Cluster diagram for samples from spring and ground-water sites based on specific conductance and dissolved-solids concentration.

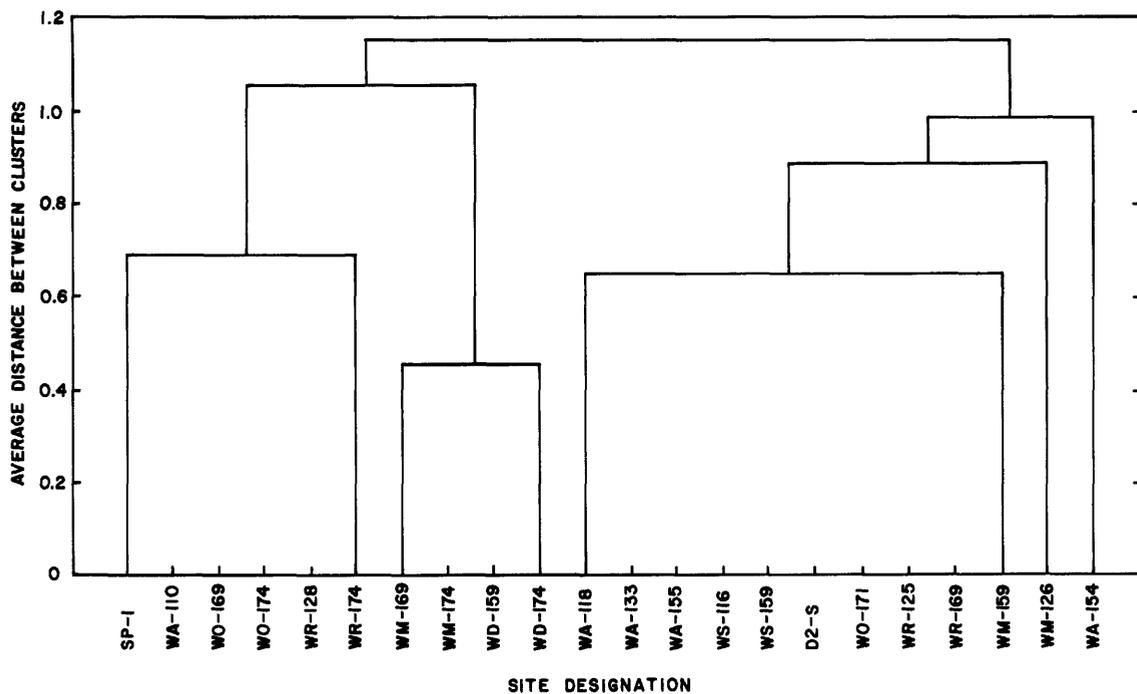


Figure 9.--Cluster diagram for samples from spring and ground-water sites based on major-dissolved-cation concentrations.

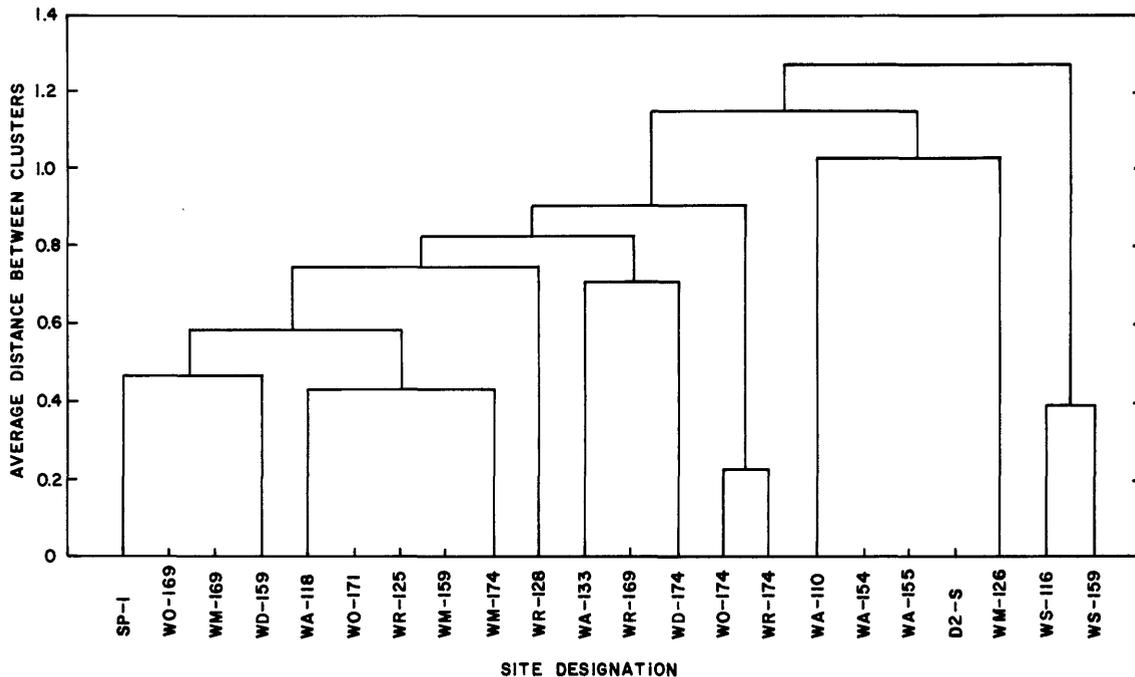


Figure 10.--Cluster diagram for samples from spring and ground-water sites based on major-dissolved-anion concentrations.

A cluster diagram based on concentrations of the major dissolved constituents combined is shown in figure 11. The groups are similar to those in figure 9.

A cluster diagram based on dissolved trace-element concentrations is shown in figure 12. The cluster pattern differs substantially from the pattern based on major-dissolved-constituent concentrations (fig. 11). An obvious difference with the trace-element groups is that the spring SP-1 sample is not part of any group. In the previous clusters, the sample from the spring generally was grouped with samples from sites WO-169, WO-174, WR-128, and WR-174. The cluster pattern of samples based on specific conductance, dissolved-solids concentration, major-dissolved-constituent concentrations, and dissolved trace-element concentrations (fig. 13) is similar to the pattern for samples based only on major-dissolved-constituent concentrations (fig. 11). For the clusters shown in figures 11-13, no single aquifer is represented solely in one group.

Cluster analysis of the ground-water samples based on stable-isotope ratios indicates six groups (fig. 14). The spring sample (SP-1) was not included in this cluster analysis because of the lack of data for sulfur-34 and the well sample (WS-116) was omitted because of missing data for carbon-13. The groups based on stable-isotope ratios differ from groups based on other variables. As with the previous cluster analyses, no single aquifer is represented solely in one group.

Neither the ion-composition diagram (fig. 7) nor the cluster analyses of selected chemical constituents (figs. 8-13) indicate uniquely identifiable chemical characteristics of water from any of the six aquifers sampled. The cluster analyses for the various combinations of chemical variables indicate that the variability of water quality within the groups of samples from each of the six aquifers

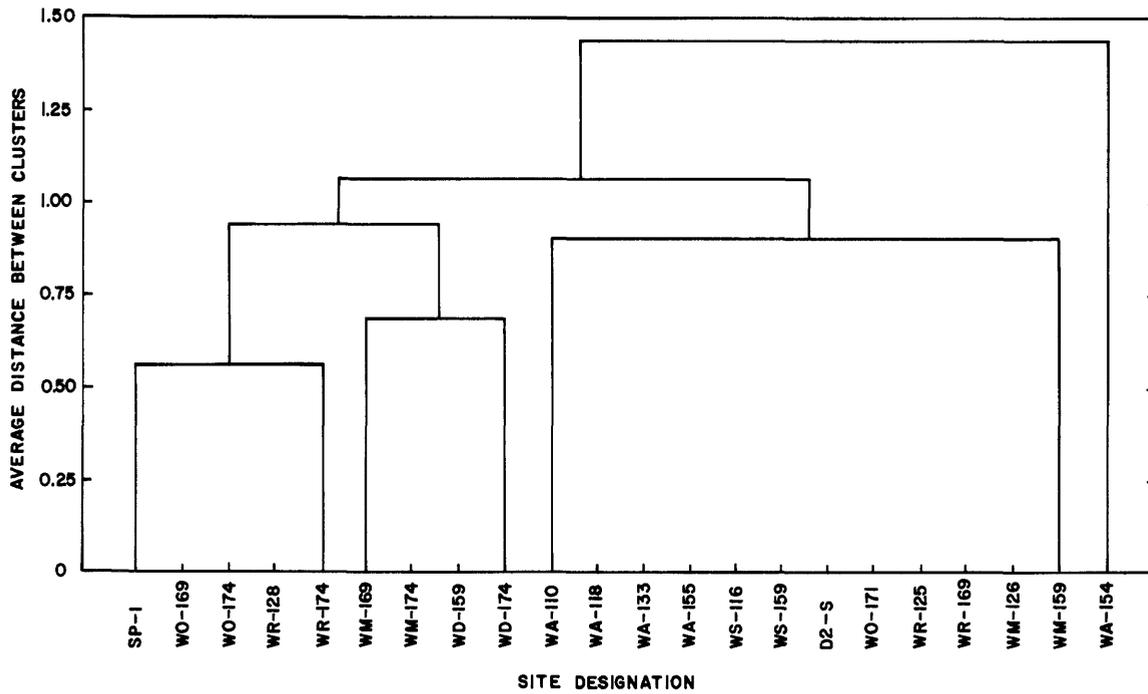


Figure 11.--Cluster diagram for samples from spring and ground-water sites based on major-dissolved-constituent concentrations.

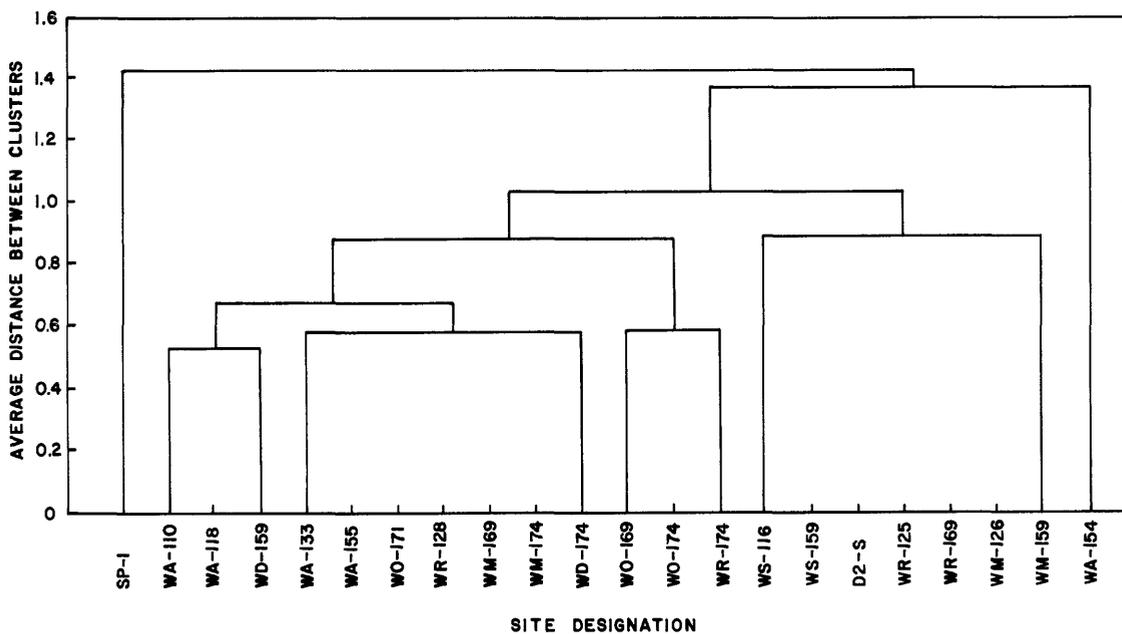


Figure 12.--Cluster diagram for samples from spring and ground-water sites based on trace-element concentrations.

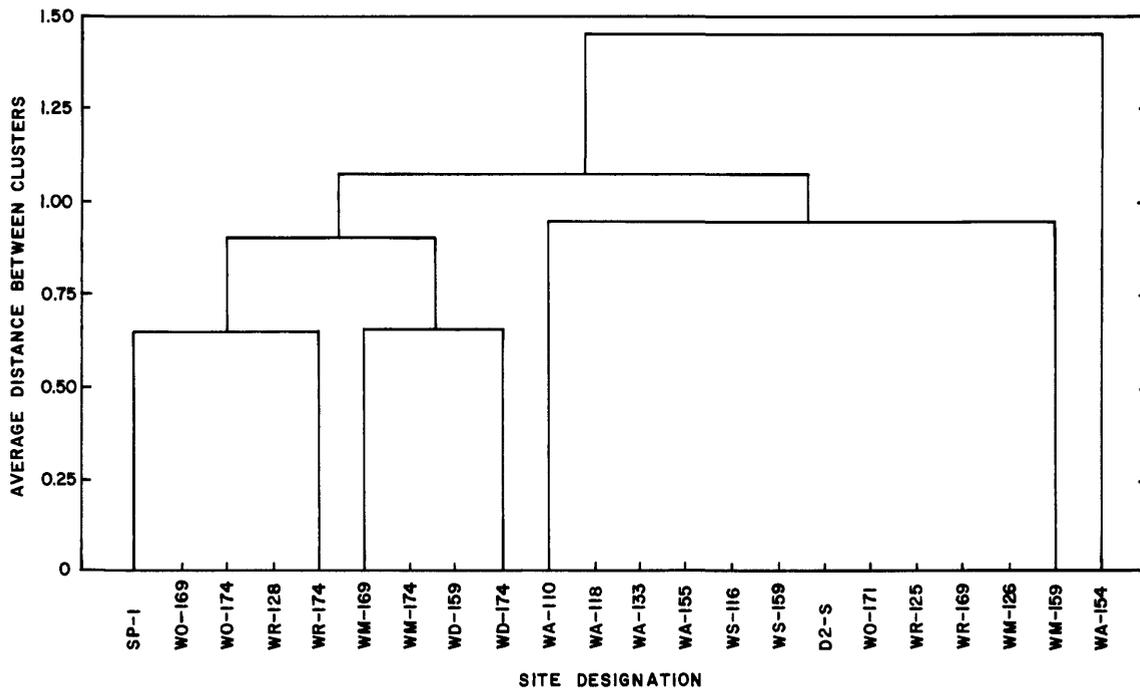


Figure 13.--Cluster diagram for samples from spring and ground-water sites based on specific conductance and concentrations of dissolved solids, major dissolved constituents, and trace elements.

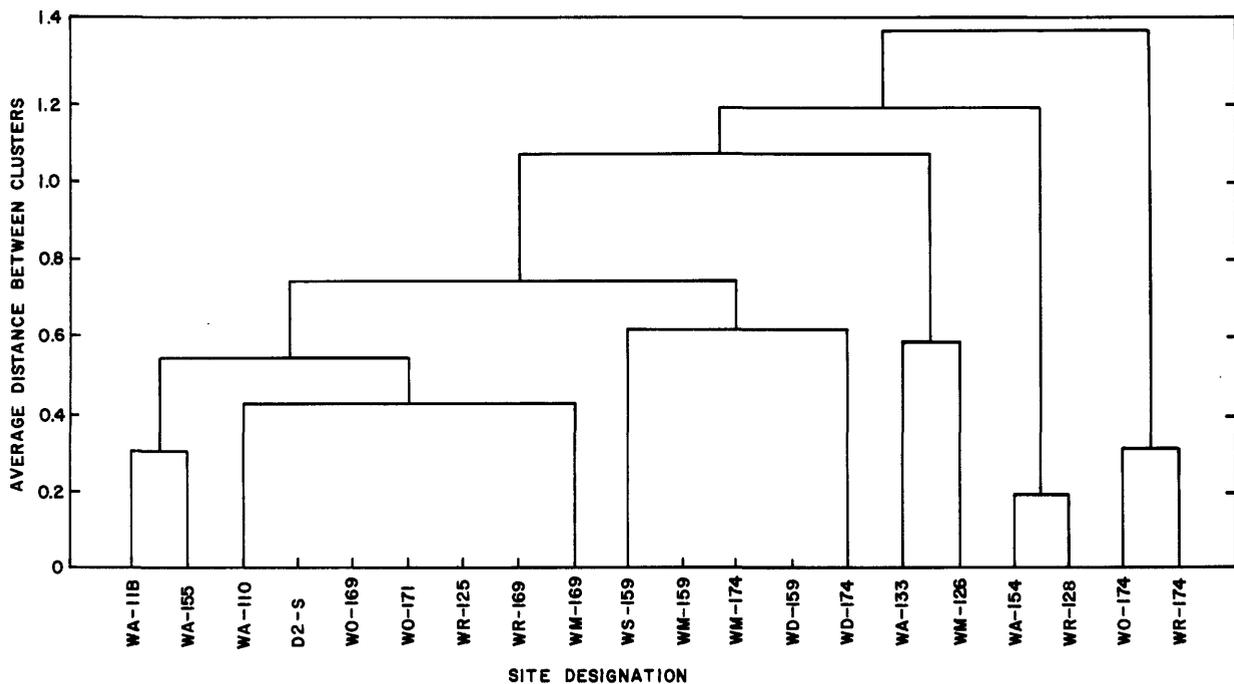


Figure 14.--Cluster diagram for samples from ground-water sites based on stable isotope ratios for deuterium, carbon-13, oxygen-18, and sulfur-34.

was equal to or greater than the variability between groups. The reasons for the variability were not discerned as part of the exploratory data analysis in this study. However, one likely possibility is the occurrence of localized geochemical reactions within each aquifer. Other possibilities include inter-aquifer mixing of water, analytical error, or contamination of samples that could have occurred during sample collection, handling, and analysis.

Based on analyses of the limited number of samples collected in this study, stable-isotope ratios (fig. 14) also did not provide a means to uniquely identify discrete aquifer sources. However, additional sampling of water from each of the six aquifers or testing different isotopes could possibly result in more definitive results by providing greater areal coverage and increasing the data base to minimize the effect of statistical outliers.

### SUMMARY

Water-quality samples were collected during April 1985 from surface-water and ground-water sites in and near East Fork Armells Creek basin in southeastern Montana. Eight surface-water samples were collected at one spring, four sites on East Fork Armells Creek, one site on Stocker Creek, and two fly-ash ponds. Streamflow also was measured on East Fork Armells Creek and Stocker Creek at the time of sampling. Twenty-one water samples were collected from wells completed in either Quaternary alluvium or the Tongue River Member of the Paleocene Fort Union Formation. Aquifers within the Tongue River Member from which samples were collected include mine spoils, Rosebud overburden, Rosebud coal bed, McKay coal bed, and sub-McKay deposits.

Base flow in East Fork Armells Creek upstream from the town of Colstrip was small and interrupted by reaches of no flow. Downstream from Colstrip, streamflow was present in all observed reaches and the stream gained flow. The largest base flow, measured at the most downstream station, was 2.11 ft<sup>3</sup>/s. Stocker Creek was the only tributary observed to contribute surface flow (0.06 ft<sup>3</sup>/s) to East Fork Armells Creek in the study area.

Water from a spring in the headwaters of East Fork Armells Creek was a magnesium bicarbonate type and had a dissolved-solids concentration of 840 mg/L. Water from the five stream sites was a magnesium sulfate type and had dissolved-solids concentrations of 3,100 to 3,500 mg/L, except for water from the site near Colstrip, which had a dissolved-solids concentration of 5,000 mg/L. Water from two fly-ash ponds also was a magnesium sulfate type but had dissolved-solids concentrations of 13,000 and 22,000 mg/L. Concentrations of trace elements in water from the spring and stream sites were typical of those for southeastern Montana. Concentrations of boron and manganese were large in water from the fly-ash ponds, but concentrations of other trace elements were relatively similar to concentrations in water from the spring and streams. Stable-isotope ratios for deuterium, carbon-13, oxygen-18, and sulfur-34 were similar for each element in water from the spring and stream sites. However, water from the fly-ash ponds was isotopically more enriched in deuterium and oxygen-18 than water from the spring and stream sites, probably as a result of evaporation.

Water from wells varied from a magnesium-calcium sulfate type in mine spoils to a sodium sulfate type in the McKay coal bed and sub-McKay deposits. Dissolved-solids concentrations in ground water ranged from 690 mg/L in the Rosebud coal bed

to 4,100 mg/L in alluvium. Water from the Rosebud overburden had the smallest median dissolved-solids concentration (1,300 mg/L) and water from the mine spoils had the largest median concentration (2,800 mg/L). Concentrations of trace elements in water from wells were similar to concentrations in the spring and stream samples, although manganese concentrations generally were smaller and strontium and boron concentrations were considerably larger in several samples. Stable-isotope ratios of ground water were similar to ratios for spring and stream samples but considerably different from ratios for deuterium and oxygen-18 in samples from the fly-ash ponds.

Water from individual aquifers could not be distinguished by either ion-composition diagrams or cluster analyses based on chemical or stable-isotope characteristics. Variability of water quality in samples from the same aquifer was equal to or greater than the variability between different aquifers.

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