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MAGNITUDE AND CHEMICAL QUALITY OF BASE FLOW OF OTTER CREEK, TONGUE RIVER, AND ROSEBUD CREEK, SOUTHEASTERN MONTANA, OCTOBER 26-NOVEMBER 5, 1977

by Roger W. Lee, Steven E. Slagle, and James R. Stimson

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METRIC CONVERSION TABLE

The following factors can be used to convert inch-pound units in this report to the International System (SI) of metric units.

Multiply inch-pound unit	By	To obtain SI unit
cubic foot per second (ft^3/s)	28.32	liter per second
foot	0.3048	meter
mile	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) by the following formula:

$$°C = 0.556\ (°F-32)$$

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ABSTRACT

Hydrologic and chemical data were collected during base-flow conditions on three streams in southeastern Montana from October 26 to November 5, 1977, to characterize the magnitude and chemical quality of base flow. Data collected on Otter Creek, Tongue River, and Rosebud Creek indicate significant downstream changes in flow rate and water quality owing to ground-water discharge.

Maximum measured flow of Otter Creek, an interrupted stream, was 1.2 ft^3/s (cubic feet per second). The water chemistry was dominated by sodium, magnesium, and sulfate ions, with a maximum dissolved-solids concentration of 3,540 milligrams per liter. The chemistry of ground-water inflow was dominated by sodium, magnesium, and sulfate, with one subreach receiving inflow of calcium bicarbonate water having a dissolved-solids concentration of about 1,100 milligrams per liter, probably from a clinker aquifer.

Interpretation of ground-water discharge to the Tongue River downstream from the Tongue River Reservoir was complicated by a discharge of 156 ft^3/s from the reservoir. The maximum flow of the Tongue River was 234 ft^3/s and the flow near the mouth was 233 ft^3/s. Major stratigraphic units of the Paleocene Fort Union Formation traversed by the Tongue River accept water as recharge or discharge water to the stream, depending on location and streamflow conditions. Minor changes in quality of the base flow indicated ground-water discharges that were dominated by sodium, sulfate, and bicarbonate plus carbonate. Dissolved-solids concentrations increased from 506 milligrams per liter near the dam to 630 milligrams per liter near the mouth.

Flow of Rosebud Creek ranged from 2.2 to 19.0 ft^3/s, and 13.6 ft^3/s was measured at the mouth. Water quality in the upstream reaches was dominated by magnesium, calcium, and bicarbonate, with significant amounts of sodium and sulfate; dissolved-solids concentrations ranged from 560 to 703 milligrams per liter. Sodium, sulfate, and dissolved solids increased downstream, indicating that most of the water discharged from aquifers within the Fort Union Formation is of the sodium sulfate type. Maximum dissolved-solids concentration in the downstream reaches was 943 mg/L.

INTRODUCTION

The prospect of large-scale strip mining of shallow coal deposits has increased concern for the water resources in eastern Montana. Some of the mining sites and potential mining sites are near stream channels; many others are in locations remote from streams and may not affect runoff to streams. Regardless of the physical setting, however, activities at any of the mines may disrupt and alter the quantity and quality of ground water that will eventually be discharged to streams.

The purpose of this report is to characterize the magnitude and chemical quality of base flow of one interrupted and two perennial streams in the northern Powder River Basin: Otter Creek, Tongue River, and Rosebud Creek (fig. 1). Streamflow was measured at 64 sites along the three streams between October 26 and November 5, 1977. Water samples for chemical analysis also were collected at 27 selected locations where streamflow measurements were made. The water samples were analyzed for chemical characteristics by the U.S. Geological Survey's water-quality laboratory in Denver, Colo.

This study is part of a program started by the Geological Survey in 1974 to define the pre-mining water resources and to assess the potential effects of coal development in the northern Powder River Basin. This report, prepared in cooperation with the U.S. Environmental Protection Agency and the U.S. Bureau of Land Management, represents the first in a series of base-flow investigations of streams in the coal region of eastern Montana.

Appreciation is expressed to the landowners who allowed access to their property for discharge measurements and water sampling. Appreciation also is extended to the personnel of the Northern Cheyenne Research Project for supplying streamflow and water-quality data for Lame Deer and Muddy Creeks.

GEOLOGIC SETTING

Geologic formations having the most significant effect on streamflow are those that immediately underlie the stream valleys. Bedrock formations transected by the streams in the study area are the Hell Creek Formation of Late Cretaceous age and the Fort Union Formation of Paleocene age. Alluvium of Holocene age underlies the channels of the streams.

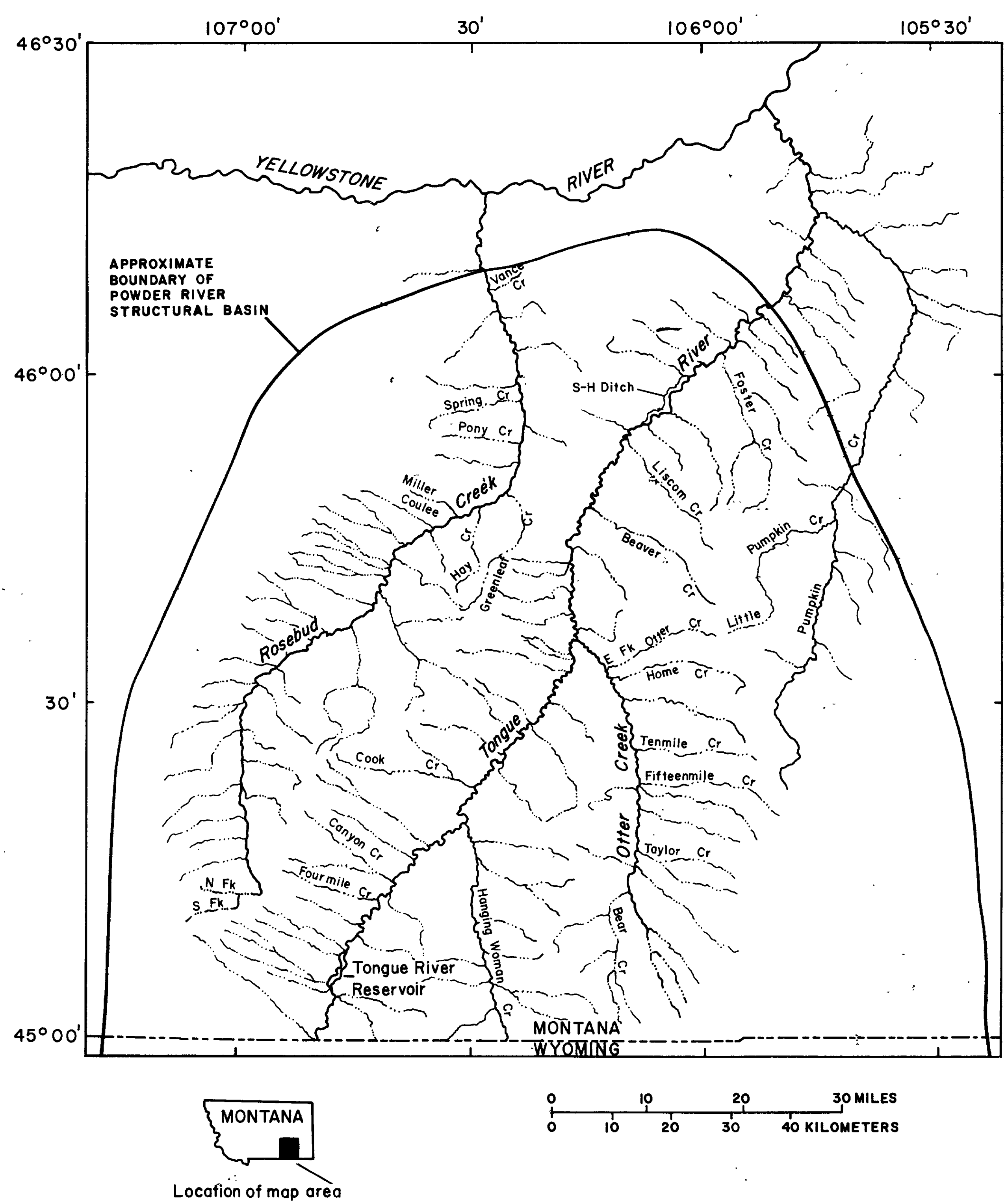


Figure 1.--Location of study area.

The Hell Creek Formation consists principally of gray to yellowish-gray siltstone and silty, sandy, carbonaceous, and bentonitic shale. Locally, yellowish-gray to tan fine- to medium-grained silty sandstone with thin coal beds predominates. The formation is as much as 850 feet thick in the study area.

The Fort Union Formation is composed of the basal Tullock Member, the intervening Lebo Shale Member, and the overlying Tongue River Member. The lower part of the Tullock Member is composed of interbedded medium- to light-gray shale, light-gray fine-grained sandstone, siltstone, and persistent thin coal beds. The member grades upward to light-gray carbonaceous shale. The Tullock Member in the study area is as much as 800 feet thick.

The Lebo Shale Member comprises as much as 600 feet of predominantly dark shale interbedded with light-gray and brown to black carbonaceous shale, siltstone, and local thin coal beds. Locally, the member contains coarse-grained channel sandstone.

Included in the Tongue River Member is as much as 2,500 feet of fine- to medium-grained massive to locally crossbedded and lenticular sandstone and siltstone. The member commonly contains shale and numerous coal beds as much as 80 feet thick. Burning of coal beds along the outcrops has baked the overlying and underlying rocks to form red and lavender clinker.

Alluvium along the streams contains sand, silt, clay, and local lenses of gravel. Gravel consists of clinker fragments on many smaller streams. Deposits are as much as 75 feet thick along the Tongue River and as much as 40 feet thick along smaller streams. This unit includes many low-lying terraces adjacent to streams. A more complete discussion of the geology is contained in the report by Lewis and Roberts (1978).

HYDROLOGIC SETTING

The Tongue River Member contains the principal aquifers in the study area. Water is transmitted through sandstone, coal, and clinker. Interbedded shale and relatively impermeable siltstone are confining layers that restrict ground-water recharge, movement, and discharge.

Shallow water, at depths generally less than 200 feet below land surface, is contained in many localized systems, with water tables generally paralleling the topography. Ground water generally moves from near the basin divide toward the major stream in each drainage basin. Recharge occurs within each drainage basin between the divide and the principal stream. Water flow in aquifers at depths of greater than about 200 feet is more regional and is not as subject to local factors such as topography and localized recharge.

Base flow consists almost entirely of ground water discharged from the shallow system. Upward leakage from deeper artesian aquifers to the streams may occur, but the amount is probably small.

DATA COLLECTION

Data collection began on October 26, 1977, and continued through November 5, 1977. Some data were collected and records computed by contractors in accordance with U.S. Geological Survey specifications and under Geological Survey quality control.

Data collection commenced 15 days after a killing frost on October 11. Vegetation generally was dormant, using negligible amounts of ground water through transpiration. Sufficient time had elapsed since cessation of evapotranspiration to permit streamflow to stabilize. Records from gaging stations on the streams showed minimal variations in streamflow and diel fluctuations were not evident.

Some precipitation was recorded in the study area during the measurement period. However, no overland flow was observed, and gaging-station records showed no indication of increased runoff. The last storm that produced overland flow in the area occurred on October 7 and 8. Gaging-station records for Rosebud Creek showed a small peak at Colstrip on October 21 and at the mouth on October 24; however, weather records showed no precipitation in the area during this period. Minimal evapotranspiration and the lack of rainfall lead to the conclusion that the predominant factors affecting streamflow and water quality were ground-water discharge to the streams (gain in streamflow) in some reaches and recharge to the ground-water system from the streams (loss in streamflow) in other reaches.

Potential measuring sites were initially selected from Geological Survey 7 1/2-minute topographic maps to provide a guide for access and to provide good accountability of tributary inflow. Landowners were contacted and an onsite reconnaissance was made of each potential location to assess adequacy of the site and to locate a suitable streamflow measuring section. Locations of streams and sampling sites are shown on plate 1.

Concurrent with main-stem streamflow measurements, points of suspected tributary inflow and diversion points were checked onsite and documented, and water samples were collected for chemical analysis. Specific conductance, dissolved oxygen, and pH were measured onsite for about one-third of the locations at which discharge measurements were made. Where flow was present, water temperature was measured at all sites except two.

BASE-FLOW CHARACTERISTICS

Otter Creek

Otter Creek drains an area of about 700 mi^2 (pl. 1). The stream heads near the Montana-Wyoming border and flows to the Tongue River at Ashland, Mont. Major tributaries to this 90-rivermile-long interrupted stream are indicated on the streamflow profile (fig. 2). The stream flows over rocks of the Tongue River Member of the Fort Union Formation only, but transects several

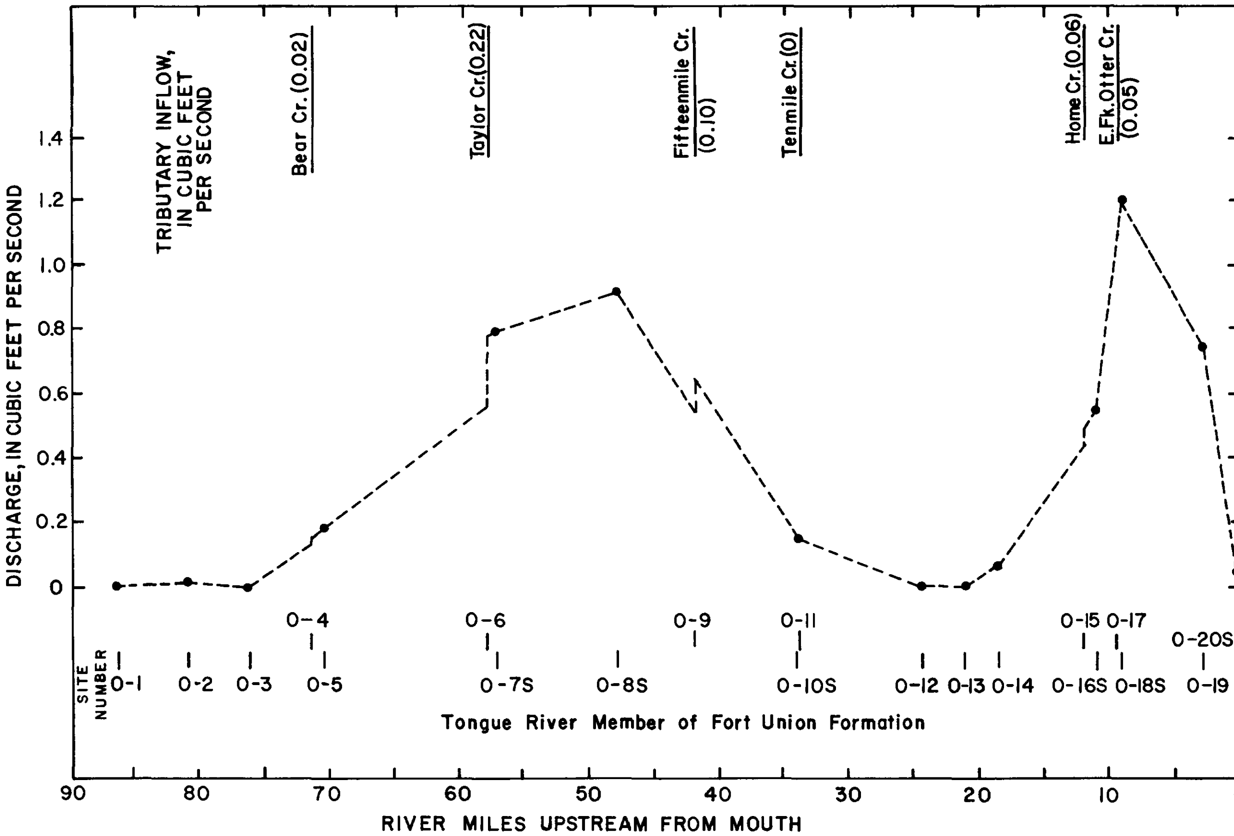


Figure 2.--Generalized streamflow profile of Otter Creek, October 26-28, 1977.

different lithologic units. Most ground-water discharge to Otter Creek is from sandstones in the Tongue River Member and from the alluvium.

During October 26-28, 1977, discharge was measured at 15 sites and water-quality samples were collected at 6 sites. A condition of no flow was observed at five sites on Otter Creek and its tributaries. Results of the discharge measurements and water-quality analyses are given in tables 1 and 2.

Reaches of major gain and loss are indicated by the streamflow profile (fig. 2). Streamflow measurements indicate flow began between sites 0-3 and 0-5 and increased through site 0-8S. Flow decreased downstream from site 0-8S and then disappeared between sites 0-10S and 0-12. Flow began again between sites 0-13 and 0-14 and increased rapidly to a measured maximum of 1.2 ft^3/s at site 0-18S. Flow decreased rapidly to 0.04 ft^3/s near the mouth.

Stiff diagrams (fig. 3) show the proportions of dissolved species in streamflow at the sampling sites. Overall, stream quality is dominated by sodium and sulfate.

Table 1.--*Discharge and temperature of Otter Creek during base flow, October 26-28, 1977*

[ft^3/s, cubic feet per second; °C, degrees Celsius]

Site number	Location	Stream	Date	Time	Discharge (ft^3/s)	Water temperature (°C)
0-1	NW1/4 SW1/4 sec. 4, T. 9 S., R. 46 E.	Otter Cr.	10-26	0900	No flow	--
0-2	NE1/4 SE1/4 sec. 18, T. 8 S., R. 46 E.	Otter Cr.	10-26	0940	0.01	5.0
0-3	NE1/4 NW1/4 sec. 31, T. 7 S., R. 46 E.	Otter Cr.	10-26	1000	No flow	--
0-4	NE1/4 NW1/4 sec. 24, T. 7 S., R. 45 E.	Bear Cr.	10-26	1020	.02	6.0
0-5	SW1/4 SE1/4 sec. 13, T. 7 S., R. 45 E.	Otter Cr.	10-26	1100	.18	15.0
0-6	NW1/4 SE1/4 sec. 30, T. 6 S., R. 46 E.	Taylor Cr.	10-26	1240	.22	11.0
0-7S	NE1/4 NW1/4 sec. 30, T. 6 S., R. 46 E.	Otter Cr.	10-26	1205	.79	9.0
0-8S	SE1/4 SW1/4 sec. 35, T. 5 S., R. 45 E.	Otter Cr.	10-26	1400	.92	9.5
0-9	NW1/4 SE1/4 sec. 23, T. 5 S., R. 45 E.	Fifteen-mile Cr.	10-26	1440	.10	11.0
0-10S	SE1/4 NW1/4 sec. 2, T. 5 S., R. 45 E.	Otter Cr.	10-27	0935	.15	8.0
0-11	NW1/4 NE1/4 sec. 2, T. 5 S., R. 45 E.	Ten-mile Cr.	10-26	1530	No flow	--
0-12	NW1/4 NW1/4 sec. 22, T. 4 S., R. 45 E.	Otter Cr.	10-27	1015	No flow	--
0-13	SE1/4 NE1/4 sec. 9, T. 4 S., R. 45 E.	Otter Cr.	10-27	1035	No flow	--
0-14	NE1/4 NW1/4 sec. 4, T. 4 S., R. 45 E.	Otter Cr.	10-27	1125	.06	8.5
0-15	SE1/4 SE1/4 sec. 29, T. 3 S., R. 45 E.	Home Cr.	10-27	1148	.06	8.5
0-16S	NW1/4 SW1/4 sec. 29, T. 3 S., R. 45 E.	Otter Cr.	10-27	1230	.55	10.0
0-17	SW1/4 NW1/4 sec. 20, T. 3 S., R. 45 E.	E. Fork Otter Cr.	10-27	1330	.05	9.0
0-18S	SE1/4 SE1/4 sec. 19, T. 3 S., R. 45 E.	Otter Cr.	10-27	1355	1.2	10.5
0-19	NE1/4 SE1/4 sec. 11, T. 3 S., R. 44 E.	Otter Cr.	10-28	1055	.75	8.5
0-20S	SW1/4 SW1/4 sec. 2, T. 3 S., R. 44 E.	Otter Cr.	10-28	1220	.04	11.0

Table 2.--*Chemical analyses of Otter Creek during base flow, October 26-28, 1977*

[Except as indicated otherwise, constituents are dissolved and constituent values are reported in milligrams per liter; micromhos, micromhos per centimeter at 25 degrees Celsius; °C, degrees Celsius; µg/L, micrograms per liter]

Site number	Date	Laboratory specific conductance (micromhos)	Onsite pH (units)	Water temperature (°C)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)
0-7S	10-26	2,650	8.2	9.0	110	180	300	16
0-8S	10-26	2,270	8.2	9.5	19	160	250	17
0-10S	10-27	4,420	8.1	8.5	83	290	630	26
0-16S	10-27	3,950	8.3	10.0	96	230	570	26
0-18S	10-27	3,200	8.3	11.0	73	140	370	20
0-20S	10-28	2,600	---	11.0	82	150	390	20

Site number	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Silica (SiO_2)	Dissolved solids residue at 180°C	Nitrite plus nitrate, total as N
0-7S	630	0	1,100	10	0.8	16	2,000	0.02
0-8S	610	0	840	9.8	.8	15	1,650	.25
0-10S	700	0	2,100	24	.6	4.1	3,540	.06
0-16S	830	0	1,600	14	1.2	7.1	3,050	.04
0-18S	730	0	980	15	.9	12	1,970	.02
0-20S	620	0	1,100	10	1.0	13	2,140	.47

Site number	Nitrogen, ammonia, total as NH_4	Nitrogen, total organic as N	Nitrogen, total kjeldahl as N	Phosphorus, total as P	Boron (B) (µg/L)	Iron (Fe) (µg/L)	Carbon, organic as C	Carbon, organic suspended as C
0-7S	0.01	0.19	0.20	0.01	330	280	6.5	0.6
0-8S	.14	.42	.56	.05	300	30	7.2	.9
0-10S	.07	.71	.78	.03	660	50	9.8	.9
0-16S	.00	.71	.71	.07	680	30	12.0	.7
0-18S	.03	.32	.35	.06	220	30	2.6	1.3
0-20S	.03	.59	.56	.00	470	30	7.8	1.7

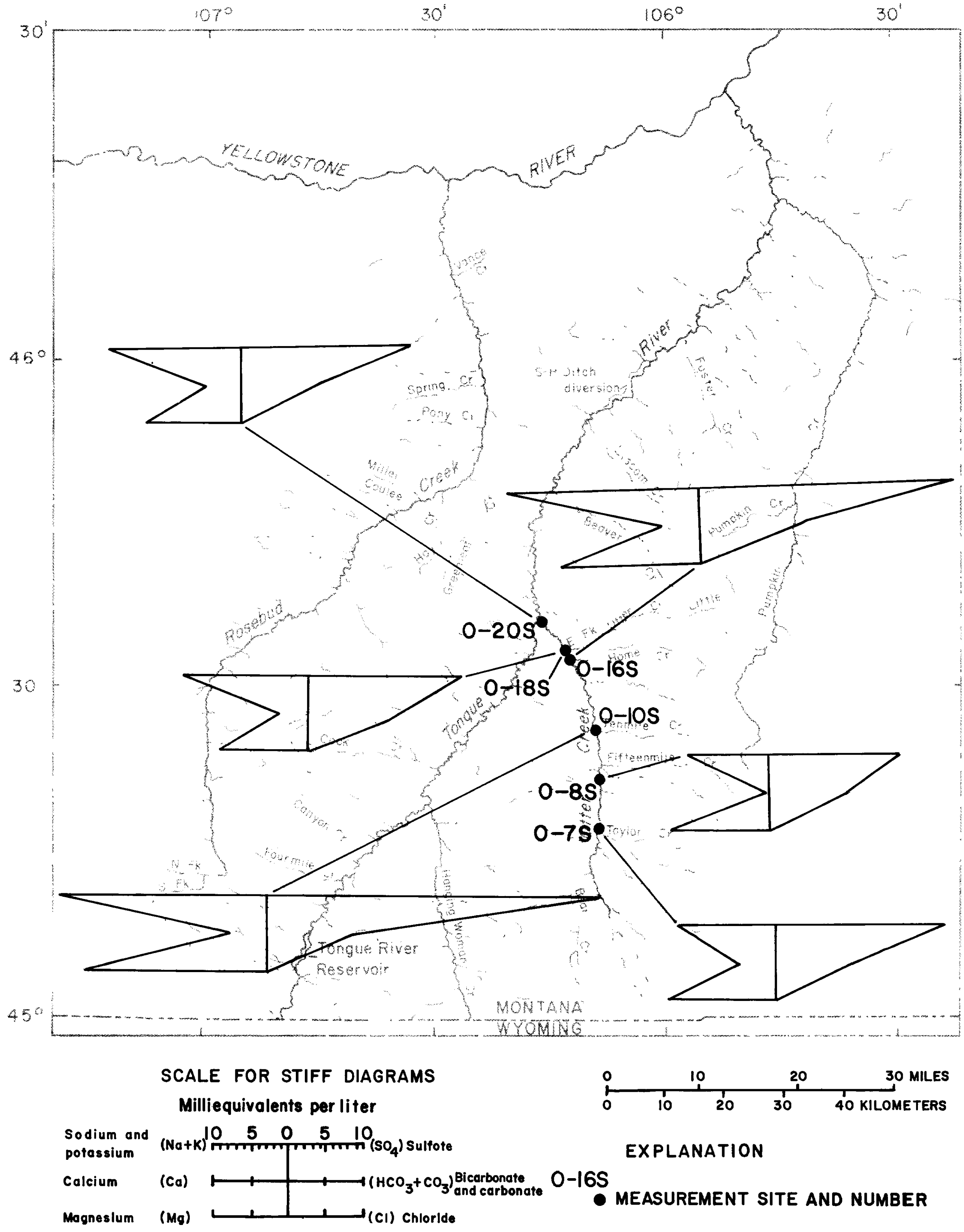


Figure 3.--Stiff diagrams of water quality for Otter Creek, October 26-28, 1977.

At site 0-7S, the water contained principally magnesium, sodium, and sulfate and had a dissolved-solids concentration of 2,000 mg/L (milligrams per liter). Water quality changed slightly downstream at site 0-8S where calcium, sodium, and sulfate decreased. Bicarbonate and magnesium decreased only slightly compared to other constituents (fig. 4). The dissolved-solids concentration at site 0-8S was 1,650 mg/L. The decrease indicated an overall dilution of water downstream from site 0-7S by inflow of water that had less concentration of dissolved solids, had similar proportions of most major ions, and was proportionately greater in bicarbonate and magnesium.

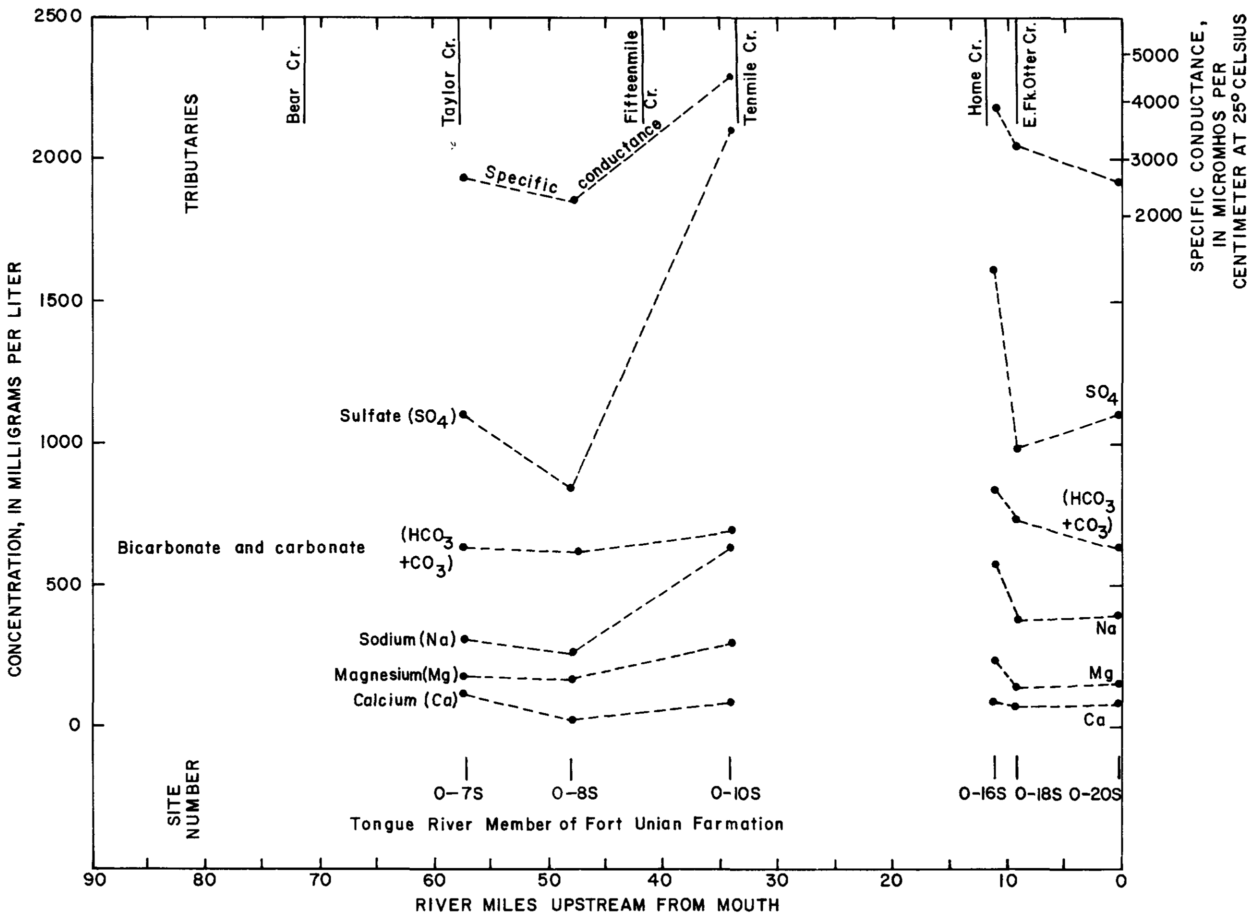
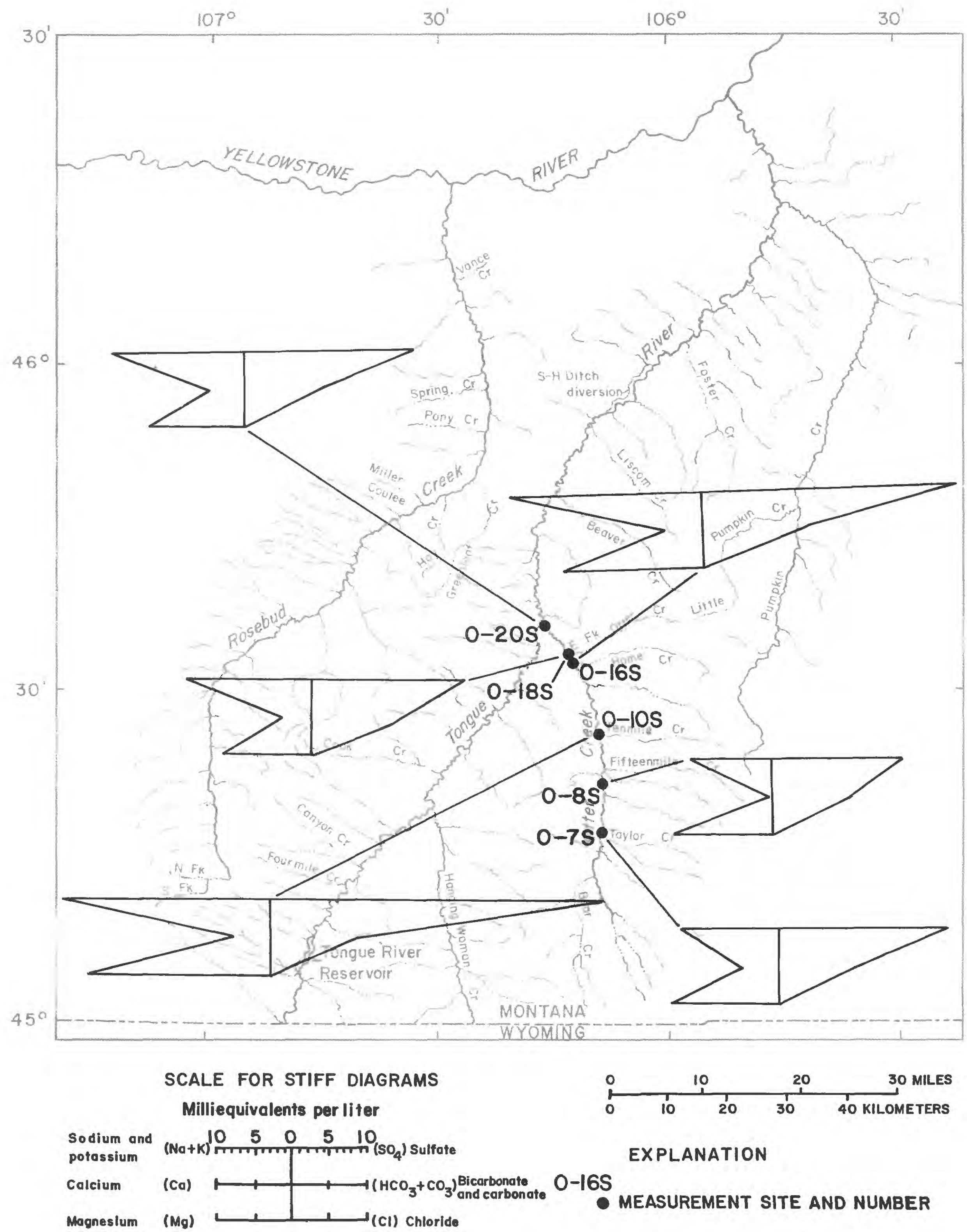


Figure 4.--Profiles of major-ion concentration and specific conductance for Otter Creek, October 26-28, 1977.

Between sites 0-8S and 0-10S, all solute concentrations increased, especially sodium and sulfate, accompanied by a significant decrease in flow. Rather than streamflow in this reach only being lost to the aquifer, which would produce no water-quality change, the data indicate the presence of both gaining and losing reaches, with the overall exchange being a loss. Flow disappeared between sites 0-10S and 0-12.



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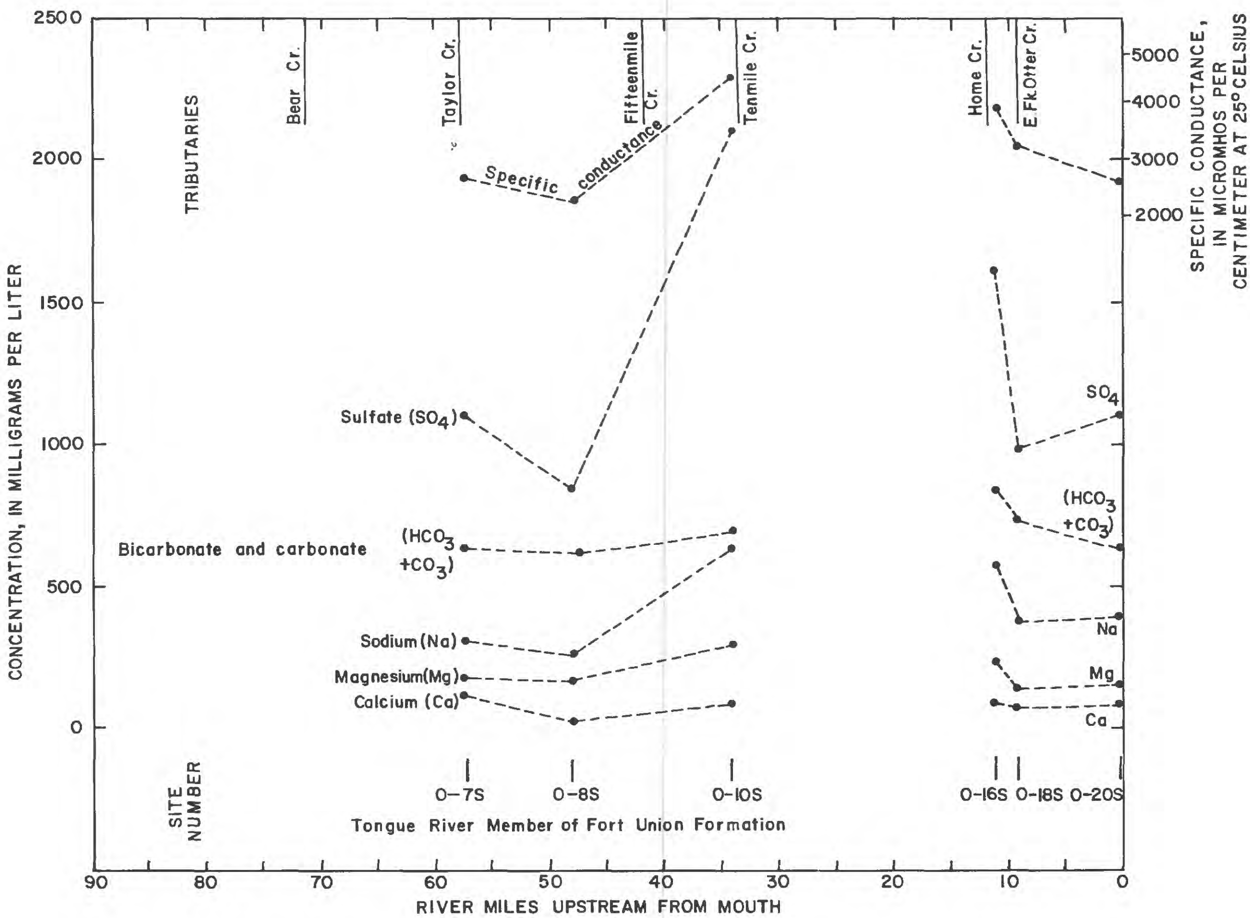

Figure 4.--Profiles of major-ion concentration and specific conductance for Otter Creek, October 26-28, 1977.

Between sites 0-8S and 0-10S, all solute concentrations increased, especially sodium and sulfate, accompanied by a significant decrease in flow. Rather than streamflow in this reach only being lost to the aquifer, which would produce no water-quality change, the data indicate the presence of both gaining and losing reaches, with the overall exchange being a loss. Flow disappeared between sites 0-10S and 0-12.

Site 0-16S was the first location a sample was collected downstream following reappearance of streamflow. The water at site 0-16S was dominated by sodium, magnesium, and sulfate and had a dissolved-solids concentration of 3,050 mg/L, which is typical of ground water in the area. Between sites 0-16S and 0-18S, a distance of 2 river miles, a significant increase in flow was measured (0.55 to 1.2 ft^3/s) accompanied by a net decrease in dissolved-solids concentration. Because no significant tributary inflows or irrigation returns were observed, the data indicate a sizable ground-water discharge consisting of water having concentrations of dissolved solids of about 1,100 mg/L and being dominated by calcium, magnesium, and bicarbonate. Water having short residence time in an aquifer containing limited soluble material, such as clinker, is the probable source of this discharge. From site 0-18S to site 0-20S, which is near the mouth of Otter Creek, sodium, sulfate, and dissolved-solids concentrations increased slightly.

Tongue River

The Tongue River drains an area of about 2,100 mi^2 in southeastern Montana downstream from the dam of the Tongue River Reservoir near Decker (pl. 1). The Tongue River is one of the largest perennial streams in the Powder River Basin, and it traverses all three members of the Fort Union Formation in flowing 189 river miles from the dam to the mouth. The major stratigraphic units crossed by the Tongue River accept water as recharge or discharge water to the stream, depending on location and streamflow conditions. Major tributaries are shown on the streamflow profile (fig. 5). Interpretation of the relationship of base flow to ground-water discharge was complicated by the sizable discharge from the Tongue River Reservoir (156 ft^3/s) measured at site T-1S.

During the sampling period, discharge was measured at 31 sites and water-quality samples were collected at 12 sites. A condition of no flow was observed at four sites on tributaries. Results of the discharge measurements are listed in table 3 and water-quality analyses are given in table 4.

Reaches of gain and loss of the Tongue River are shown by the streamflow profile (fig. 5). The magnitudes of gain and loss are significant, even though the fluctuations are proportionately small in comparison to the reservoir discharge. A sizable loss (24 ft^3/s) occurred between sites T-20 and T-22S where the stream crosses the Tongue River Member-Lebo Shale Member contact. A sizable gain (28 ft^3/s) occurred between T-26 and T-27S where the stream crosses the Lebo Shale Member-Tullock Member contact. A part of this gain can probably be attributed to subsurface return flow from adjacent land irrigated by a diversion ditch that originates about 0.2 mile upstream from site T-26. Net change in streamflow from the dam to the mouth was a gain of 77 ft^3/s.

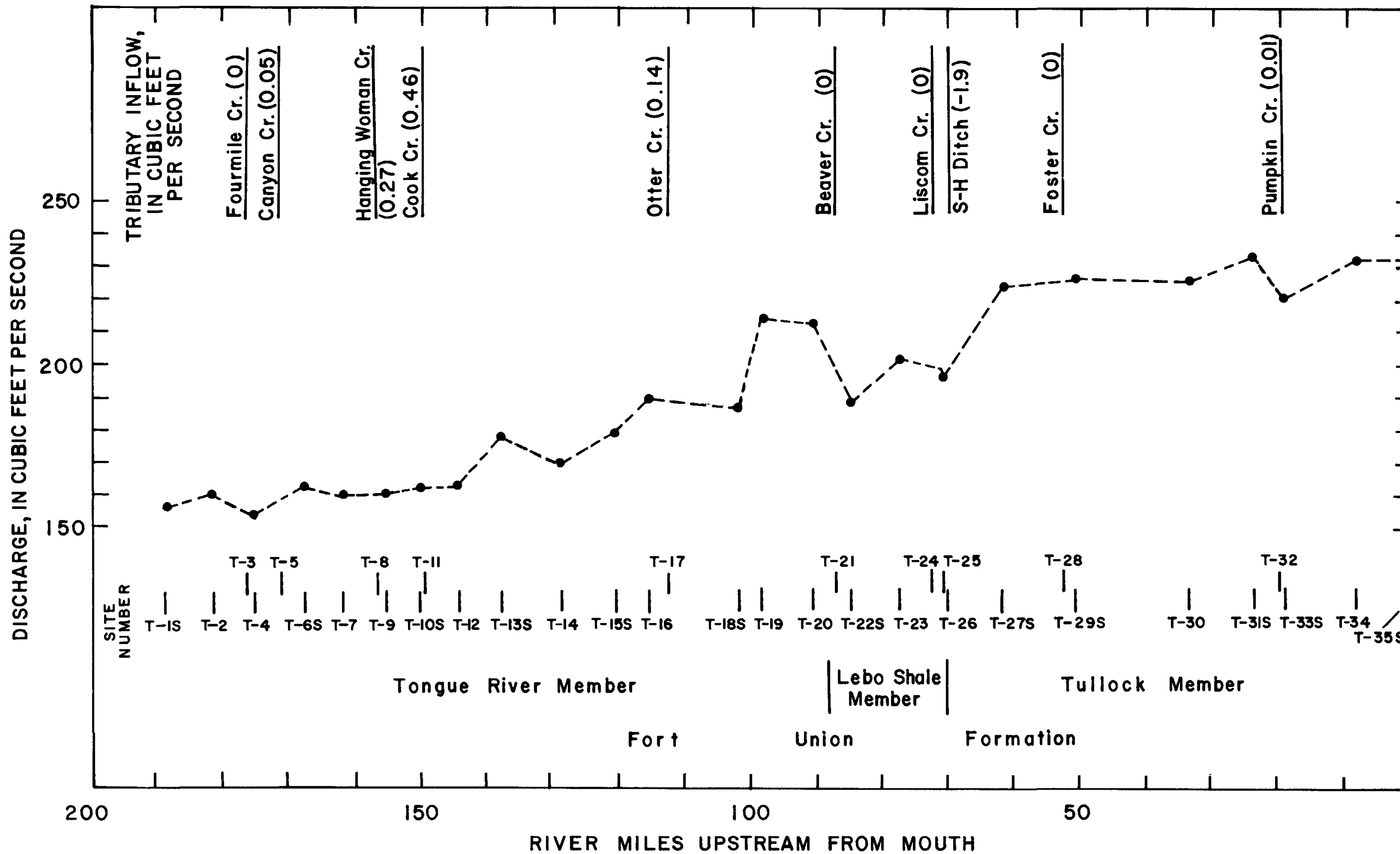

Figure 5.--Generalized streamflow profile of the Tongue River, November 2-5, 1977.

Table 3.--*Discharge and temperature of the Tongue River during base flow, November 2-5, 1977*

[ft3/s, cubic feet per second; °C, degrees Celsius]

Site number	Location	Stream	Date	Time	Discharge (ft^3/s)	Water temperature (°C)
T-1S	SE1/4 SE1/4 sec. 12, T. 8 S., R. 40 E.	Tongue R.	11-2	1415	156	10.0
T-2	SE1/4 SE1/4 sec. 32, T. 7 S., R. 41 E.	Tongue R.	11-2	1620	160	10.0
T-3	NW1/4 NE1/4 sec. 28, T. 7 S., R. 41 E.	Fourmile Cr.	11-2	----	No flow	--
T-4	SW1/4 NE1/4 sec. 22, T. 7 S., R. 41 E.	Tongue R.	11-3	0835	154	7.0
T-5	NW1/4 SE1/4 sec. 11, T. 7 S., R. 41 E.	Canyon Cr.	11-3	0940	.05	5.0
T-6S	NE1/4 SE1/4 sec. 31, T. 6 S., R. 42 E.	Tongue R.	11-3	1120	162	9.0
T-7	NE1/4 NE1/4 sec. 27, T. 6 S., R. 42 E.	Tongue R.	11-3	1300	159	8.5
T-8	NW1/4 NW1/4 sec. 18, T. 6 S., R. 43 E.	Hanging Woman Cr.	11-3	1415	.27	6.5
T-9	SE1/4 SE1/4 sec. 1, T. 6 S., R. 42 E.	Tongue R.	11-3	1530	160	8.0
T-10S	NE1/4 NW1/4 sec. 25, T. 5 S., R. 42 E.	Tongue R.	11-3	0755	163	4.5
T-11	NE1/4 NW1/4 sec. 25, T. 5 S., R. 42 E.	Cook Cr.	11-3	0955	.46	4.5
T-12	SW1/4 SW1/4 sec. 8, T. 5 S., R. 43 E.	Tongue R.	11-3	0745	163	5.0
T-13S	NE1/4 NW1/4 sec. 34, T. 4 S., R. 43 E.	Tongue R.	11-3	1115	178	5.0
T-14	SE1/4 NW1/4 sec. 8, T. 4 S., R. 44 E.	Tongue R.	11-3	0950	170	5.0
T-15S	NW1/4 NE1/4 sec. 28, T. 3 S., R. 44 E.	Tongue R.	11-3	1340	183	6.0
T-16	SE1/4 NW1/4 sec. 10, T. 3 S., R. 44 E.	Tongue R.	11-3	1145	190	5.0
T-17	SW1/4 SW1/4 sec. 2, T. 3 S., R. 44 E.	Otter Cr.	11-3	1230	.14	--
T-18S	SE1/4 SW1/4 sec. 10, T. 2 S., R. 44 E.	Tongue R.	11-4	0720	187	3.0
T-19	NW1/4 SW1/4 sec. 27, T.1 S., R. 44 E.	Tongue R.	11-3	1540	215	6.5

Table 3.--*Discharge and temperature of the Tongue River during base flow, November 2-5, 1977*--Continued

Site number	Location	Stream	Date	Time	Dis-charge (ft^3/s)	Water tem-pera-ture (°C)
T-20	SE1/4 NW1/4 sec. 2, T. 1 S., R. 44 E.	Tongue R.	11-4	0755	213	4.5
T-21	SE1/4 NE1/4 sec. 34, T. 1 N., R. 44 E.	Beaver Cr.	11-4	0720	No flow	--
T-22S	SW1/4 NE1/4 sec. 14, T. 1 N., R. 44 E.	Tongue R.	11-4	0830	189	4.0
T-23	SW1/4 NW1/4 sec. 6, T. 1 N., R. 45 E.	Tongue R.	11-4	1000	202	4.5
T-24	SE1/4 NW1/4 sec. 33, T. 2 N., R. 45 E.	Liscom Cr.	11-4	0900	No flow	--
T-25	NW1/4 SW1/4 sec. 16, T. 2 N., R. 45 E.	S-H Ditch	11-4	1240	1.9*	6.0
T-26	NW1/4 SW1/4 sec. 16, T. 2 N., R. 45 E.	Tongue R.	11-4	1220	197	5.0
T-27S	SE1/4 SW1/4 sec. 30, T. 3 N., R. 46 E.	Tongue R.	11-4	1005	225	4.0
T-28	SE1/4 NW1/4 sec. 12, T. 3 N., R. 46 E.	Foster Cr.	11-4	0945	No flow	--
T-29S	SE1/4 NW1/4 sec. 6, T. 3 N., R. 47 E.	Tongue R.	11-4	1055	227	4.5
T-30	SE1/4 NW1/4 sec. 6, T. 4 N., R. 48 E.	Tongue R.	11-4	1545	226	7.0
T-31S	SW1/4 SE1/4 sec. 6, T. 5 N., R. 48 E.	Tongue R.	11-4	1245	234	7.0
T-32	NW1/4 SW1/4 sec. 35, T. 6 N., R. 48 E.	Pumpkin Cr.	11-5	0900	.01	3.5
T-33S	NW1/4 SE1/4 sec. 19, T. 6 N., R. 48 E.	Tongue R.	11-4	1345	221	6.5
T-34	NW1/4 SE1/4 sec. 23, T. 7 N., R. 47 E.	Tongue R.	11-5	1045	233	6.0
T-35S	NW1/4 SW1/4 sec. 33, T. 8 N., R. 47 E.	Tongue R.	11-5	0755	233	3.0

*Diversion from Tongue River

Table 4.--*Chemical analyses of the Tongue River during base flow, November 2-5, 1977.*

[Except as indicated otherwise, constituents are dissolved and constituent values are reported in milligrams per liter; micromhos, micromhos per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, micrograms per liter]

Site number	Date	Laboratory specific conductance (micromhos)	Onsite pH (units)	Water temperature (°C)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)
T-1S	11-2	758	8.0	10.0	65	49	37	4.4	270	0	210	3.4
T-6S	11-3	772	7.6	9.0	60	49	39	4.4	260	0	210	3.5
T-10S	11-3	790	8.2	4.5	67	51	42	4.5	270	0	220	3.5
T-13S	11-3	813	8.5	5.0	64	53	45	4.6	240	28	230	3.7
T-15S	11-3	818	8.7	6.0	65	52	45	4.5	280	14	230	3.6
T-18S	11-4	830	8.4	3.0	65	54	47	4.7	260	12	230	3.8
T-22S	11-4	855	7.7	4.0	68	52	50	4.9	290	0	240	4.0
T-27S	11-4	861	8.4	4.0	68	53	54	4.9	270	12	240	4.2
T-29S	11-4	887	7.2	4.5	66	55	57	5.0	300	0	250	4.3
T-31S	11-4	905	8.5	7.0	67	54	60	5.0	280	12	250	4.5
T-33S	11-4	914	7.9	6.5	69	53	53	5.1	300	0	250	4.3
T-35S	11-5	940	8.6	3.0	67	54	76	4.9	300	26	260	4.7

Site number	Fluoride (F)	Silica (SiO_2)	Dissolved solids, residue at 180°C	Nitrite plus nitrate, total as N	Nitrogen, ammonia total as NH_4	Nitrogen total organic as N	Nitrogen, total kjeldahl as N	Phosphorus, total as P	Boron (B) (μg/L)	Iron (Fe) (μg/L)	Carbon, organic as C	Carbon, organic suspended as C
T-1S	0.3	5.9	506	0.01	0.05	0.71	0.76	0.02	120	30	6.9	0.8
T-6S	.3	3.0	514	.01	.02	.33	.35	.01	110	30	4.9	.6
T-10S	.3	4.5	535	.01	.01	.49	.50	.01	110	40	4.2	.6
T-13S	.3	4.9	548	.00	.01	.36	.37	.01	110	30	4.2	.4
T-15S	.3	5.0	549	.01	.01	.19	.20	.02	110	20	4.1	.6
T-18S	.3	5.2	557	.00	.01	.24	.25	.01	120	20	4.2	---
T-22S	.3	5.6	567	.00	.01	.31	.32	.01	130	20	3.7	.4
T-27S	.4	6.2	596	.00	.01	.36	.37	.00	130	30	4.1	.8
T-29S	.3	6.0	590	.00	.01	.29	.30	.01	130	20	3.6	.3
T-31S	.3	6.2	617	.01	.01	.17	.18	.01	100	20	4.0	.6
T-33S	.4	6.2	607	.01	.01	.33	.34	.00	130	20	3.7	---
T-35S	.3	6.6	630	.02	.01	.34	.35	.02	140	30	3.7	---

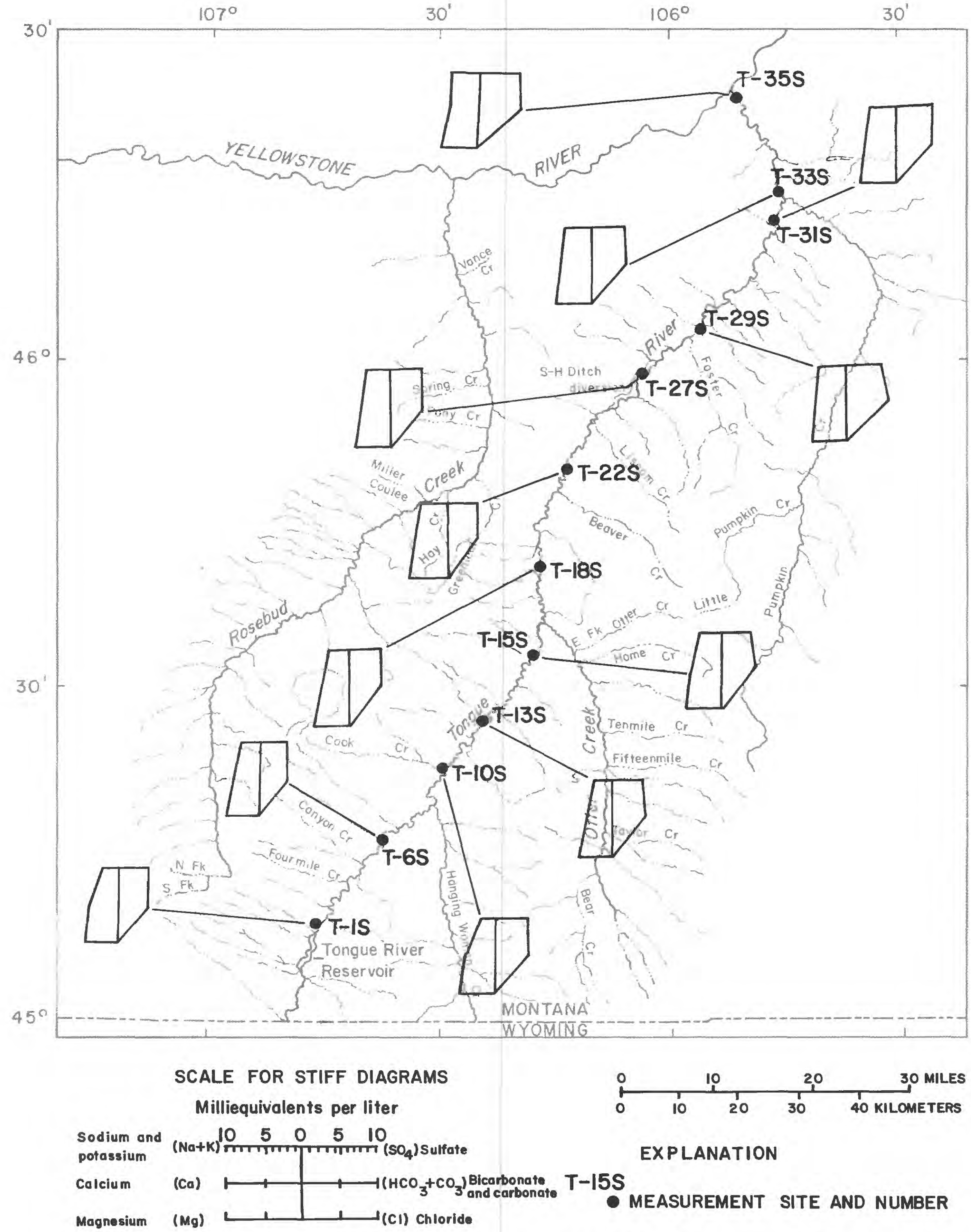

Figure 6.--Stiff diagrams of water quality for the Tongue River, November 2-5, 1977.

Water quality changed only slightly along the study reach of the Tongue River (fig. 6), primarily because the large flow from the reservoir masked the proportionately smaller ground-water discharges. Calcium, magnesium, and potassium generally increased slightly downstream (fig. 7). Sodium, bicarbonate plus carbonate, and sulfate showed the largest increases from upstream to downstream, which may be an indication of the chemical composition of the ground water being added to streamflow. Dissolved-solids concentration increased downstream from 506 to 630 mg/L. Ground-water exchanges, and the accompanying water-quality changes as the stream crosses the various geologic units, could be assessed more accurately under the more ideal condition of base flow without reservoir discharge.

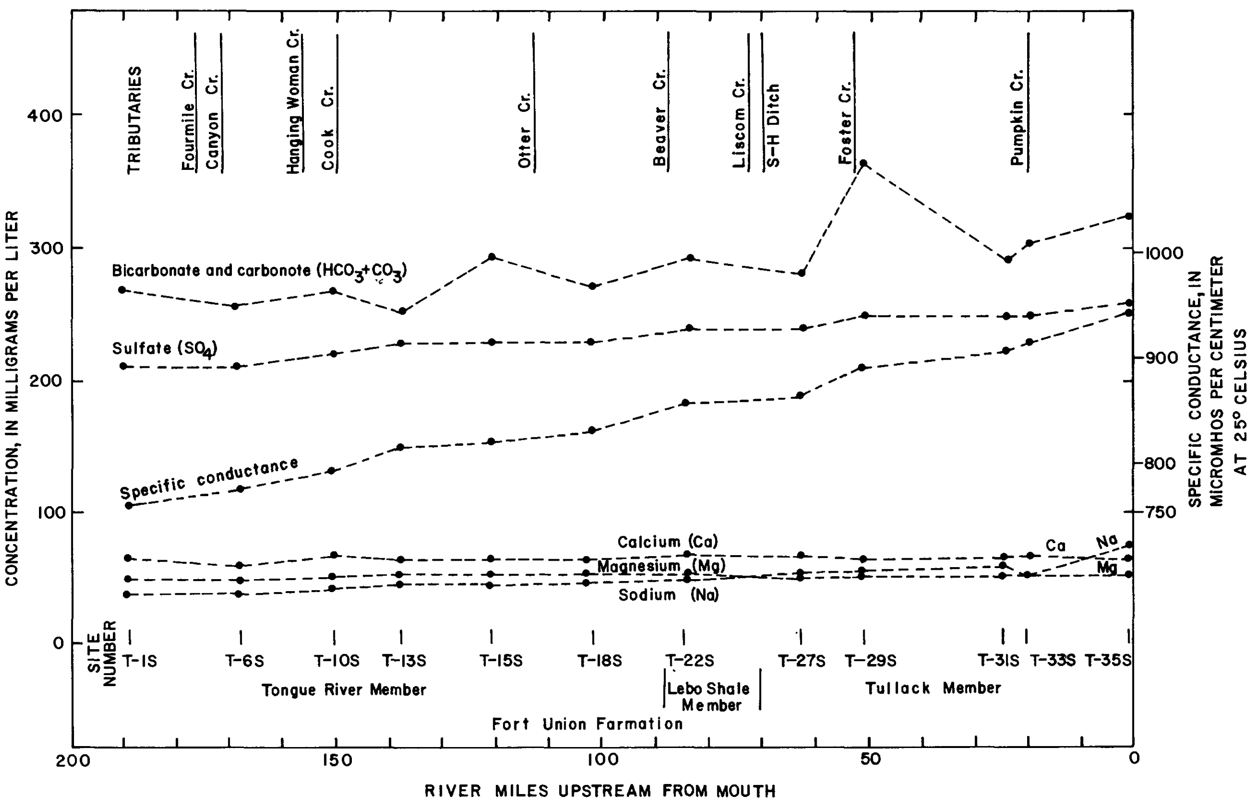

Figure 7.--Profiles of major-ion concentration and specific conductance for the Tongue River, November 2-5, 1977.

Rosebud Creek

Rosebud Creek drains an area of about 1,300 mi^2 in southeastern Montana (pl. 1). The stream heads south of Kirby and flows north about 200 river miles to the Yellowstone River at Rosebud, Mont. Major tributaries to this perennial stream are shown in figure 8.

During the sampling period October 31-November 2, 1977, discharge was measured or estimated at 19 sites and water-quality samples were collected at 9 sites. A condition of no flow was observed at five sites on tributaries. Results of the discharge measurements are listed in table 5 and water-quality analyses are given in table 6.

Significant gains and losses are shown graphically on figure 8. Streamflow in the upper reaches of Rosebud Creek tended to gain after an initial loss between sites R-1S and R-2. Where the stream crosses the lower part of the Tongue River Member, Lebo Shale Member, Tullock Member, and Hell Creek Formation from site R-7 to the mouth, there was a net loss in streamflow, indicating some recharge to these units. Streamflow decreased from a maximum of 19.0 ft^3/s at site R-7 to 13.6 ft^3/s at the mouth.

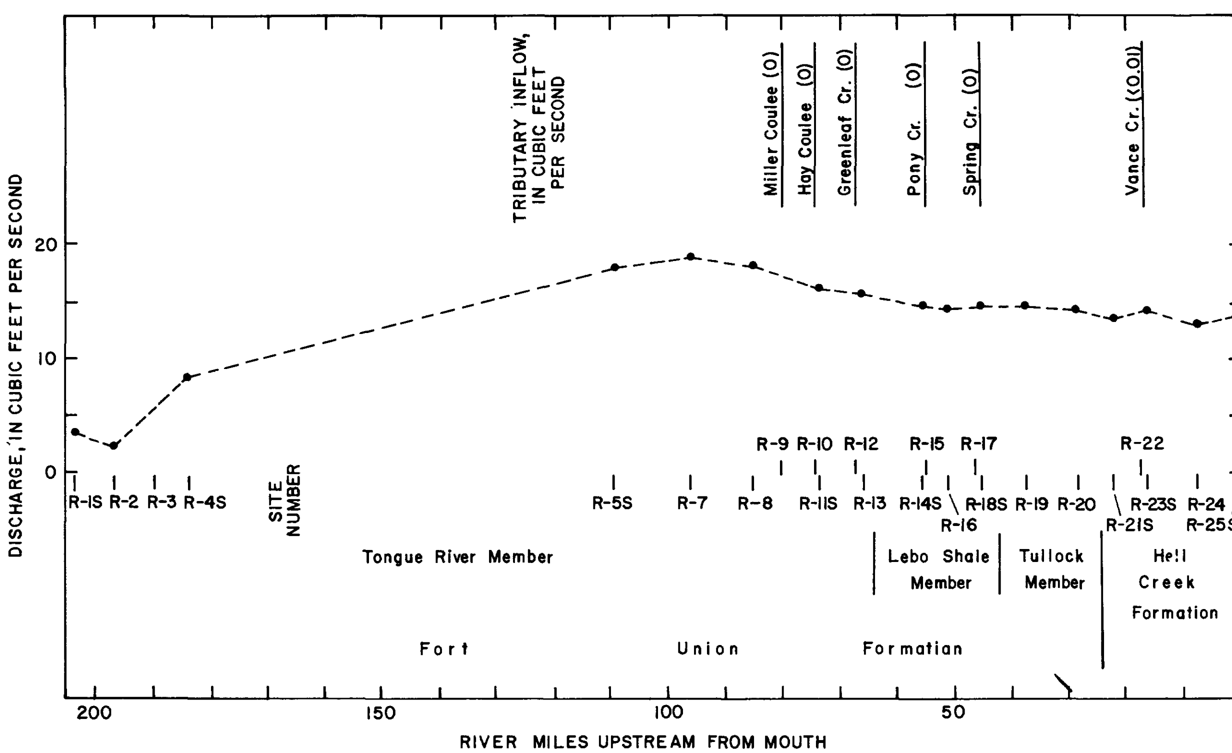

Figure 8.--Generalized streamflow profile of Rosebud Creek, October 31-November 2, 1977.

Table 5.--*Discharge and temperature of Rosebud Creek during base flow, October 31-November 2, 1977*

[ft^3/s, cubic feet per second; °C, degrees Celsius]

Site number	Location	Stream	Date	Time	Discharge (ft^3/s)	Water temperature (°C)
R-1S	NE1/4 SE1/4 sec. 20, T. 7 S., R. 39 E.	Rosebud Cr.	10-31	1610	3.5	6.0
R-2	NE1/4 SW1/4 sec. 9, T. 7 S., R. 39 E.	Rosebud Cr.	10-31	1615	2.2	5.0
R-3	NE1/4 NW1/4 sec. 29, T. 6 S., R. 39 E.	Rosebud Cr.	10-31	1710	5.3	5.0
R-4S	SE1/4 NW1/4 sec. 8, T. 6 S., R. 39 E.	Rosebud Cr.	11-1	0805	8.3	2.5
R-5S	NW1/4 SW1/4 sec. 8, T. 2 S., R. 41 E.	Rosebud Cr.	11-1	0835	18.0	5.0
R-7	NW1/4 NW1/4 sec. 23, T. 1 S., R. 41 E.	Rosebud Cr.	10-31	1510	19.0	7.0
R-8	SW1/4 NE1/4 sec. 8, T. 1 S., R. 42 E.	Rosebud Cr.	10-31	1615	18.3	7.5
R-9	NE1/4 NW1/4 sec. 3, T. 1 S., R. 42 E.	Miller Coulee	10-31	1700	No flow	---
R-10	NW1/4 NW1/4 sec. 34, T. 1 N., R. 42 E.	Hay Coulee	10-31	1715	No flow	---
R-11S	NW1/4 NE1/4 sec. 34, T. 1 N., R. 42 E.	Rosebud Cr.	11-1	0845	16.5	6.0
R-12	NW1/4 NW1/4 sec. 29, T. 1 N., R. 43 E.	Greenleaf Cr.	11-1	1030	No flow	---
R-13	NE1/4 NE1/4 sec. 29, T. 1 N., R. 43 E.	Rosebud Cr.	11-1	0955	15.9	5.5
R-14S	SE1/4 SE1/4 sec. 29, T. 2 N., R. 43 E.	Rosebud Cr.	11-1	1120	14.9	7.5
R-15	NE1/4 SE1/4 sec. 29, T. 2 N., R. 43 E.	Pony Cr.	11-1	1105	No flow	---
R-16	NW1/4 SE1/4 sec. 16, T. 2 N., R. 43 E.	Rosebud Cr.	11-1	1215	14.6	7.0
R-17	NW1/4 NW1/4 sec. 4, T. 2 N., R. 43 E.	Spring Cr.	11-1	1330	No flow	---
R-18S	NE1/4 SW1/4 sec. 33, T. 3 N., R. 43 E.	Rosebud Cr.	11-1	1235	14.8	7.5
R-19	SW1/4 SE1/4 sec. 8, T. 3 N., R. 43 E.	Rosebud Cr.	11-1	1345	14.9	7.0
R-20	NE1/4 SW1/4 sec. 30, T. 4 N., R. 43 E.	Rosebud Cr.	11-1	1510	14.3	6.0

Table 5.--*Discharge and temperature of Rosebud Creek during base flow, October 31-November 2, 1977*--Continued

Site number	Location	Stream	Date	Time	Discharge (ft^3/s)	Water temperature (°C)
R-21S	NW1/4 SE1/4 sec. 13, T. 4 N., R. 42 E.	Rosebud Cr.	11-1	1505	13.7	7.5
R-22	NW1/4 SW1/4 sec. 34, T. 5 N., R. 42 E.	Vance Cr.	11-1	1600	.01*	---
R-23S	SW1/4 SE1/4 sec. 28, T. 5 N., R. 42 E.	Rosebud Cr.	11-1	1620	14.3	7.5
R-24	SW1/4 SE1/4 sec. 5, T. 5 N., R. 42 E.	Rosebud Cr.	11-2	1215	13.0	7.0
R-25S	NW1/4 NE1/4 sec. 21, T. 6 N., R. 42 E.	Rosebud Cr.	11-2	1015	13.6	9.0

*Estimated

Table 6.--*Chemical analyses of Rosebud Creek during base flow, October 31-November 2, 1977.*

[Except as indicated otherwise, constituents are dissolved and constituent values are reported in milligrams per liter; micromhos, micromhos per centimeter at 25 degrees Celsius; °C, degrees Celsius; µg/L, micrograms per liter]

Site number	Date	Laboratory specific conductance (micromhos)	Onsite pH (units)	Water temperature (°C)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)
R-1S	10-31	1,030	8.2	6.0	72	88	24	6.9	540	0	200	4.1
R-4S	11-1	860	8.4	2.5	75	69	25	8.5	440	26	120	3.8
R-5S	11-1	1,150	8.4	5.0	78	96	70	10	440	43	270	4.9
R-11S	11-1	1,220	8.6	6.0	73	100	81	11	410	51	320	5.2
R-14S	11-1	1,260	8.5	7.5	76	100	90	11	460	26	360	5.9
R-18S	11-1	1,290	8.0	7.5	75	110	38	11	500	0	360	5.7
R-21S	11-1	1,310	8.5	7.5	76	100	110	12	440	30	390	6.2
R-23S	11-1	1,280	8.6	7.5	74	100	94	11	450	24	360	7.2
R-25S	11-2	1,290	8.5	9.0	71	87	120	11	450	18	370	6.4

Site number	Fluoride (F)	Silica (SiO_2)	Dissolved solids, residue at 180°C	Nitrite plus nitrate, total as N	Nitrogen, ammonia, total as NH_4	Nitrogen, total organic as N	Nitrogen, total kjeldahl as N	Phosphorus, total as P	Boron (B) (µg/L)	Iron (Fe) (µg/L)	Carbon, organic as C	Carbon, organic suspended as C
R-1S	0.6	14	703	0.01	0.00	0.38	0.38	0.05	90	30	6.4	0.7
R-4S	.7	18	560	.10	.03	.39	.42	.07	110	20	4.2	1.5
R-5S	.7	17	790	.01	.07	.17	.24	.04	180	20	5.5	.8
R-11S	.7	16	861	.00	.01	.24	.25	.04	190	20	5.4	1.1
R-14S	.7	16	908	.01	.04	.24	.28	.03	200	20	5.8	.9
R-18S	.7	15	929	.00	.00	.30	.30	.04	210	20	5.9	1.0
R-21S	.7	14	943	.01	.01	.47	.48	.07	210	30	5.9	---
R-23S	.7	14	938	.01	.01	.38	.39	.05	210	30	5.7	1.4
R-25S	.7	12	902	.05	.01	.65	.66	.12	210	40	6.2	2.0

Water quality changed significantly along Rosebud Creek (fig. 9). Generally, water quality in the upstream reaches was dominated by magnesium, calcium, and bicarbonate, with significant amounts of sodium and sulfate, and a dissolved-solids concentration of about 700 mg/L. Quality of streamflow in the upstream reaches may result from discharge from the abundant clinker and sandstone aquifers that are present in the Tongue River Member. Sodium and sulfate increased significantly downstream (fig. 10), with concomitant increases in dissolved solids, indicating that most of the water discharged from aquifers within the Fort Union Formation was of the sodium sulfate type and had a large dissolved-solids concentration. Calcium, magnesium, and bicarbonate plus carbonate showed little change downstream. The sodium concentration at site R-18S was anomalously small and the entire analysis, although reported, may not be representative.

Although no data were collected for the 75-mile reach of Rosebud Creek between sites R-4S and R-5S, tributaries contributed significant volumes of water. Flow and water-quality data for Lame Deer and Muddy Creeks were provided by Northern Cheyenne Research Project personnel (Charles Andrews, written commun., 1979). The data show that the average discharge for Lame Deer Creek was 3.12 ft^3/s for October 26 through November 5, 1977. Flow data for Muddy Creek were not available but the flow is reported to generally exceed that of Lame Deer Creek. Water from Lame Deer Creek contained principally magnesium, sodium, calcium, bicarbonate, and sulfate with a dissolved-solids concentration of 800 mg/L, and water from Muddy Creek was characterized by magnesium, calcium, sodium, bicarbonate, and sulfate with a dissolved-solids concentration of 1,050 mg/L, based on samples collected during late September 1977.

Major-ion concentrations for both Muddy Creek and Lame Deer Creek differed from those upstream on Rosebud Creek. Sodium, bicarbonate, and carbonate concentrations of Lame Deer Creek exceeded those of Rosebud Creek at site R-5S, downstream from the mouth of Lame Deer Creek, indicating that a significant percentage of the constituents at site R-5S was contributed by Lame Deer Creek inflow. Calcium concentration for Lame Deer Creek was less than that at site R-4S on Rosebud Creek, which leads to the conclusion that the increase in calcium concentration at site R-5S was not a result of Lame Deer Creek inflow. Concentrations of all major ions except carbonate in Muddy Creek exceeded those of Rosebud Creek at site R-5S. These tributaries had a significant effect on both the quantity and quality of the flow of Rosebud Creek. They contributed about 65 percent of the net change in flow between sites R-4S and R-5S. The water contributed represents base flow from the Lame Deer Creek and Muddy Creek subbasins of the Rosebud Creek drainage basin; both subbasins are underlain by rocks of the Tongue River Member of the Fort Union Formation.

Downstream from Lame Deer and Muddy Creeks, the ground-water inflow became dominated by sodium and sulfate, with greater dissolved solids. Paucity of data between sites R-4S and R-5S precludes definitive analysis of the water-quality changes.

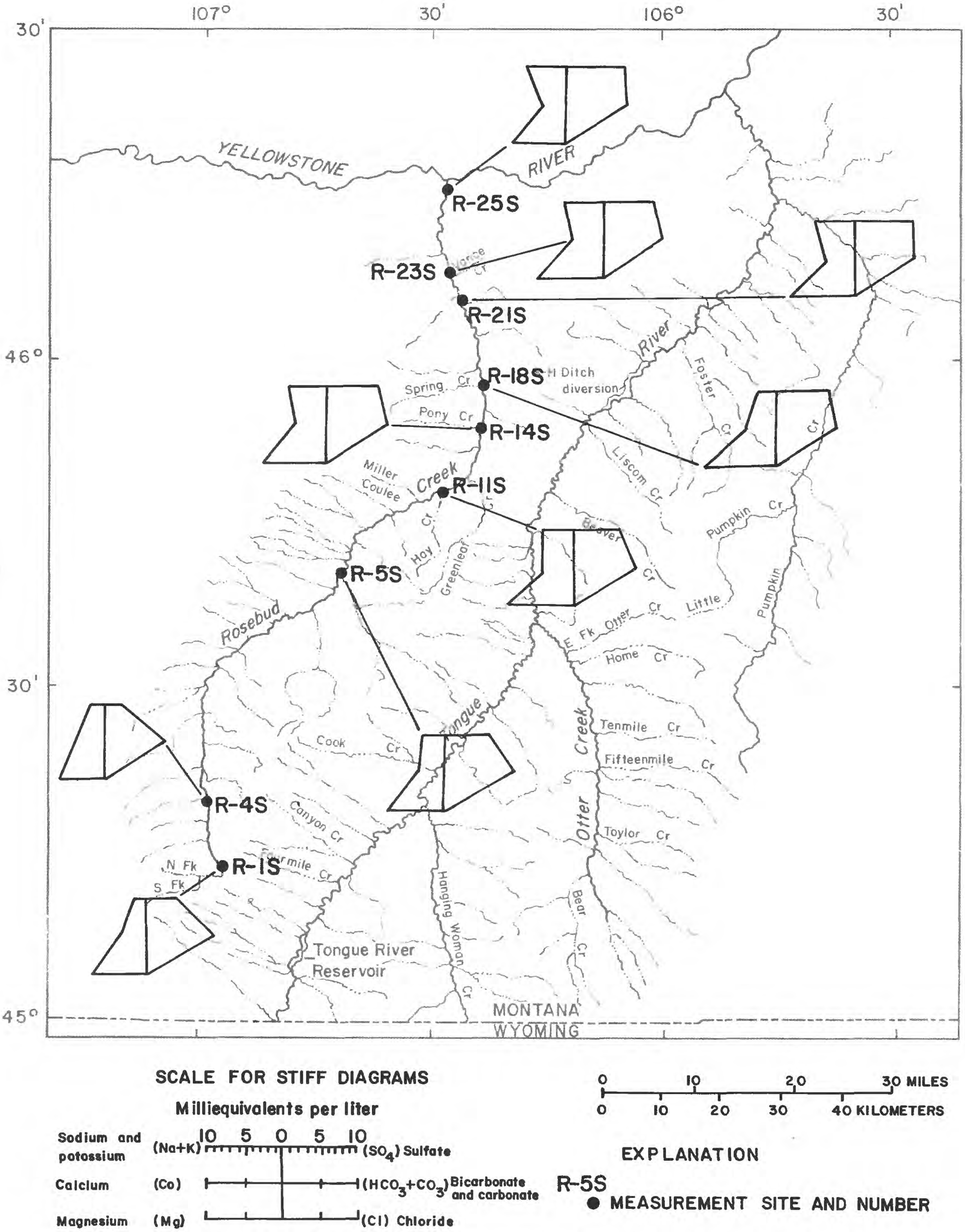

Figure 9.--Stiff diagrams of water quality for Rosebud Creek, October 31-November 2, 1977.

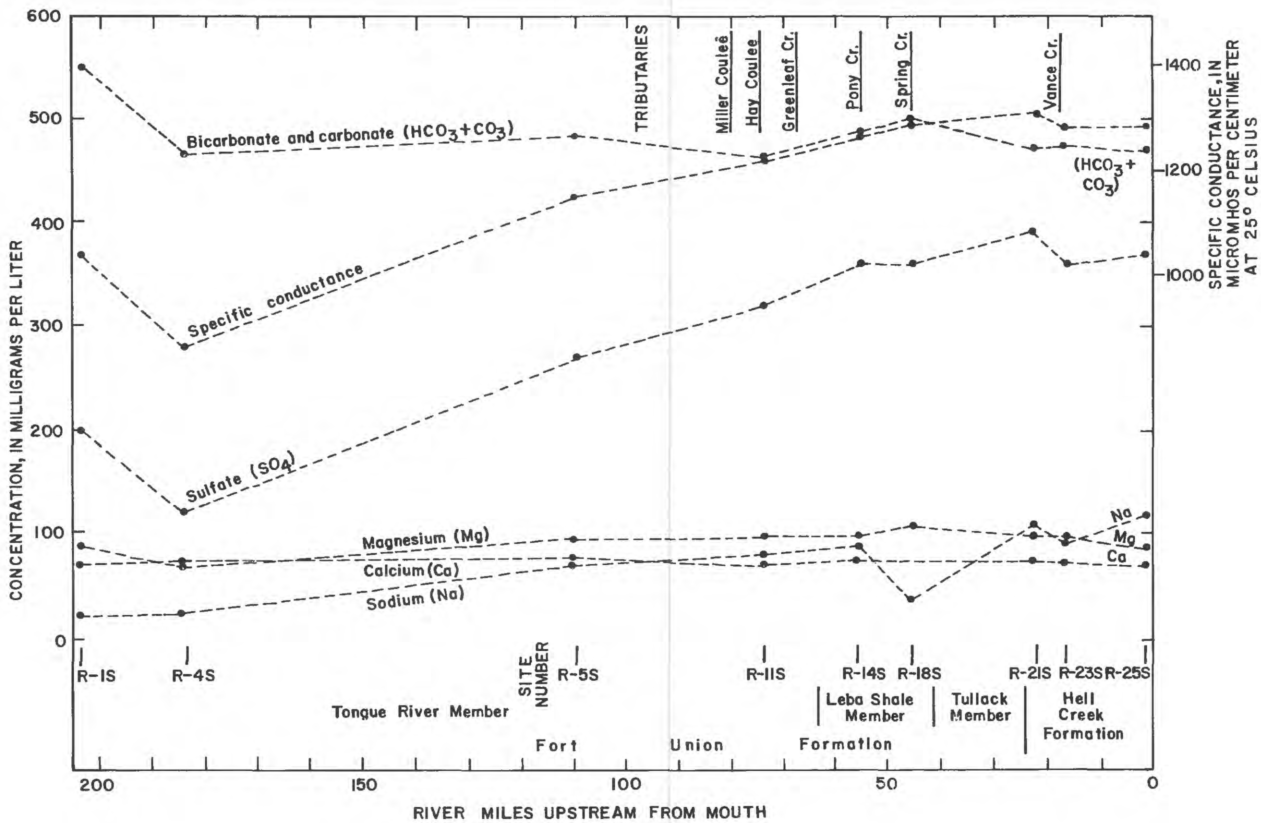

Figure 10.--Profiles of major-ion concentration and specific conductance for Rosebud Creek, October 31-November 2, 1977.

Although total surface-water flow decreased downstream from site R-7, indicating recharge to the aquifers, sodium and sulfate increased slightly; the increase indicates that some reaches received ground-water discharge dominated by those solutes. It is apparent that both gain and loss occurred, with the net change being a loss of flow downstream from site R-7.

SUMMARY

Between October 26 and November 5, 1977, discharge measurements were made at 64 sites and water samples were collected at 27 sites on Otter Creek, Tongue River, and Rosebud Creek to characterize the rate and chemical quality of base flow. These streams are among the major drainages in the coal region of southeastern Montana. Bedrock formations transected by the streams are the Hell Creek and Fort Union Formations. Alluvium underlies the stream channels.

Otter Creek had several reaches of loss and gain along its length; the net change through the study reach was a gain of 0.04 ft^3/s. The maximum flow measured was 1.2 ft^3/s at site O-18S. The quality of ground-water discharge to Otter Creek can be characterized as dominated by sodium, magnesium and sulfate, and a dissolved-solids concentration of about 3,000 mg/L. One exception, between sites 0-16S and 0-18S, is the inflow of water containing proportionately greater concentrations of calcium, magnesium, and bicarbonate with a dissolved-solids concentration of about 1,100 mg/L. The source of this discharge probably is a localized aquifer of clinker. Otter Creek transects no major geologic contacts along its length, but does flow over several different lithologic units within the Tongue River Member of the Fort Union Formation.

Ground-water discharge to the Tongue River was difficult to characterize because of the large amount of water being released from the Tongue River Reservoir. Major stratigraphic units of the Fort Union Formation traversed by the Tongue River accept water as recharge and discharge water to the stream. Water exchange between stream and aquifers resulted in a net gain in flow of 77 ft^3/s through the study reach. Flow increased from 156 ft^3/s below the dam of the Tongue River Reservoir to 233 ft^3/s near the mouth. Water quality changed only slightly along the study reach of the Tongue River. Sodium, bicarbonate plus carbonate, and sulfate showed the largest increases, which may be an indication of the chemical composition of the ground-water discharge. Dissolved-solids concentrations increased from 506 mg/L near the dam to 630 mg/L near the mouth.

Flow in Rosebud Creek increased from the headwaters to near the middle of the study reach, then gradually decreased downstream to the mouth. The initial flow measured was 3.5 ft^3/s and the maximum flow measured was 19.0 ft^3/s. Water quality changed significantly along the stream. Dominant major solutes in the upper reaches were magnesium, calcium, and bicarbonate, with significant amounts of sodium and sulfate. Dissolved-solids concentrations in the upper reaches ranged from 560 to 703 mg/L. Sodium, sulfate, and dissolved solids increased downstream, indicating that most of the water discharged from aquifers within the Fort Union Formation contains large concentrations of sodium and sulfate.

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