WATER QUALITY OF SELECTED STREAMS IN THE COAL AREA OF EAST-CENTRAL MONTANA

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 78-142

Prepared in cooperation with the
U.S. Bureau of Land Management and the
Montana Department of Fish and Game

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No.

4. Title and Subtitle WATER QUALITY OF SELECTED STREAMS IN THE COAL AREA OF EAST-CENTRAL MONTANA	5. Report Date April 1979
	6.
7. Author(s) P. W. McKinley	8. Performing Organization Rept. No. USGS/WRI 78-142
9. Performing Organization Name and Address U.S. Geological Survey, Water Resources Division 428 Federal Building, Drawer 10076 Helena, Montana 59601	10. Project/Task/Work Unit No.
	11. Contract/Grant No.
12. Sponsoring Organization Name and Address U.S. Geological Survey, Water Resources Division 428 Federal Building, Drawer 10076 Helena, Montana 59601	13. Type of Report & Period Covered Final
	14.

15. Supplementary Notes

Prepared in cooperation with the U.S. Bureau of Land Management and the Montana Department of Fish and Game

16. Abstracts

Big Dry Creek, Little Dry Creek, Timber Creek, and Nelson Creek form the Big Dry Creek basin, which is tributary to the Missouri River. These streams contain water of the sodium sulfate type. Concentrations were high for dissolved solids (433-4,570 mg/L) and generally low for nutrients and trace elements. Prairie Elk Creek, Sand Creek, and the Redwater River flow directly into the Missouri River. Prairie Elk and Sand Creeks have mainly sodium bicarbonate water, whereas the Redwater River is predominantly sodium sulfate water. All three streams contain water of high dissolved-solids concentration (160-3,370 mg/L) and generally low nutrient and trace-element concentrations. Burns Creek is tributary to the Yellowstone River. The water type is generally sodium sulfate during the spring and summer and sodium bicarbonate during the fall and winter. Water from Burns Creek ranged from 382 to 1,420 mg/L dissolved solids.

17. Key Words and Document Analysis. 17a. Descriptors

Water quality*, streamflow*, anions, cations, dissolved solids, sediment transport, specific conductivity, trace elements, Montana

17b. Identifiers/Open-Ended Terms

Sodium hazard, salinity hazard, Big Dry Creek, Little Dry Creek, Timber Creek, Nelson Creek, Prairie Elk Creek, Sand Creek, Redwater River, Burns Creek

17c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
No restriction on distribution.	UNCLASSIFIED	56
	20. Security Class (This Page) UNCLASSIFIED	22. Price

WATER QUALITY OF SELECTED STREAMS IN THE COAL AREA OF EAST-CENTRAL MONTANA

By P. W. McKinley

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 78-142

Prepared in cooperation with the

U.S. Bureau of Land Management and the

Montana Department of Fish and Game

April 1979

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

H. William Menard, Director

For additional information write to:

U.S. Geological Survey
Federal Office Building
301 South Park
Drawer 10076
Helena, Montana 59601

CONTENTS

ILLUSTRATIONS

TABLE

METRIC CONVERSION TABLE

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

Multiply inch-pound units	By	To obtain metric units
acre	4047	square meter (m^2)
	.4047	hectare (ha)
cubic foot per second (ft^3/s)	28.32	liter per second (L/s)
foot (ft)	.3048	meter (m)
inch (in)	25.4	millimeter (mm)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
ton (short) per day (ton/day)	907.2	kilogram per day (kg/day)
	.9072	metric ton per day (t/day)

temperature, degrees Celsius (°C) = 0.556 (°F-32)

GLOSSARY

Alluvium. A general term for sand, silt, and mud deposited by a stream, along its banks or upon its flood plain.

Anion. Negatively charged ion.

Aquifer. A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

Base flow. Sustained or fair weather runoff, which in most streams is composed largely of ground-water inflow.

Cation. Positively charged ion.

Concentration. A measure of the amount of dissolved substance contained per unit of volume.

Correlation coefficient. A measure of the degree of closeness of the linear relationship between two variables. As the correlation coefficient approaches 1.00 or -1.00, the variables become closer to the same linear line.

Direct runoff. Water entering stream channels promptly after rainfall or snowmelt.

Evaporation. Process by which water escapes from water surfaces and moist soil and enters the atmosphere as a vapor.

Formation. A distinct lithologic unit that may be used in geologic mapping, generally confined to bedded or stratified rocks.

Hydrograph. A graph showing stream discharge or constituent concentration of water with respect to time.

Inorganic. Designating or composed of matter that is not animal or vegetable.

Intermittent stream. One which flows only at certain times of the year when it receives water from springs or from some surface source.

Ion. An atom or molecule which has gained or lost one or more electrons and which thus has a negative or positive charge.

Organic. Pertaining to compounds containing the carbon atom. For exceptions, refer to inorganic.

Overland flow. The flow of rainwater or snowmelt over the land surface toward stream channels.

Perennial stream. One which flows year-round.

Runoff. That part of the precipitation that appears in surface streams. Runoff is a combination of base flow and direct runoff.

WATER QUALITY OF SELECTED STREAMS IN THE COAL AREA OF EAST-CENTRAL MONTANA

By

P. W. McKinley

ABSTRACT

In October 1975 the U.S. Geological Survey established a network of nine data-collection stations on eight streams in east-central Montana to monitor water quality in potential coal-mining areas. The purpose of this report is to summarize and evaluate the water-quality data that have been collected during the first 2 years of network operation.

The physical measurements investigated were discharge, suspended sediment and water temperature. Chemical measurements were major ions, nutrients, and trace elements. Some constituent values are compared to various standards to evaluate suitability of the water for different uses.

Big Dry Creek, Little Dry Creek, Timber Creek, and Nelson Creek are the principal streams draining the Big Dry Creek basin, which is tributary to the Missouri River. These streams all flow intermittently. Sampled discharges of the streams ranged from 0.12 to 224 cubic feet per second. Water type is sodium sulfate. Concentrations were high for dissolved solids (433-4,570 milligrams per liter) and generally low for nutrients and trace elements.

Prairie Elk Creek, Sand Creek, and the Redwater River flow directly into the Missouri River. Flow is perennial only in the lower Redwater River and Prairie Elk Creek. Sampled discharges ranged from 0.01 to 1,170 cubic feet per second. Prairie Elk and Sand Creeks have mainly sodium bicarbonate water, whereas the Redwater River at Circle and near Vida is predominantly sodium sulfate water. These streams contained water having high mean dissolved-solids concentration (1,200, 1,220, 2,560, and 2,080 milligrams per liter, respectively) and generally low nutrient and trace-element concentrations.

Burns Creek is tributary to the Yellowstone River, and normally maintains perennial flow. Sampled discharge ranged from 0.32 to 63 cubic feet per second. The water type is generally sodium sulfate during the spring and sodium bicarbonate during the fall and winter. Water from Burns Creek ranged in dissolved-solids concentration from 382 to 1,420 milligrams per liter. Nutrients and trace-element concentrations were low.

INTRODUCTION

East-central Montana is located in the Northern Great Plains coal field. Because of its vast supply of near-surface low-sulfur coal, the area is becoming increasingly important as a potential source of supply for meeting future energy needs. At the present time coal is being extracted by surface-mining methods at one mine and many of the proposals for future coal mining include this area.

Some of the potential mining sites are near stream channels, whereas many others are in upland locations. Regardless of the physical setting, mining could alter the quality of water in streams or the quality of ground water that eventually is discharged to streams. In addition to actual mining practices, related activities such as manufacturing, transportation, and services for an increasing population could also pose threats to surface-water quality.

An assessment of the water resources as near to their premining state as possible was deemed necessary when it became evident that mining might be conducted on a large scale. An adequate data base would make possible the verification of any water-quality degradation and provide a basis for making necessary land-use, water-use, and development-impact decisions. Prior to 1975, only limited water-quality information was available for the major streams in the study area and almost no information had been collected for the smaller streams.

In October 1975, a network of nine data-collection stations was established by the U.S. Geological Survey on eight streams to monitor water quality in potential mining areas; five of these were continuous-record streamflow stations (fig. 1). The U.S. Geological Survey, the U.S. Bureau of Land Management, and the Montana Department of Fish and Game provided funding for the investigation.

Purpose and scope

The purpose of this report is (1) to summarize the water-quality data collected during the first 2 years (3 years for one station) of network operation and (2) to provide a general description of the water quality at each data-collection station. Although the data are published by the U.S. Geological Survey (issued annually), some users will find the statistical summaries and the various graphs in this report to be of more use than the data tabulation alone. A principal objective of this report is to interpret the data for those without a technical background in the field of water quality. Land users, administrators, and professionals in affiliated fields are among readers who may find the report useful.

About 60 different water-quality measurements made on a routine schedule at each of the network stations are summarized in this report. The properties measured are the same as those being analyzed throughout the Northern Great Plains in similar programs, as reported by Knapton and McKinley (1977).

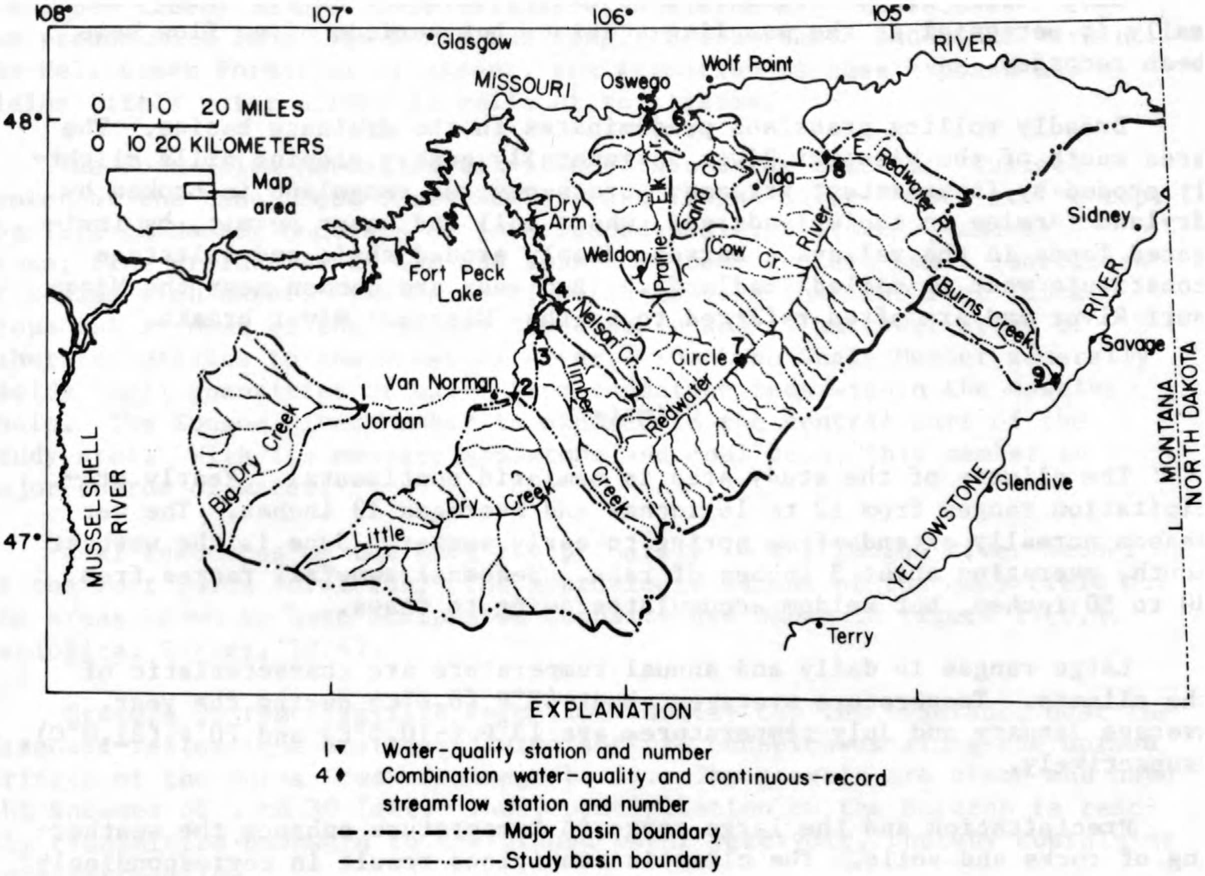


Figure 1.--Locations of study area and water-quality stations.

Drainage and topography

The study area (fig. 1) is in east-central Montana between the Missouri and Yellowstone Rivers. Big Dry Creek, Little Dry Creek, Timber Creek, Nelson Creek, Prairie Elk Creek, Sand Creek, Redwater River, and Burns Creek are streams having one or more network stations. All the streams are tributaries of the Missouri River except Burns Creek, which is a tributary of the Yellowstone River.

Big Dry Creek drains the area south of Fort Peck Lake. It receives the flow of Little Dry Creek from the south before entering Fort Peck Lake at Dry Arm. Timber and Nelson Creeks flow into Dry Arm of Fort Peck Lake from the southeast. All streams have periods of intermittent flow at the sampling stations.

Prairie Elk Creek, Sand Creek, and the Redwater River flow north and join the Missouri River downstream from Fort Peck Lake. Prairie Elk Creek and the Redwater River are normally perennial streams, whereas flow in Sand Creek is intermittent.

Burns Creek flows southeast into the Yellowstone River. Flow normally is perennial at the sampling station, but periods of no flow have been recorded.

Broadly rolling grassland predominates in the drainage basins. The area south of the Missouri River is generally gently sloping hills slightly eroded by intermittent streams. Grass-covered rangeland is broken by dryland farming in the uplands and, where soil and water permit, by irrigated lands in the valleys. Barren, deeply eroded shale and siltstone constitute what is called "badlands." Badlands are common near the Missouri River and are often referred to as the "Missouri River breaks."

Climate

The climate of the study area is semiarid continental. Yearly precipitation ranges from 12 to 16 inches and averages 13 inches. The wet season normally extends from spring to early summer. June is the wettest month, averaging about 3 inches of rain. Seasonal snowfall ranges from 30 to 50 inches, but seldom accumulates owing to thaws.

Large ranges in daily and annual temperature are characteristic of the climate. Temperature averages about 43°F (6.0°C) during the year. Average January and July temperatures are 13°F (-10.5°C) and 70°F (21.0°C), respectively.

Precipitation and the large range in temperature enhance the weathering of rocks and soils. The climatic conditions result in correspondingly large changes in the quantity and quality of water in the streams.

Geology and water-bearing characteristics

The geologic formations exposed in the area are, in ascending order, the Bearpaw Shale, Fox Hills Sandstone, and Hell Creek Formation all of Cretaceous age; the Fort Union Formation and Flaxville Formation of Tertiary age; and the glacial deposits and alluvium of Quaternary age.

About 200 feet of Bearpaw Shale is exposed in the lower part of the Prairie Elk Creek drainage. The Bearpaw consists of predominantly dark marine shale with some siltstone. Only a minor amount of water from the Bearpaw might be contributing to streamflow, because this unit is not an aquifer in the study area. Any water derived from this formation would contain high concentrations of dissolved sodium and chloride.

The Fox Hills Sandstone is predominantly a sandstone unit as thick as 150 feet. The Hell Creek Formation consists of mostly shale and siltstone; locally, however, sandstone as much as 100 feet thick predominates. Sandstones of the Fox Hills Sandstone and Hell Creek Formation are exposed along the drainages of the middle part of Prairie Elk Creek, lower Sand Creek, and extreme lower Nelson Creek. Wells tapping sandstones within these two formations yield water ranging from 500 to 2,000 mg/L (milligrams per liter) in dissolved solids, with sodium and bicarbonate being the predominant ions (Van Lewen and King, 1971). Where sandstone within the Hell Creek Formation is absent, the formation is less exposed and yields little water either to wells or to streams.

The Fort Union Formation is divided into three members: Tullock Member at the base, Lebo Shale Member, and Tongue River Member at the top. The Tullock Member consists of interbedded shale, siltstone, and sandstone; fine-grained sandstone and thin coal beds contain small quantities of sodium-rich water. The Tullock, which is less than 200 feet thick, crops out in most of the Big Dry Creek basin and in narrower areas of other tributaries to the Missouri River. The Lebo Shale Member generally yields small quantities of water from sandstone beds within the massive shale. The Tongue River Member is exposed in the central part of the study area. With its massive sandstone and coal beds, this member is a major source of water.

Coal resources of the area are primarily in the Tongue River Member of the Fort Union Formation. The approximate extent of the coal field and the areas known to have strippable deposits are shown in figure 2 (U.S. Geological Survey, 1974).

Gravels of the Flaxville Formation locally cap the highlands near the Missouri-Yellowstone drainage divide and are conspicuous along the upland fringes of the Burns Creek drainage basin. The gravels are clean and have thicknesses of 5 to 30 feet. Thus, precipitation on the outcrop is readily transmitted downward to the ground-water reservoir, thereby sustaining local streamflow.

Continental glaciers advanced southward across the northern half of the study area during Pleistocene time, leaving a thin deposit of unsorted gravel, sand, silt, and clay. Several glacial lakes developed south of the ice margin. The largest lake covered most of the Big Dry and Little Dry Creek basins. As the ice retreated, glacial drainageways were developed by melt water flowing toward the Missouri and Yellowstone Rivers. The major streams of the area now occupy those glacial drainageways.

Alluvium composed of gravel, sand, silt, and clay forms the channel of most streams. Water stored in the alluvium generally helps to sustain streamflow between periods of precipitation and snowmelt. At times, however, water is lost from the stream to the alluvium. The alluvium in the central valleys reaches a maximum thickness of about 50 feet.

PROPERTIES MEASURED

Measurable water properties can be divided into three categories: physical, chemical, and biological. In this study, physical and chemical properties are emphasized. The physical properties include discharge, suspended sediment, and water temperature. The chemical properties are divided into major ions, nutrients, and trace elements.

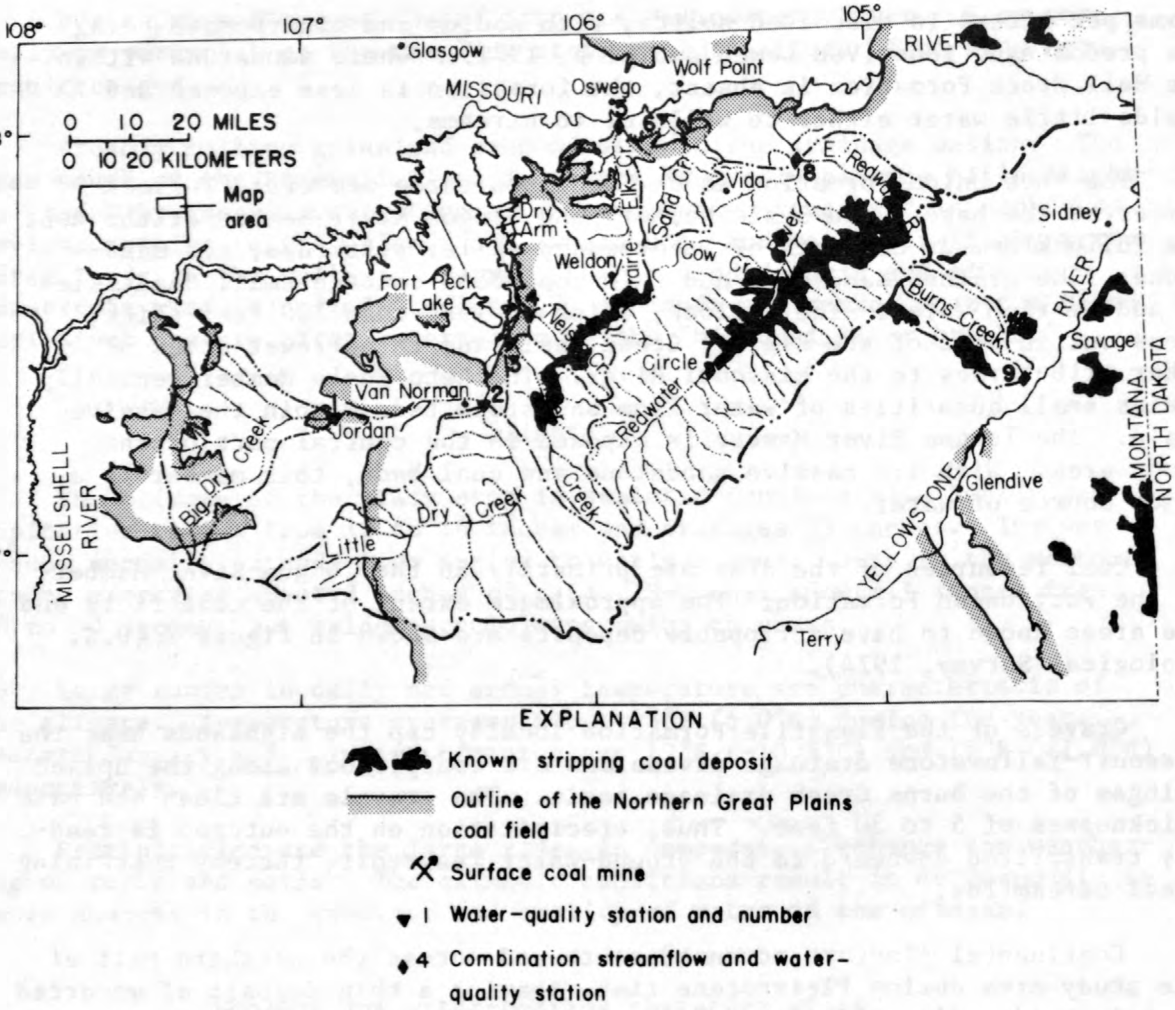


Figure 2.--Locations of strippable coal in study area. Map from U.S. Geological Survey (1974).

Physical properties

Discharge of a stream is the volume of water that passes a given point within a given period of time. Besides being a medium of transport, discharge affects the concentration of dissolved and suspended constituents present. Generally, as the discharge increases the concentration decreases. However, as stream discharge increases, the total load of dissolved and suspended constituents also increases.

Suspended sediment is solid material that is moved in suspension in water and is maintained in suspension by the upward components of turbulent currents or by colloidal suspension. Suspended sediment is an integral part of stream chemical quality because of its ability to act as a transporting mechanism for organic and inorganic matter. Organic matter often comprises a large percentage of the sediment particle itself. Inorganic matter is absorbed and (or) adsorbed onto sediment particles, resulting in the sediment transporting portions of the load that normally are dissolved. The quantity of suspended sediment transported by streams is identified as sediment load. Sediment load, once deposited, can fill reservoirs, channels, and fish hatcheries and create many other undesirable economic effects.

Water temperature fluctuates daily, seasonally, and in response to certain of man's activities. Of special concern are man-created temperature increases that can have a lethal effect on aquatic growth. Temperature directly influences dissolved-oxygen concentration, organic decomposition, aquatic growth, and particle transport.

Chemical properties

Most dissolved elements and compounds occur in stream waters as ions. The ions that are the principal components of dissolved solids are referred to as major ions, and they are composed of two groups, cations and anions. The cations consist mainly of calcium, magnesium, sodium, and potassium; the anions are mainly bicarbonate, carbonate, chloride, fluoride, nitrate, and sulfate.

The major ions and other dissolved solids are leached by water percolating through weathered soil and rocks near the land surface or by dissolution as the water moves through the earth as ground water. Bicarbonate and carbonate ions can also originate from the solution of carbon dioxide in the atmosphere and respiration by aquatic plants.

Nitrogen and phosphorus are nutrients essential to plant growth. They are not the only nutrients needed by plants, but they are often the nutrients that in low enough concentration will limit growth. The three forms of nitrogen analyzed are: nitrite-nitrate, ammonia, and organic nitrogen. Nitrate is the form most commonly produced and used by plants. It is a product of organic decomposition in the soil. Nitrite is often found as a transient form in organic decomposition and is seldom found in large quantities. Ammonia in the form of the ammonium ion is derived from biochemical processes, is dissolved from the atmosphere, and is a product of man's activities. Total organic nitrogen is calculated by subtracting ammonia from total kjeldahl nitrogen.

Phosphorus is not as readily available in the environment as is nitrogen. The forms in which phosphorus is likely to be present in natural water are somewhat uncertain, but the most probable forms are the phosphate anion, complexes with metal ions, and colloidal particulate material (Hem, 1970, p. 183).

Some constituents in water are grouped as trace elements because they generally occur in small concentrations compared to the major ions. Elements in this category that were analyzed are aluminum, arsenic, beryllium, boron, cadmium, chromium, copper, iron, lead, lithium, manganese, mercury, molybdenum, nickel, selenium, vanadium, and zinc. Trace elements can occur in either the dissolved or the suspended form. The dissolved concentration is determined for a water sample after it is passed through a filter having a pore size of 0.45 micrometer (micron), which is about 0.00002 inch. Total concentration is determined on an unfiltered sample containing both dissolved and suspended components. Suspended concentration, then, is calculated by subtracting the dissolved from the total concentration. In this report, both dissolved and total concentrations are reported if the data were available.

Specific conductance, pH, biochemical oxygen demand, and dissolved oxygen are not specifically chemical properties but are a measure of chemical characteristics of a water. The specific conductance is a general indication of the dissolved-solids concentration. It is a measure of the ability of water to conduct an electrical current and is reported in micromhos per centimeter at 25°C. The higher the concentration of dissolved solids, the higher the specific conductance.

The pH measurement is a representation of the hydrogen-ion activity. It is defined as the negative base-10 log of the hydrogen-ion activity in moles per liter. The pH affects the solubilities and the chemical forms in which some compounds are found. For example, at a pH greater than 8.3, the bicarbonate ion begins a transition to the carbonate ion; this transition is complete at a pH of 13.0.

The biochemical oxygen demand, BOD, is the oxygen required by bacteria in oxidizing organic matter during an incubation period of 5 days. BOD is used as a general indication of the organic load of the stream. The organic load can be of natural or manmade origin.

Dissolved oxygen in streams is derived from the atmosphere and from water plants, and fluctuates with biological activity, water temperature, and barometric pressure. The solubility of oxygen decreases as the water temperature increases and as the barometric pressure decreases. Dissolved oxygen is a variable parameter and is valid for only a short time at the point of sampling. Depleted oxygen supply can be an indication of organic pollution.

CLASSIFICATION STANDARDS

Many standards and schemes of classification have been devised as a means to discuss water quality and to determine the suitability of water for various uses. This section lists some tables and standards to which reference has been made in this report.

A common, though not precise, way to identify water is on the basis of the predominant cation and anion, such as calcium sulfate or sodium bicarbonate. Identification of the chemical type of water requires that the analytical results be expressed in comparable units. Concentration in milligrams per liter is multiplied by the particular factor in the table following (from Hem, 1970) to convert into milliequivalents per liter, thus making unit concentration of all ions chemically equivalent.

Cation:	Conversion factor
Sodium	0.04350
Potassium	.02557
Calcium	.04990
Magnesium	.08226
Anion:	
Chloride	.02821
Sulfate	.02082
Bicarbonate	.01639
Carbonate	.03333

References are made throughout the text to drinking water standards. They refer to the primary and secondary drinking water standards of the U.S. Environmental Protection Agency (1975, 1977) that were in effect at the end of the study. According to the primary standards, the following substances should not be present in amounts greater than those shown:

	Level	
Constituent	Milligrams per liter	Micrograms per liter
Arsenic	0.05	50
Cadmium	.010	10
Chromium	.05	50
Fluoride	1.4 to 2.4	--
Lead	.05	50
Mercury	.002	2
Nitrate (as N)	10.	--
Selenium	.01	10

An excessive concentration of any of the above constituents constitutes a basis for rejection of the drinking water supply (U.S. Environmental Protection Agency, 1975). If the water is acceptable on the basis of this set of standards, secondary standards (listed below) are considered (U.S. Environmental Protection Agency, 1977). These are to be complied with unless no better supply is available.

Substance	Level
Chloride	250 mg/L
Copper	1 mg/L
Iron	0.3 mg/L
Manganese	0.05 mg/L
pH	6.5 to 8.5 units
Sulfate	250 mg/L
Dissolved solids	500 mg/L
Zinc	5 mg/L

Livestock raising is a major industry throughout the area and stock consumption an important water use. McKee and Wolf (1963, p. 112) list the upper limits of dissolved-solids concentration for various types of stock as follows:

Livestock	Concentration, in milligrams per liter
Poultry	2,860
Pigs	4,290
Horses	6,435
Cattle (dairy)	7,150
Cattle (beef)	10,000
Sheep (adult)	12,900

Some investigators (see, for example, Weeth and others, 1960) suggest that these values are much too high for optimum growth and development of livestock. Also, certain major ions may be more limiting than the sum of all constituents. For example, stock can tolerate the highest dissolved solids when the water is of the sodium chloride type.

Based on sodium adsorption (sodium hazard) and conductivity (salinity hazard), a diagram published by the U.S. Salinity Laboratory Staff (1954) is widely used for evaluating irrigation waters (fig. 3). The diagram is divided into 16 areas that are used to rate the degree to which a particular water may create salinity problems and undesirable ion-exchange effects on irrigated land. However, soil conditions, as well as irrigation methods, are not considered and certainly account for some variability in the classification.

All waters within the basin have been classified by the Montana Department of Health and Environmental Sciences in accordance with the statewide scheme to establish maximum allowable changes in water quality and limits for pollutants which affect prescribed beneficial uses of State waters. Detailed criteria for streams within the study area can be obtained by contacting the Montana Department of Health and Environmental Sciences in Helena, Montana.

QUALITY OF THE WATER

A description of the water quality at nine sampling stations follows. The stations are grouped by drainage basin and listed in downstream order (see table 1). Each station is introduced by a discussion of the drainage. Where streamflow was monitored, the hydrograph for the 1976 water year is shown. Interpretation of the water-quality data concludes the description.

The discussion for each station is accompanied by a listing that summarizes values for the properties, a graph of major-ion relationships for selected samples, and a graph showing the relationship of water discharge to suspended-sediment load (or where less than six samples were collected,

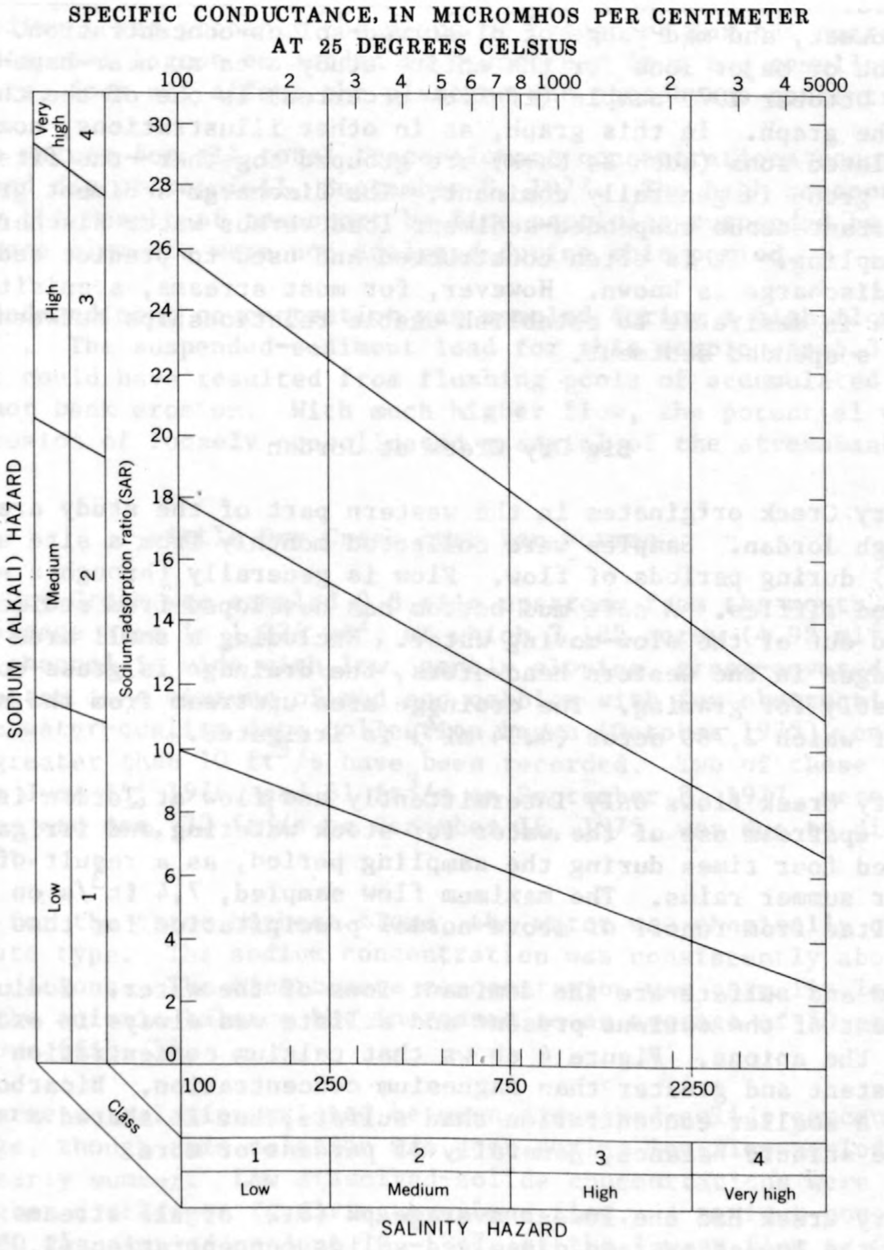


Figure 3.--Classification of water for irrigation.

a listing of sediment results). In the listing of values of the properties, the heading "No. of Analyses" refers to the number of times the constituent was analyzed. The "Mean" is a <u>time</u>-weighted mean in which all samples are given equal emphasis. A <u>discharge</u>-weighted mean is sometimes of more benefit and is often used when samples are collected more frequently (daily). Constituent values listed in the table under "Range" such as discharge, suspended sediment, and specific conductance, pertain only to those measurements made during sampling, even though continuous-record or once-daily measurements are available for some stations. Each major-ion graph depicts samples of the highest, lowest, and mid-range of dissolved-solids concentration. To enable a comparison of major ions for the entire study area at near-base-flow conditions, the October 1975 sample (if flow occurred) is one of the three samples shown on the graph. In this graph, as in other illustrations, some of the closely related ions (such as Na+K) are grouped together--the first designated ion of the group is generally dominant. The discharge-sediment graph is a plot of instantaneous suspended-sediment load versus water discharge at the time of sampling. It is often constructed and used to predict sediment loads when only discharge is known. However, for most streams, acquisition of more data points is desirable to establish usable relationships between water discharge and suspended sediment.

Big Dry Creek at Jordan

Big Dry Creek originates in the western part of the study area and flows east through Jordan. Samples were collected monthly from a site at Jordan (station 1) during periods of flow. Flow is generally through a succession of pools and riffles. A soft mud bottom has developed from sediment that has settled out of the slow-moving water. Excluding a small area of pine-covered ridges in the western headwaters, the drainage is grass-covered and is used mostly for grazing. The drainage area upstream from the station is 521 mi^2, of which 2,780 acres (4.34 mi^2) is irrigated.

Big Dry Creek flows only intermittently and flow at Jordan is frequently reduced by upstream use of the water for stock watering and irrigation. Flow was observed four times during the sampling period, as a result of spring snowmelt or summer rains. The maximum flow sampled, 7.4 ft^3/s on June 21, 1976, resulted from runoff of above-normal precipitation for that month.

Sodium and sulfate are the dominant ions of the water. Sodium comprised 80-85 percent of the cations present and sulfate was always in excess of 50 percent of the anions. Figure 4 shows that calcium concentration is relatively constant and greater than magnesium concentration. Bicarbonate was present in a smaller concentration than sulfate, but it shared a significant part of the anionic balance, generally 35 percent or more.

Big Dry Creek had the lowest average pH (8.2) of all streams sampled and shared the lowest average dissolved-solids concentration (1,090 mg/L) with Burns Creek. The low values are due to all the samples being collected during the spring when the direct runoff greatly exceeded the ground-water inflow. Dissolved oxygen was consistently above 90-percent saturation.

Phosphorus concentrations were low (less than 0.2 mg/L) except for one sample on September 8, 1977, when the concentration was 6.8 mg/L. This value is uncommonly high for eastern Montana where phosphorus concentrations are commonly less than 1.0 mg/L. Organic nitrogen and nitrite-nitrate concentrations were also high (5.4 and 5.2 mg/L, respectively) for this date. A suspended-sediment analysis was not available but a turbidity of 7,400 JTU

(Jackson turbidity units) indicates a large suspended-sediment concentration. Suspended sediment was probably the means of transport for the nutrients. The sewage disposal lagoon at Jordan is downstream from the sampling site and, therefore, does not affect the nitrogen and phosphorus concentrations.

Maximum values for all total trace-element concentrations occurred during the second day of rainfall, September 8, 1977. The high concentrations were largely the result of transport by fine particles suspended by runoff. Dissolved trace elements were not analyzed during this period.

Suspended-sediment concentration was sampled during a high flow on June 21, 1976. The suspended-sediment load for this sample was 5.3 tons/day. The sediment could have resulted from flushing pools of accumulated sediment and from minor bank erosion. With much higher flow, the potential would be large for erosion of loosely consolidated material of the streambanks.

Little Dry Creek near Van Norman

Little Dry Creek was sampled 0.8 mile upstream from the mouth (station 2). The drainage area is 1,224 mi^2, of which 3,185 acres (4.98 mi^2) is irrigated. The channel is wide with low, gently sloping, grass-covered banks. The creek bottom is a mixture of mud and cobbles with few obstructions to flow. Since water-quality data collection began (October 1975), only three discharges greater than 10 ft^3/s have been recorded. Two of these flows, 224 ft^3/s on June 15, 1976, and 61 ft^3/s on September 8, 1977, were the result of rains and one, 32 ft^3/s on December 16, 1975, was due to direct runoff from snowmelt.

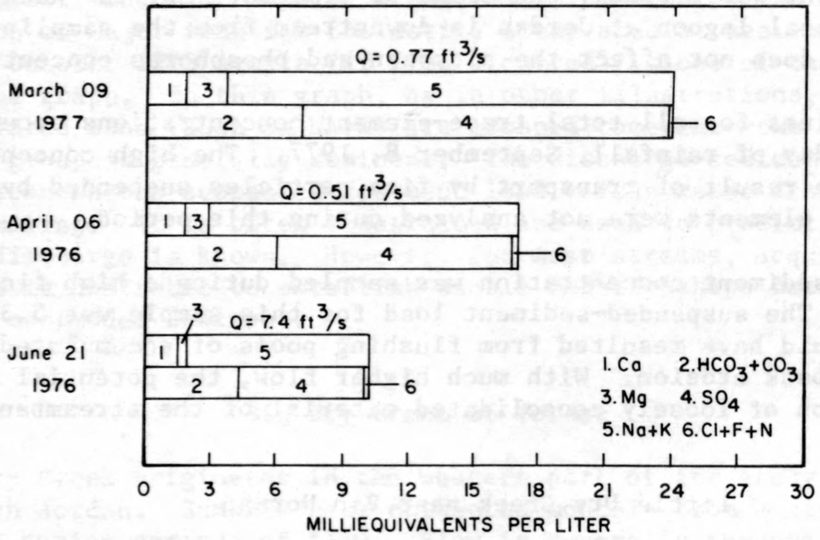
Except for the three highest flows, the water was chemically of the sodium sulfate type. The sodium concentration was consistently above 75 percent of the cations. The bicarbonate concentration was normally less than 35 percent of the anionic balance but increased to an average of 50 percent for the high flows (fig. 5).

An inverse correlation existed between dissolved-solids concentration and discharge, though this relation was poor during low-flow periods in the spring and early summer. Low dissolved-solids concentrations were associated with the higher discharges involving overland flow. A maximum concentration of 2,460 mg/L was sampled on June 14, 1977, at the lowest flow of 0.12 ft^3/s.

Dissolved-oxygen saturation reached a high of 141 percent, which represents a concentration of 10 mg/L at 29°C. Low-flow and heavy algal-growth conditions were noted when dissolved-oxygen saturations were greater than 100 percent. A low saturation of 75 percent was recorded on December 16, 1975, because of ice cover. The remaining saturations ranged from 80 to 97 percent.

Total nitrogen and total phosphorus exceeded 1 mg/L only during periods of high flow that were associated with high suspended-sediment concentration.

RELATIONSHIP OF MAJOR IONS FOR SELECTED SAMPLES



SUSPENDED SEDIMENT FOR SELECTED DAYS

	Date	Time	Temperature (°C)	Instantaneous discharge (ft^3/s)	Suspended sediment (mg/L)	Suspended sediment discharge (tons/day)
1976	Apr. 06	1200	12.0	0.51	68	0.09
	June 21	1430	23.5	7.4	263	5.3
1977	Mar. 09	0830	1.5	.77	78	.16

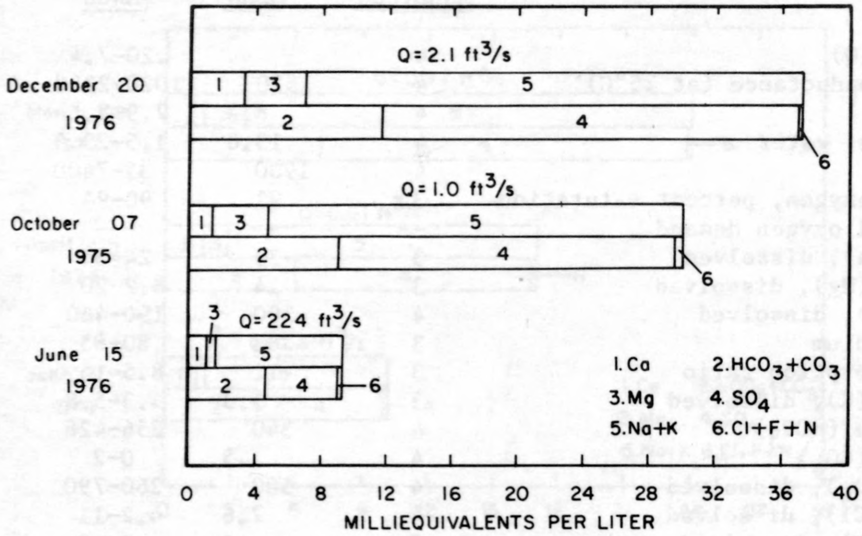
Figure 4.--Relationships of major ions, suspended sediment, and

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	4		.20-7.4	ft^3/s
Specific conductance (at 25°C)	4	1520	1020-2250	µmhos/cm
pH	4	8.2	7.9-8.5	units
Temperature, water	4	13.0	1.5-23.5	°C
Turbidity	4	1900	35-7400	JTU
Dissolved oxygen, percent saturation	3	92	90-94	percent
Biochemical oxygen demand	--	---	---	mg/L
Calcium (Ca), dissolved	3	30	24-34	mg/L
Magnesium (Mg), dissolved	3	14	8.2-20	mg/L
Sodium (Na), dissolved	4	300	190-460	mg/L
Percent sodium	3	83	80-85	percent
Sodium-adsorption ratio	3	12	8.5-15	---
Potassium (K), dissolved	3	5.3	4.3-5.8	mg/L
Bicarbonate (HCO_3)	4	340	256-428	mg/L
Carbonate (CO_3)	4	.5	0-2	mg/L
Sulfate (SO_4), dissolved	4	500	260-790	mg/L
Chloride (Cl), dissolved	4	7.6	4.2-11	mg/L
Fluoride (F), dissolved	3	.3	.2-.3	mg/L
Silica (SiO_2), dissolved	3	3.8	.9-8.0	mg/L
Dissolved solids (calculated)	3	1090	628-1540	mg/L
Nitrite plus nitrate, total as N	4	1.3	.00-5.2	mg/L
Nitrogen, ammonia, total as N	4	.03	.00-.05	mg/L
Nitrogen, total organic as N	4	1.9	.61-5.4	mg/L
Nitrogen, total kjeldahl as N	4	1.9	.61-5.4	mg/L
Phosphorus, total as P	4	1.8	.07-6.8	mg/L
Suspended sediment	3	136	68-263	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	3	30-140	2	1600-200000	µg/L
Arsenic	3	0-1	2	1-48	µg/L
Beryllium	3	0	2	10-20	µg/L
Boron	3	110-180	---	---	µg/L
Cadmium	3	0-1	2	<10-10	µg/L
Chromium	3	0-<10	2	10-330	µg/L
Copper	3	2-20	2	<10-440	µg/L
Iron	3	70-130	2	2000-270000	µg/L
Lead	3	0-4	2	<100-400	µg/L
Lithium	3	10-40	2	30-180	µg/L
Manganese	3	7-70	2	250-4100	µg/L
Mercury	3	.0-<.5	2	.1-.7	µg/L
Molybdenum	3	1-2	2	1	µg/L
Nickel	3	3-6	2	<50-450	µg/L
Selenium	3	0-1	2	0-2	µg/L
Vanadium	3	.5-2.3	---	---	µg/L
Zinc	3	10-30	2	10-1100	µg/L

analytical values for Big Dry Creek at Jordan (station 1).

RELATIONSHIP OF MAJOR IONS FOR SELECTED SAMPLES



DISCHARGE-SUSPENDED SEDIMENT LOAD RELATIONSHIP

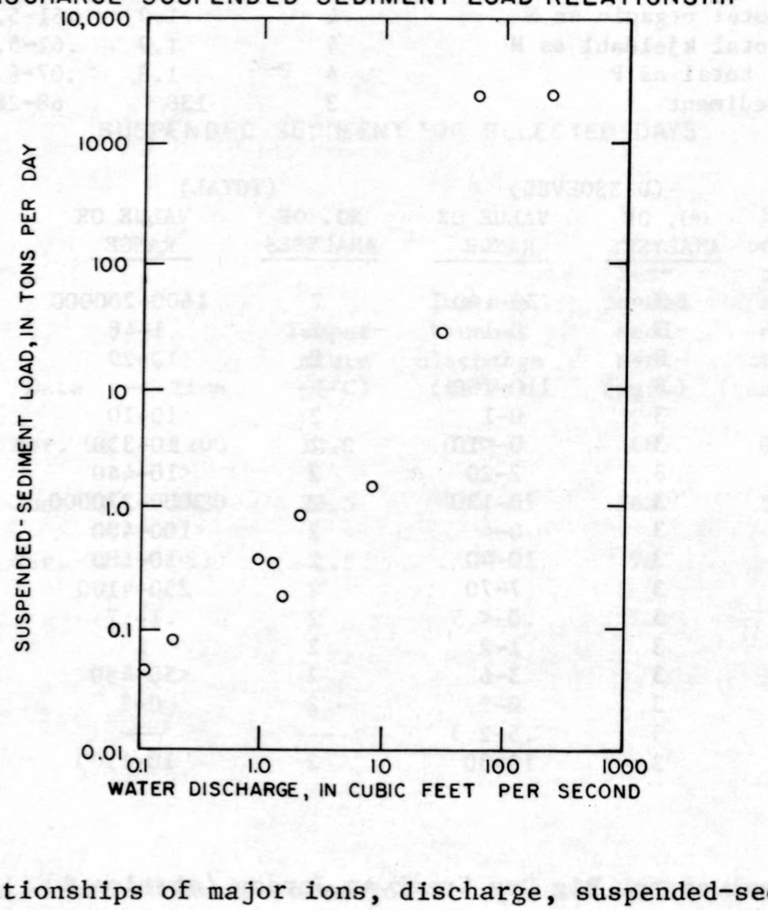


Figure 5.--Relationships of major ions, discharge, suspended-sediment load,

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	10		.12-224	ft^3/s
Specific conductance (at 25°C)	10	2120	695-3420	μmhos/cm
pH	10	8.4	7.9-8.8	units
Temperature, water	10	11.5	.0-29.0	°C
Turbidity	10	1100	10-8300	JTU
Dissolved oxygen, percent saturation	9	97	75-141	percent
Biochemical oxygen demand	---	---	---	mg/L
Calcium (Ca), dissolved	9	32	17-63	mg/L
Magnesium (Mg), dissolved	9	28	6.5-46	mg/L
Sodium (Na), dissolved	10	440	120-760	mg/L
Percent sodium	9	83	76-86	percent
Sodium-adsorption ratio	9	14	6.1-21	---
Potassium (K), dissolved	9	7.4	3.7-12	mg/L
Bicarbonate (HCO_3)	10	450	225-708	mg/L
Carbonate (CO_3)	10	6	0-31	mg/L
Sulfate (SO_4), dissolved	10	740	160-1300	mg/L
Chloride (Cl), dissolved	10	9.9	3.3-19	mg/L
Fluoride (F), dissolved	9	.3	.2-.4	mg/L
Silica (SiO_2), dissolved	9	3.4	.5-7.3	mg/L
Dissolved solids (calculated)	9	1570	433-2460	mg/L
Nitrite plus nitrate, total as N	10	.46	.00-1.2	mg/L
Nitrogen, ammonia, total as N	10	.04	.00-.08	mg/L
Nitrogen, total organic as N	10	1.9	.34-8.6	mg/L
Nitrogen, total kjeldahl as N	10	2.0	.34-8.7	mg/L
Phosphorus, total as P	10	1.1	.02-8.5	mg/L
Suspended sediment	10	1890	44-14000	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	9	0-170	5	280-170000	μg/L
Arsenic	9	0-1	5	1-50	μg/L
Beryllium	9	0-10	5	0-10	μg/L
Boron	9	120-360	---	---	μg/L
Cadmium	9	0-1	5	1-20	μg/L
Chromium	9	0-10	5	0-280	μg/L
Copper	9	1-11	5	<10-470	μg/L
Iron	9	10-510	5	360-270000	μg/L
Lead	9	1-5	5	73-500	μg/L
Lithium	9	10-60	5	40-200	μg/L
Manganese	9	0-30	5	40-4600	μg/L
Mercury	9	.0-<.5	5	.0-1.2	μg/L
Molybdenum	9	1-3	4	0-4	μg/L
Nickel	9	2-7	5	<50-450	μg/L
Selenium	9	0-1	5	0-1	μg/L
Vanadium	9	.0-6.0	---	---	μg/L
Zinc	9	0-20	5	0-1200	μg/L

and analytical values for Little Dry Creek near Van Norman (station 2).

Comparison of total organic nitrogen to total nitrite plus nitrate indicated that nutrients generally increased with an increase in organic matter. On September 8, 1977, the maximum phosphorus concentration for the study area, 8.5 mg/L, was sampled. Most of the time, the phosphorus concentration was less than 0.5 mg/L.

Trace elements, like nutrients, are partly transported by sediment and, therefore, are increased significantly during discharges having high suspended-sediment concentrations. The September 8, 1977, sample was collected from rainfall runoff having high concentrations of sediment and trace elements. Big Dry Creek, Little Dry Creek, and Prairie Elk Creek also had high concentrations of trace elements associated with high concentrations of sediment. Where high sediment concentrations were absent, so were high trace-element concentrations.

Sulfate and dissolved-solids concentrations exceeded the drinking water standards for all samples except during the two highest flows. Dissolved-solids concentration was always below the upper limit for optimum growth of livestock. The water is considered to have a medium to very high sodium hazard for irrigation for all but the high-flow samples. A high to very high salinity hazard is present for most flows sampled (fig. 3).

Suspended-sediment concentration was highest on September 8, 1977, when 14,000 mg/L was sampled. Summer rains produce high suspended-sediment loads because fine dust particles are available for transport by sheet erosion. Suspended-sediment load showed good correlation with discharge.

Timber Creek near Van Norman

Timber Creek flows northwest to the Dry Arm of Fort Peck Lake. At the sampling site (station 3) the valley is narrow and the flow is entrenched in a meandering, grassy channel. Flow through successive ponds followed by deposition of fines has created a predominantly mud bottom. There is no recorded irrigation in this basin of slightly more than 287 mi^2. Timber Creek flows only intermittently; flow was observed four times during the sampling period.

The variation in water composition is small, probably because of the limited range of discharges sampled, 0.76 to 21 ft^3/s. Sodium and sulfate concentrations each constitute over 65 percent of the cation-anion balance (fig. 6).

Dissolved-solids concentration, although high (1,180-3,840 mg/L) for all samples, seemed to be affected by whether the runoff was from rainfall or snowmelt rather than the volume of discharge. A heavy runoff from rainfall of 21 ft^3/s on June 14, 1976, produced a dissolved-solids concentration of 1,740 mg/L. Runoff from snowmelt of 3.5 ft^3/s on March 17, 1976, produced a dissolved-solids concentration of 1,180 mg/L. Frozen ground probably contributed to the low concentration. The lowest flows generally contained the highest concentrations of dissolved solids and probably consisted mostly of water from subsurface flow.

The data showed mixed correlation between discharge and the physical and nutrient parameters. Oxygen averaged 75 percent of saturation for the two runoff-related discharges. The highest saturation recorded was 109 percent from a low-flow sample on April 5, 1977. Nitrogen concentration and pH correlated poorly with discharge. The nitrogen present was mainly organic nitrogen, but its normal association with sediment was not obvious from the data. Phosphorus increased with increased sediment during one sampling, but was constant for the other samples.

Dissolved trace-element concentrations were low except for boron, which ranged from 430 to 1,200 μg/L. Although boron is an essential element for plant growth, concentrations greater than 1 mg/L (1,000 μg/L) can be toxic to sensitive plants (Environmental Studies Board, 1972).

Dissolved-solids and sulfate concentrations were well over the recommended limit for drinking water but below the limits for livestock. The sodium-adsorption ratio and the specific conductance indicate a potential medium to very high sodium hazard and a high to very high salinity hazard to crops irrigated with the water (fig. 3).

The erosion potential of the creek cannot be determined from the low flows sampled. However, based on the barren creek banks and the poorly consolidated shale and lignite observed near the creek, a large sediment concentration would be expected during high flows. The maximum suspended-sediment concentration measured was 518 mg/L during the maximum discharge of 21 ft^3/s, which was confined to the stream channel. Suspended-sediment loads are noted for each discharge in figure 6.

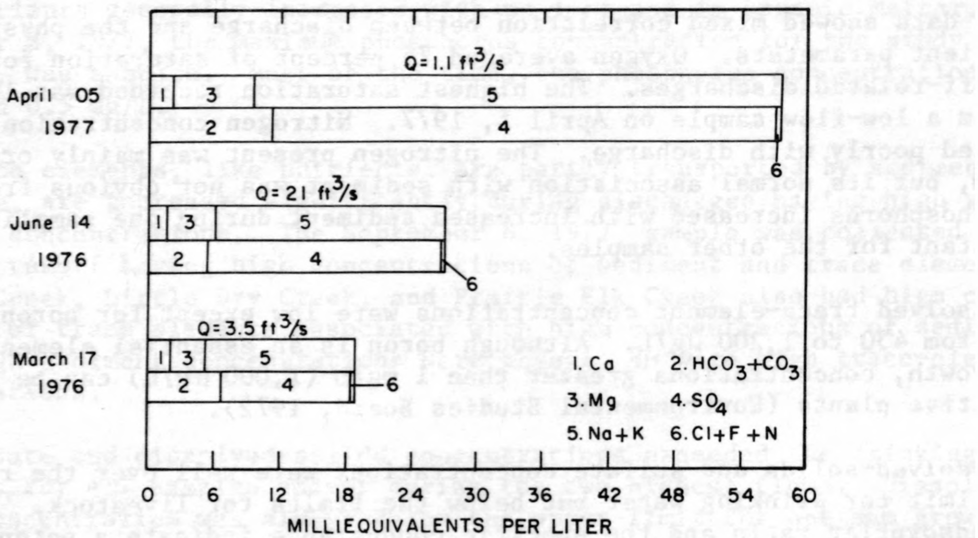
Nelson Creek near Van Norman

Samples were collected at the gaging station (station 4) 1.5 miles upstream from where the creek enters Dry Arm of Fort Peck Lake. Steep barren shale and poorly consolidated sandstone banks are common in the lower drainage. Material forming the streambanks has been eroded to produce a sandy loam channel that supports a light growth of grass and sage. This is the smallest drainage basin, 100 mi^2, studied in this investigation. The water of Nelson Creek is used to irrigate 66 acres (0.10 mi^2).

The streamflow hydrograph for 1976 (fig. 7) shows that high flows are of short duration on this creek. Flow is most consistent during periods of snowmelt from February through April. Runoff from rainfall in June and July produced two peaks of more than 10 ft^3/s, each lasting less than 1 day. Smaller peaks in October were also in response to rainfall runoff. As a result of the short duration of peak flows, no discharges greater than 7.7 ft^3/s were sampled.

Nelson Creek had the highest sampled sodium and sulfate concentrations, 1,200 and 2,700 mg/L respectively, in the study area. The dissolved-solids concentration, which consists largely of the major ions, was also high at 4,570 mg/L. These concentrations were sampled on April 27, 1976, at the end

RELATIONSHIP OF MAJOR IONS FOR SELECTED SAMPLES



SUSPENDED SEDIMENT FOR SELECTED DAYS

	Date	Time	Temperature (°C)	Instantaneous discharge (ft^3/s)	Suspended sediment (mg/L)	Suspended sediment discharge (tons/day)
1976	Mar. 17	1230	1.0	3.5	45	0.43
	Apr. 28	1000	6.5	.76	150	.31
	June 14	1230	14.5	21	518	29
1977	Apr. 05	1230	9.0	1.1	73	.22

Figure 6.--Relationships of major ions, suspended sediment, and

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	4		.76-21	ft^3/s
Specific conductance (at 25°C)	4	3070	1850-4800	μmhos/cm
pH	4	8.6	8.3-8.9	units
Temperature, water	4	7.8	1.0-14.5	°C
Turbidity	4	76	15-250	JTU
Dissolved oxygen, percent saturation	4	85	74-109	percent
Biochemical oxygen demand	---	---	---	mg/L
Calcium (Ca), dissolved	4	37	27-52	mg/L
Magnesium (Mg), dissolved	4	62	40-93	mg/L
Sodium (Na), dissolved	4	620	300-1100	mg/L
Percent sodium	4	77	71-84	percent
Sodium-adsorption ratio	4	14	8.1-23	---
Potassium (K), dissolved	4	8.3	7.5-9.1	mg/L
Bicarbonate (HCO_3)	4	510	310-700	mg/L
Carbonate (CO_3)	4	16	0-43	mg/L
Sulfate (SO_4), dissolved	4	1200	590-2200	mg/L
Chloride (Cl), dissolved	4	8.4	3.4-16	mg/L
Fluoride (F), dissolved	4	.4	.2-.6	mg/L
Silica (SiO_2), dissolved	4	3.4	1.0-5.9	mg/L
Dissolved solids (calculated)	4	2200	1180-3840	mg/L
Nitrite plus nitrate, total as N	4	.07	.00-.26	mg/L
Nitrogen, ammonia, total as N	4	.06	.01-.13	mg/L
Nitrogen, total organic as N	4	1.4	1.1-2.1	mg/L
Nitrogen, total kjeldahl as N	4	1.5	1.1-2.1	mg/L
Phosphorus, total as P	4	.11	.05-.27	mg/L
Suspended sediment	3	197	45-518	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	4	10-50	2	700-6000	μg/L
Arsenic	4	0-5	2	1-9	μg/L
Beryllium	4	0	2	10	μg/L
Boron	4	430-1200	---	---	μg/L
Cadmium	4	0	2	0-< 10	μg/L
Chromium	4	0-<10	2	0-< 10	μg/L
Copper	4	3-10	2	10-20	μg/L
Iron	4	70-170	2	940-8400	μg/L
Lead	4	2-3	2	13-< 100	μg/L
Lithium	4	20-40	2	20-30	μg/L
Manganese	4	10-60	2	90-190	μg/L
Mercury	4	.0-<.5	2	.0-<.5	μg/L
Molybdenum	4	2-4	2	3-4	μg/L
Nickel	4	2-7	2	19-50	μg/L
Selenium	4	0	2	0	μg/L
Vanadium	4	.6-3.4	---	---	μg/L
Zinc	4	0-20	2	10-50	μg/L

analytical values for Timber Creek near Van Norman (station 3).

of a low-flow period when the effects of ground-water inflow and evaporation were at a maximum. The dominance of sodium and sulfate at different discharges is shown by the bar graph in figure 8. The complete range in chemical concentration of the stream cannot be known without some samples from periods of high flow.

The pH had a relatively wide range of 7.3 to 8.8. On September 8, 1977, a sample of rainfall runoff had a pH of 7.3, which was lowest for the study area, and a dissolved-oxygen saturation of 68 percent. Dissolved oxygen was below saturation in all samples. The biochemical oxygen demand at this station, which was the highest average for the study, did not correlate with discharge, dissolved-oxygen saturation, or time of year.

The nitrogen and phosphorus concentrations were equal to or less than 3 mg/L and 0.3 mg/L, respectively, for all samples. Nitrite plus nitrate contained about 16 percent of the nitrogen measured.

Sparsely vegetated land and barren shale slopes present the potential for high sediment loads. However, because of the lack of high flows during the study, the highest sediment load was 5.9 tons/day on March 17, 1956, when the discharge was 7.7 ft^3/s. The graph of suspended-sediment load

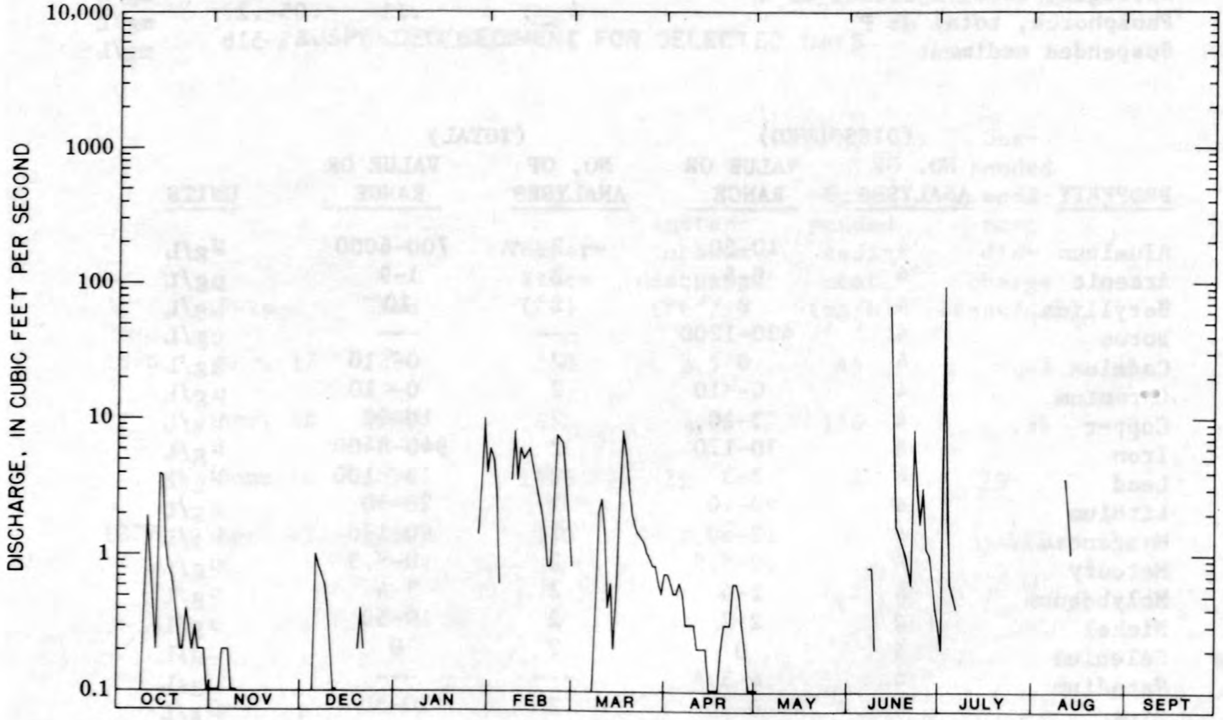


Figure 7.--Hydrograph of stream discharge for Nelson Creek near Van Norman, 1976 water year. Breaks in line continuity represent periods of no flow.

versus water discharge (fig. 8) shows a fair correlation for the samples collected. The ability of the creek to transport sediment will be largely unknown until high flows can be sampled.

An exception to the low total and dissolved trace-element concentration was boron. Concentrations of boron averaged 420 μg/L and ranged from 120 to 910 μg/L. Other concentrations for total and dissolved trace elements are listed in figure 8.

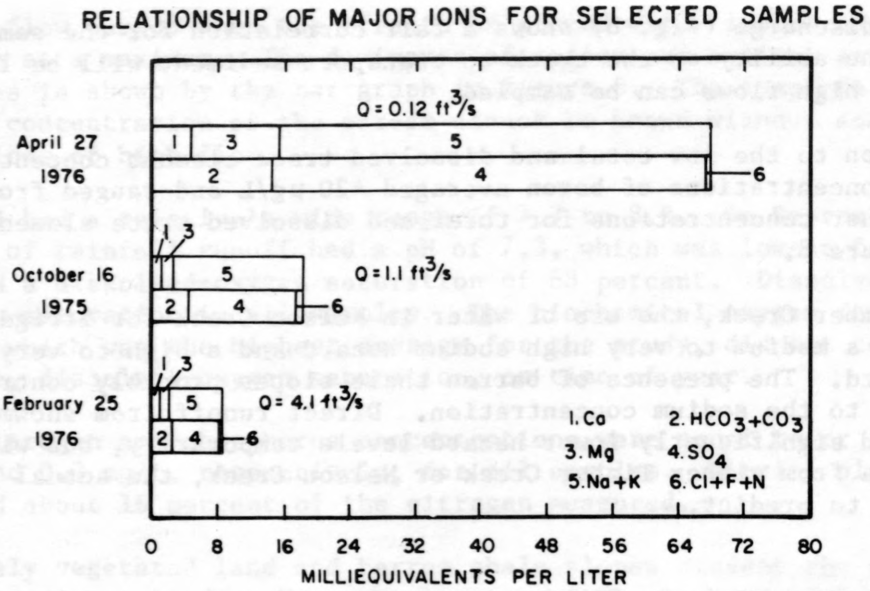
As with Timber Creek, the use of water in Nelson Creek for irrigation would present a medium to very high sodium hazard and a high to very high salinity hazard. The presence of barren shale slopes probably contributes significantly to the sodium concentration. Direct runoff from snowmelt or rainfall could significantly lower hazard levels temporarily, but without high-flow data from either Timber Creek or Nelson Creek, the actual effects are difficult to predict.

Prairie Elk Creek near Oswego

Prairie Elk Creek heads near Weldon and flows north to the Missouri River. The broad gentle slopes in the headwaters area give way downstream to rough badlands produced by erosion of shale and sandstone near the Missouri River. Prairie Elk Creek has a valley about 1 mile wide and meanders through an area of saline soil that has limited irrigation (59 acres or 0.09 mi^2). Vegetation is mostly grasses and sagebrush. Rangeland is the major land use with some farming in the headwaters and alluvial valleys. The creek is sampled about 1 mile upstream from the mouth at the gaging station (station 5). The drainage area upstream from the site is 352 mi^2.

The hydrograph (fig. 9) shows that Prairie Elk Creek is a perennial stream having its major flow during the periods of snowmelt in February and March. Precipitation received in June, which is usually a wet month, recharges the alluvial aquifers and prolongs flows during summer. The magnitude of discharge in the spring is determined by the snowpack and the intensity of warm weather and accompanying warm winds. Rapid changes in the discharge from snowmelt or rainfall have a profound effect on the water chemistry and sediment transport. Sampled discharge ranged from 0.06 to 1,170 ft^3/s.

Sodium derived primarily from the soil is the major cation in the water. Although Prairie Elk Creek water is strongly dominated by sodium, the lowest concentration (43 mg/L) in the study area was sampled here (fig. 10). The concentration of magnesium was greater than calcium only when sodium was greater than 90 percent of the total cations. Bicarbonate is the dominant anion in the water of Prairie Elk Creek (fig. 10). Of the sites studied, Sand Creek (east of the Prairie Elk Creek, fig. 1) was the only other drainage in which bicarbonate was always the dominant anion. The bicarbonate source in these drainages probably is sandstones in the Fox Hills Sandstone and lower part of the Hell Creek Formation. Sulfate is present in large concentrations, averaging more than 40 percent of the anionic balance.



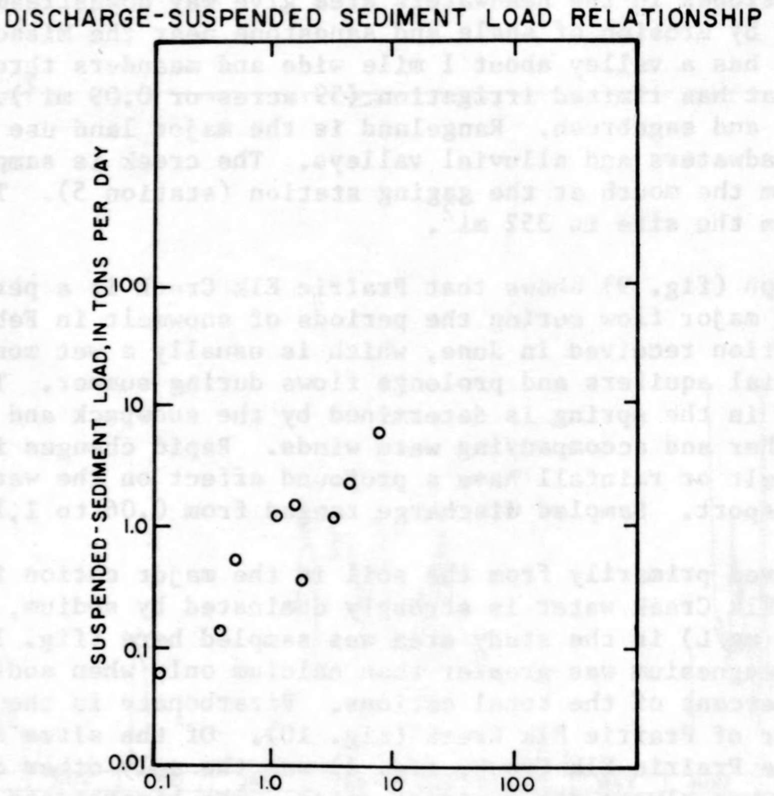


Figure 8.--Relationships of major ions, discharge, suspended-sediment

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	10		.12-7.7	ft^3/s
Specific conductance (at 25°C)	10	2590	770-5850	μmhos/cm
pH	10	8.3	7.3-8.8	units
Temperature, water	10	7.3	.0-18.0	°C
Turbidity	10	120	20-310	JTU
Dissolved oxygen, percent saturation	10	79	64-96	percent
Biochemical oxygen demand	9	3.8	2.2-5.1	mg/L
Calcium (Ca), dissolved	10	44	23-95	mg/L
Magnesium (Mg), dissolved	10	46	12-130	mg/L
Sodium (Na), dissolved	10	520	120-1200	mg/L
Percent sodium	10	76	65-83	percent
Sodium-adsorption ratio	10	12	4.5-22	---
Potassium (K), dissolved	10	7.1	4.9-10	mg/L
Bicarbonate (HCO_3)	10	390	98-783	mg/L
Carbonate (CO_3)	10	10	0-62	mg/L
Sulfate (SO_4), dissolved	10	1100	260-2700	mg/L
Chloride (Cl), dissolved	10	7.6	2.7-14	mg/L
Fluoride (F), dissolved	10	.4	.1-.7	mg/L
Silica (SiO_2), dissolved	10	4.6	.1-7.8	mg/L
Dissolved solids (calculated)	10	1910	528-4570	mg/L
Nitrite plus nitrate, total as N	10	.25	.01-.63	mg/L
Nitrogen, ammonia, total as N	10	.04	.00-.09	mg/L
Nitrogen, total organic as N	10	1.3	.69-2.5	mg/L
Nitrogen, total kjeldahl as N	10	1.4	.73-2.6	mg/L
Phosphorus, total as P	10	.15	.02-.30	mg/L
Suspended sediment	9	240	78-411	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	4	10-30	4	410-15000	μg/L
Arsenic	4	0-2	4	1-7	μg/L
Beryllium	4	0-10	4	0-10	μg/L
Boron	10	120-910	---	---	μg/L
Cadmium	4	0-3	4	0-20	μg/L
Chromium	4	0	4	10-70	μg/L
Copper	4	4-12	4	10-50	μg/L
Iron	10	40-140	4	1900-20000	μg/L
Lead	4	0-9	4	10-<100	μg/L
Lithium	4	20-50	4	20-40	μg/L
Manganese	4	10-160	4	140-280	μg/L
Mercury	4	.0-.4	4	.0-<.5	μg/L
Molybdenum	4	0-3	4	0-3	μg/L
Nickel	4	3-7	4	19-50	μg/L
Selenium	4	1-2	4	0-3	μg/L
Vanadium	4	.0-2.5	---		μg/L
Zinc	4	10-20	4	30-110	μg/L

load, and analytical values for Nelson Creek near Van Norman (station 4).

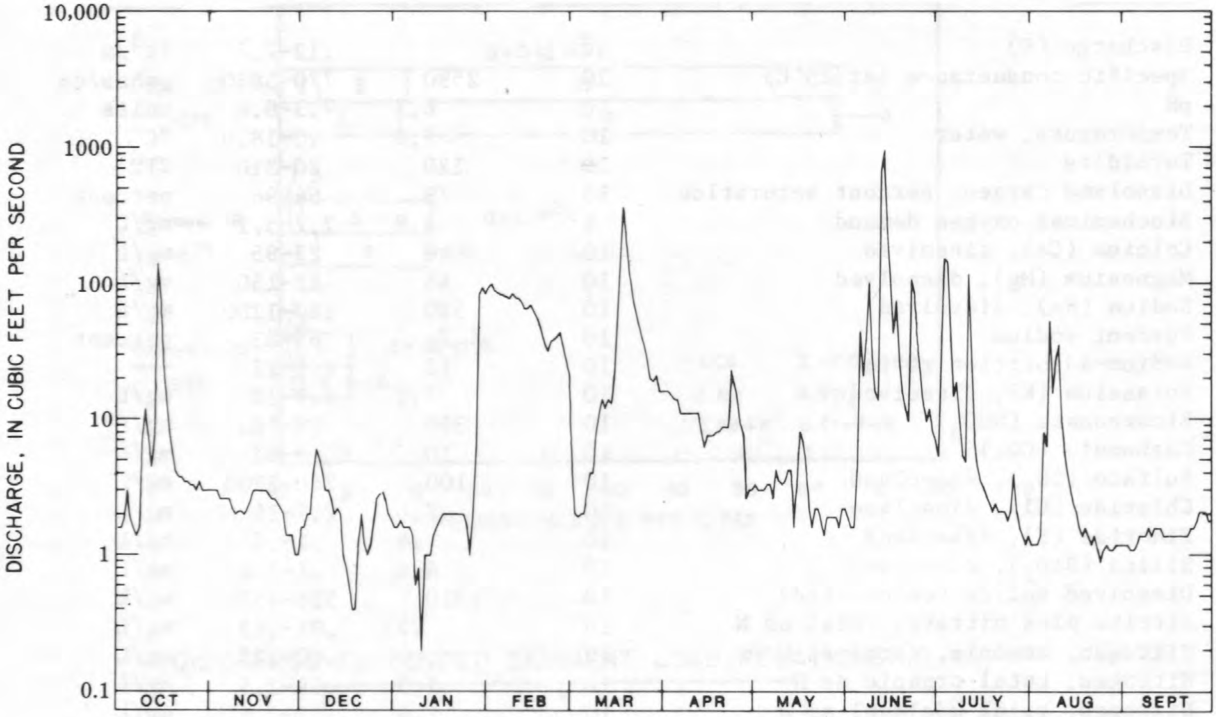


Figure 9.--Hydrograph of stream discharge for Prairie Elk Creek near Oswego, 1976 water year.

Discharge and dissolved-solids concentrations had a poor inverse correlation. However, high dissolved-solids concentrations (633 to 2,380 mg/L) tend to be associated with low flows, and low concentrations (160 to 363 mg/L) with direct runoff from snowmelt and rainfall.

Bicarbonate and carbonate ions affected the pH, which averaged 8.5 and ranged from 7.6 to 9.1. With one exception, pH values less than 8.5 all occurred during ice cover. The exception was a pH of 8.1 measured during rainfall runoff on June 13, 1976. Dissolved oxygen averaged 91 percent of saturation and ranged from 16 to 124 percent. A high concentration of algae suspected at this site may be the cause of dissolved oxygen fluctuation in the summer. Only two samples were below 76 percent--16 percent on January 18, 1977, and 48 percent on February 10, 1977. Both samples were taken during periods of low flow and complete ice cover. Saturations greater than 100 percent were common during spring and summer flows when good mixing took place and some algae growth was present.

Nutrients correlated well with suspended sediment. The correlation coefficient for nitrogen and suspended sediment was 0.96. As in other drainages, the majority of the nitrogen was combined with organic material, probably associated with sediment. Phosphorus and suspended sediment had a correlation coefficient of 0.83--a good indication that the sediment is transporting this nutrient. The correlation between discharge and nutrient concentration was poor.

Dissolved trace-element concentrations were relatively low compared to total concentrations. Total aluminum and iron concentrations were high because of high concentrations of sediment.

The major use of water from Prairie Elk Creek is for stock watering and some irrigation. Use for irrigation is hindered by high salinity and sodium hazards in both the soil and the water (Montana Water Resources Board, 1971). The water presents no hazard to livestock.

Prairie Elk Creek generally appears muddy and has the highest average suspended-sediment concentration, 2,300 mg/L, in the study area. Suspended-sediment concentration and discharge data had a poor correlation coefficient, 0.23, which is reflected in the discharge-suspended sediment load graph in figure 10.

Sand Creek near Wolf Point

Sand Creek drains part of the Missouri River "breaks" and enters the Missouri River about 6.5 miles southwest of Wolf Point. Samples were taken at a county road bridge, 2.8 miles upstream from the mouth (station 6). The creek channel is approximately 150 feet wide at the sampling site and has a muddy sand bottom. Irrigated land comprises about 380 acres (0.59 mi^2) of the 202 mi^2 drainage area upstream from the sampling site. Streamflow is in response to spring snowmelt and heavy summer rainstorms. Flow during summer and late fall is sustained by ground-water inflow. The stream is often dry in late summer and early fall.

Sand Creek, like Prairie Elk Creek, contains water of the sodium bicarbonate type. The bar graph of figure 11 shows the dominance of sodium for a range of flows. Bicarbonate and carbonate averaged more than 55 percent of the anion balance. The source of the bicarbonate and carbonate may be the sandstone of the Fox Hills Sandstone and the lower part of the Hell Creek Formation. Sulfate comprised at least 60 percent of the anions during two of the three highest flows, probably as a result of overland flow in the upper drainage.

The dissolved-solids concentration fluctuated inversely with the discharge. Rapid runoff of summer rains and flow over frozen ground in the winter normally limited the dissolved mineral content during high flows. Low flow is strongly affected by the high dissolved-solids concentration of ground-water inflow.

The pH closely follows the bicarbonate and carbonate changes, reaching a maximum of 9.2 twice and averaging 8.7 (fig. 11). Dissolved-oxygen saturation ranged from 80 to 120 percent. The high percentage was probably a result of algal activity during a warm summer day. Turbidity reached 3,200 and 5,600 JTU on March 30, 1977, and June 16, 1977, respectively. These high turbidities were the result of rain and snowmelt eroding barren or sparsely vegetated shale and sandstone slopes.

Nutrient concentrations were generally low but increased with higher sediment concentrations and discharges. Inorganic nitrogen averaged 16 percent of the nitrogen load. The remaining nitrogen was in the organic form.

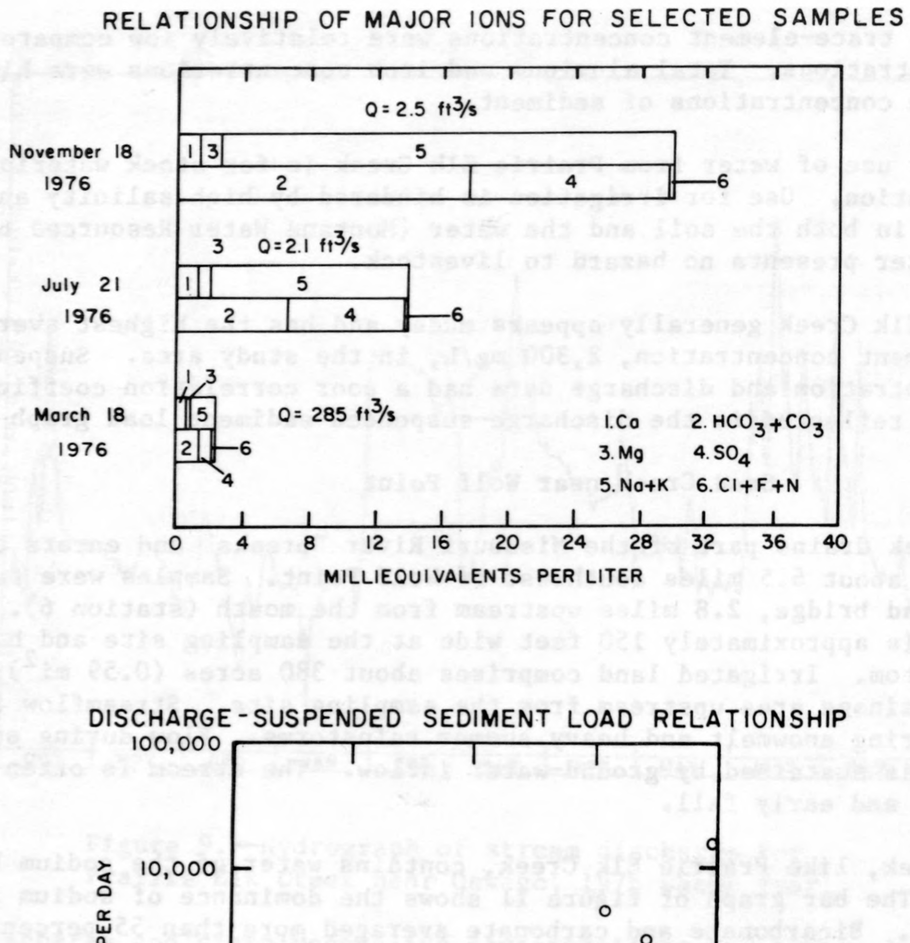
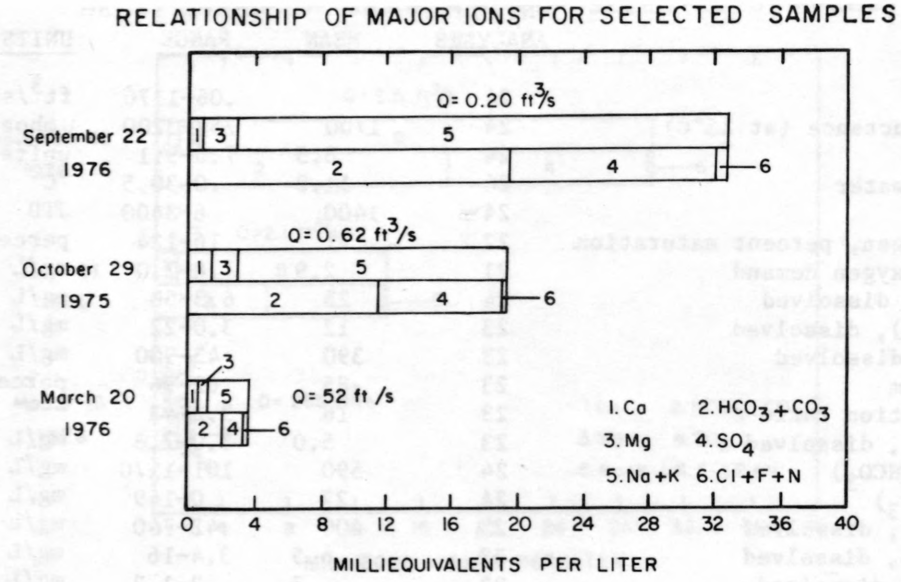


Figure 10.--Relationships of major ions, discharge, suspended-sediment

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	24		.06-1170	ft^3/s
Specific conductance (at 25°C)	24	1700	257-3200	μmhos/cm
pH	24	8.5	7.6-9.1	units
Temperature, water	24	11.0	.0-30.5	°C
Turbidity	24	1400	6-8400	JTU
Dissolved oxygen, percent saturation	22	91	16-124	percent
Biochemical oxygen demand	21	2.9	.8-7.0	mg/L
Calcium (Ca), dissolved	24	22	6.3-50	mg/L
Magnesium (Mg), dissolved	23	12	3.0-22	mg/L
Sodium (Na), dissolved	23	390	43-900	mg/L
Percent sodium	23	85	62-96	percent
Sodium-adsorption ratio	23	16	3.2-43	---
Potassium (K), dissolved	23	5.0	3.0-7.8	mg/L
Bicarbonate (HCO_3)	24	590	101-1170	mg/L
Carbonate (CO_3)	24	27	0-149	mg/L
Sulfate (SO_4), dissolved	23	400	42-740	mg/L
Chloride (Cl), dissolved	22	6.5	3.4-16	mg/L
Fluoride (F), dissolved	23	.7	.2-1.2	mg/L
Silica (SiO_2), dissolved	23	9.5	2.4-52	mg/L
Dissolved solids (calculated)	22	1200	160-2380	mg/L
Nitrite plus nitrate, total as N	22	.38	.00-3.2	mg/L
Nitrogen, ammonia, total as N	24	.09	.00-.35	mg/L
Nitrogen, total organic as N	24	1.9	.16-9.8	mg/L
Nitrogen, total kjeldahl as N	24	2.0	.26-10	mg/L
Phosphorus, total as P	23	.74	.01-5.3	mg/L
Suspended sediment	23	2300	90-12500	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	6	0-540	6	1600-160000	μg/L
Arsenic	6	1-4	7	1-80	μg/L
Beryllium	6	0-10	6	0-10	μg/L
Boron	24	60-1000	---	---	μg/L
Cadmium	6	0-1	7	2-20	μg/L
Chromium	6	0-10	7	0-290	μg/L
Copper	6	2-18	7	<10-490	μg/L
Iron	23	10-640	7	2000-250000	μg/L
Lead	6	0-4	7	<100-400	μg/L
Lithium	6	50-160	7	60-260	μg/L
Manganese	6	5-150	7	90-3500	μg/L
Mercury	5	.0-.1	7	.0-1.7	μg/L
Molybdenum	6	0-5	6	1-4	μg/L
Nickel	6	3-20	7	<50-550	μg/L
Selenium	6	0-5	7	0-3	μg/L
Vanadium	6	.0-49	---	---	μg/L
Zinc	6	10-130	7	6-1000	μg/L

load, and analytical values for Prairie Elk Creek near Oswego (station 5).



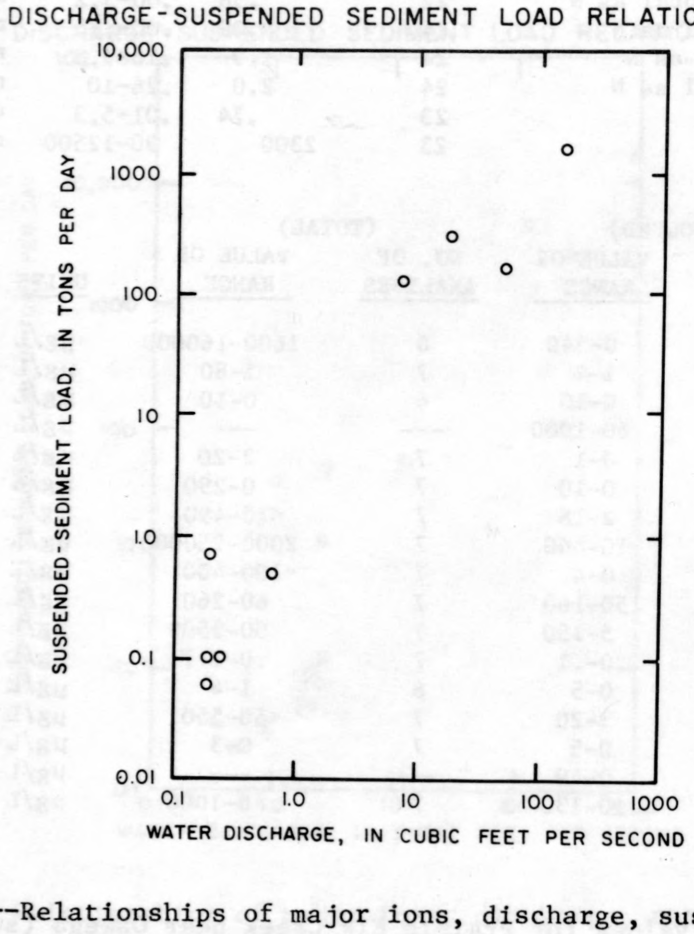


Figure 11.--Relationships of major ions, discharge, suspended-sediment

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	9		.20-165	ft^3/s
Specific conductance (at 25°C)	9	1800	360-3230	μmhos/cm
pH	9	8.7	8.0-9.2	units
Temperature, water	9	12.3	.5-30.0	°C
Turbidity	9	1300	30-5600	JTU
Dissolved oxygen, percent saturation	8	95	80-120	percent
Biochemical oxygen demand	---	---	---	mg/L
Calcium (Ca), dissolved	9	19	12-26	mg/L
Magnesium (Mg), dissolved	9	13	4.5-24	mg/L
Sodium (Na), dissolved	9	410	52-820	mg/L
Percent sodium	9	85	65-93	percent
Sodium-adsorption ratio	9	17	3.1-32	---
Potassium (K), dissolved	9	5.8	4.9-7.5	mg/L
Bicarbonate (HCO_3)	9	470	128-800	mg/L
Carbonate (CO_3)	9	130	0-435	mg/L
Sulfate (SO_4), dissolved	9	400	63-770	mg/L
Chloride (Cl), dissolved	8	7.9	3.5-14	mg/L
Fluoride (F), dissolved	9	1.1	.2-2.1	mg/L
Silica (SiO_2), dissolved	9	8.6	2.5-12	mg/L
Dissolved solids (calculated)	8	1220	212-2480	mg/L
Nitrite plus nitrate, total as N	9	.65	.01-2.6	mg/L
Nitrogen, ammonia, total as N	9	.09	.00-.15	mg/L
Nitrogen, total organic as N	9	2.0	.73-4.1	mg/L
Nitrogen, total kjeldahl as N	9	2.1	.74-4.0	mg/L
Phosphorus, total as P	9	.58	.04-1.8	mg/L
Suspended sediment	9	2180	107-7010	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	9	10-1100	4	3000-42000	μg/L
Arsenic	9	0-6	4	1-57	μg/L
Beryllium	9	0	3	0-10	μg/L
Boron	9	110-1100	---	---	μg/L
Cadmium	9	0-1	4	0-<10	μg/L
Chromium	9	0-30	4	0-70	μg/L
Copper	9	3-28	4	20-130	μg/L
Iron	9	40-310	4	4200-69000	μg/L
Lead	9	0-12	4	0-<100	μg/L
Lithium	9	10-170	4	60-150	μg/L
Manganese	9	0-260	4	190-1400	μg/L
Mercury	8	.0-5.3	4	.0-<.5	μg/L
Molybdenum	9	0-7	4	1-5	μg/L
Nickel	9	5-43	4	<50-180	μg/L
Selenium	8	0-3	4	1-3	μg/L
Vanadium	9	.4-4.0	---	---	μg/L
Zinc	9	6-70	4	30-300	μg/L

load, and analytical values for Sand Creek near Wolf Point (station 6).

The average total phosphorus concentration, 0.58 mg/L, was average for the study area. Two periods of direct runoff from rainfall in June 1977 increased the phosphorus concentration to 1.3 and 1.8 mg/L.

Total and dissolved trace elements were sampled three times--twice during low flow and once during high flow. Maximum measured concentrations of total iron and aluminum were 69,000 mg/L and 42,000 mg/L, respectively (fig. 11). The average boron concentration of 563 μg/L was above normal for the area, owing to two samples containing 1,100 μg/L.

Classification of the water for irrigation shows that normally the hazard is medium to high for sodium and high for salinity. If the water is classified for irrigation according to flow, the high flows show low to medium levels and the low flows are normally in the high-hazard range. Dissolved-solids concentrations for all samples were below the upper limits for livestock use.

The suspended-sediment concentrations of samples collected at Sand Creek were closely related to discharge. The land is susceptible to sheet erosion because of the moderate vegetation cover and the weathering of surface material during periods of no precipitation. Sand is a major component of the suspended-sediment load and the channel bed. Sand is available as sediment load from glacial and alluvial deposits, and from sandstone in the Fox Hills Sandstone and Hell Creek Formation. During a period of direct runoff from rainfall on June 13, 1976, the maximum suspended-sediment load, 1,550 tons/day, was calculated from a peak discharge of 165 ft^3/s and a suspended-sediment concentration of 3,470 mg/L (fig. 11).

Redwater River Basin

The western headwaters of the Redwater River flow intermittently through an area of broad, grass-covered hills and valleys. The eastern headwaters flow intermittently and have developed abrupt narrow valleys. The valley of the Redwater River changes from long, gentle slopes and rolling grasslands that are moderately incised in the central part of the basin to abrupt rugged breaks near the mouth. The lower valley ranges in width from one-fourth to one-half mile. In this area the river channel is 10 to 20 feet deep and 60 feet wide.

Land use has historically been for rangeland but farming and mineral development have brought diversification. The basin is mostly rangeland and supported livestock as early as 1884. The crops are raised chiefly through dryland farming methods, although irrigation is practiced where soil permits and good water is available. In 1951, oil and gas were found in the Williston basin, of which the study area is a part, and since then other fields have been discovered. Lignite coal is found mostly in the Tongue River Member of the Fort Union Formation, which underlies much of the uplands (fig. 2). The coal is not presently being developed.

Two water-quality stations are operated on the Redwater River. The site at the town of Circle (station 7) was originally established in April 1929 and has stage record to the present. Monthly water-quality data collection was initiated in October 1974. The site at Redwater River near

Vida (station 8) was established as a stage-recording gage and water-quality station in October 1975.

Redwater River at Circle

The sampling site (station 7) is immediately east of Circle where the river meanders through a channel about 10 to 15 feet deep. A wide grassy flood plain stretches east of the river. White salt deposits on the stream banks are evidence of evaporation of water primarily composed of the more-mineralized ground-water inflow. The bottom is composed of sand and gravel and supports a moderate aquatic growth. Alluvium and soils overlie the Tongue River Member of the Fort Union Formation throughout this upper drainage. The drainage area is 547 mi^2, of which 2,532 acres (3.96 mi^2) is irrigated. Irrigation of additional acreages is hindered by the lack of water and the drainage properties of the soil (Montana Water Resources Board, 1971).

The hydrograph (fig. 12) indicates that the major flows originate from early snowmelts in February and from rains during the summer that provide short periods of flow. The mean daily flow at Circle for the 1976 water year was 4.86 ft^3/s, which is considerably less than the 37-year average of 14.2 ft^3/s. Sampled discharges for water years 1975-77 ranged from 0.01 to 22 ft^3/s.

The water sampled was predominantly a sodium sulfate type and did not vary significantly with season or discharge. The bar graph (fig. 13) shows a large

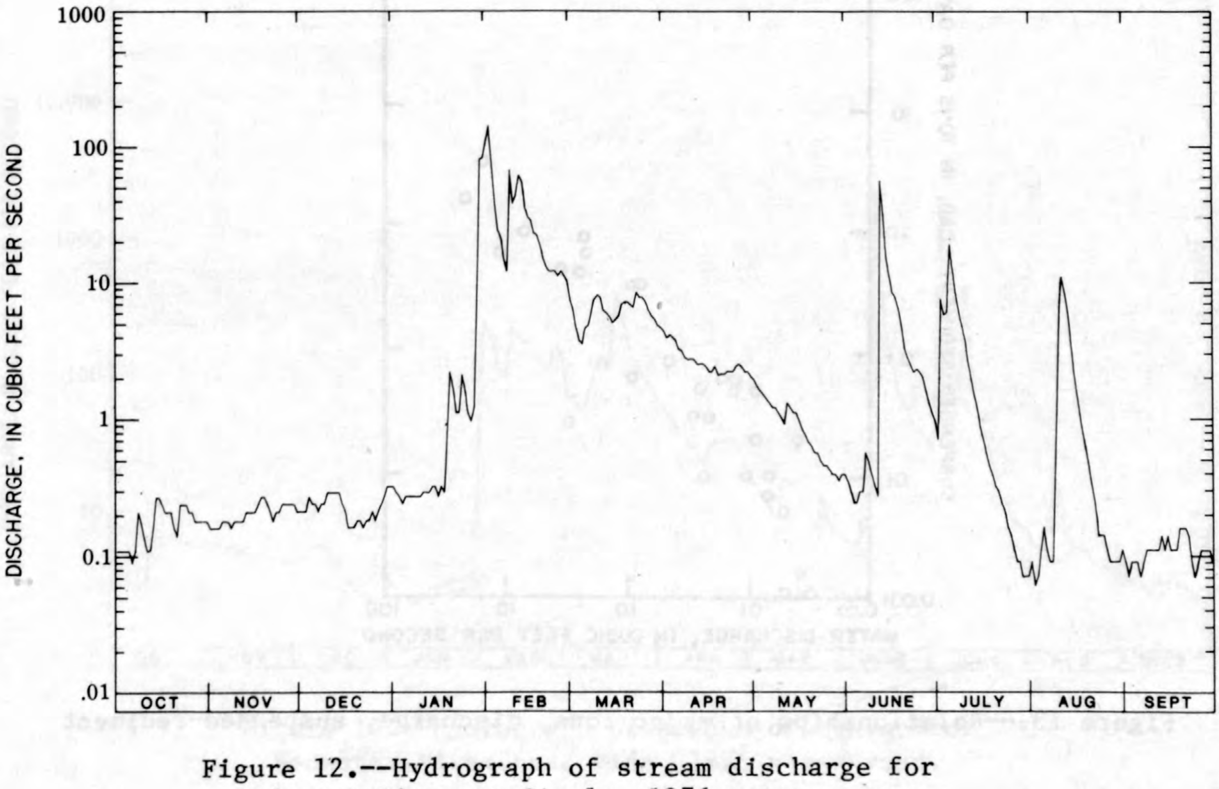
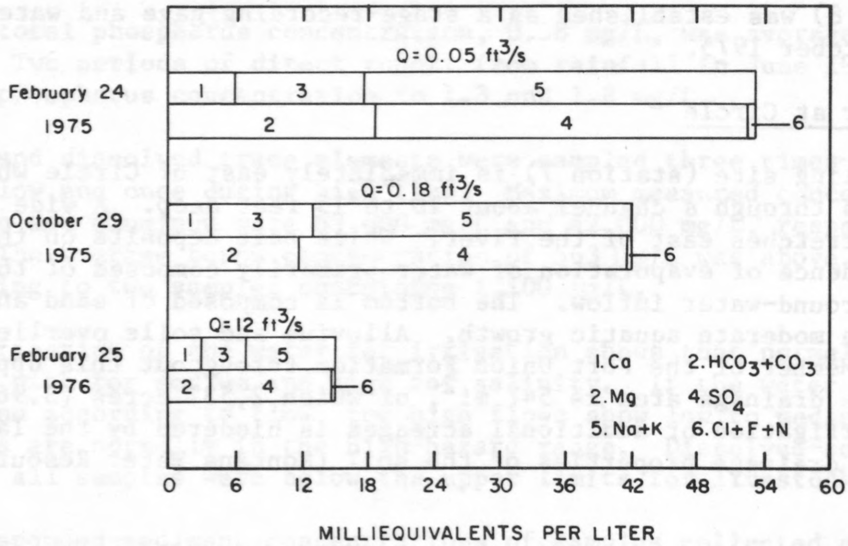


Figure 12.--Hydrograph of stream discharge for Redwater River at Circle, 1976 water year.

RELATIONSHIP OF MAJOR IONS FOR SELECTED SAMPLES



DISCHARGE - SUSPENDED SEDIMENT LOAD RELATIONSHIP

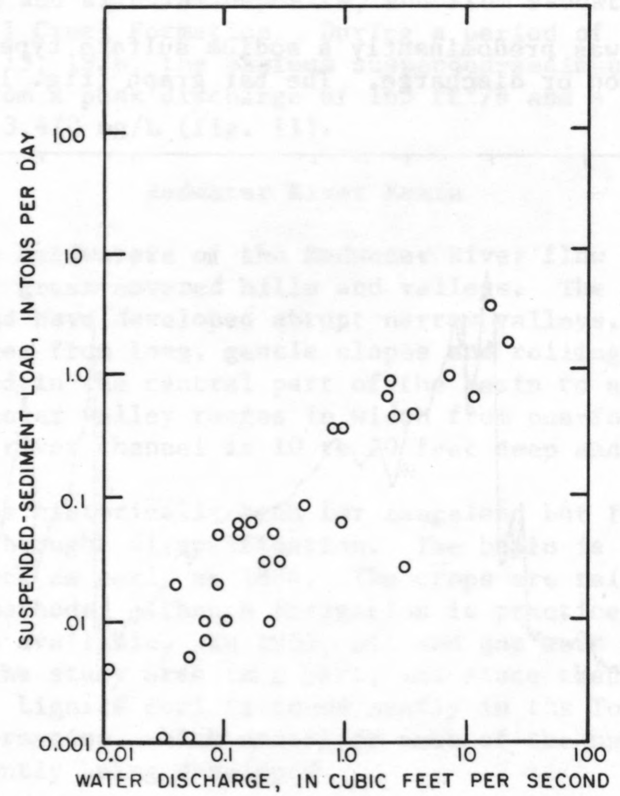


Figure 13.--Relationships of major ions, discharge, suspended-sediment

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	35		.01-22	ft^3/s
Specific conductance (at 25°C)	35	3450	1800-4800	µmhos/cm
pH	35	8.3	7.6-8.7	units
Temperature, water	35	8.9	.0-25.0	°C
Turbidity	35	19	2-65	JTU
Dissolved oxygen, percent saturation	35	82	24-119	percent
Biochemical oxygen demand	32	2.2	.4-4.9	mg/L
Calcium (Ca), dissolved	35	87	39-120	mg/L
Magnesium (Mg), dissolved	35	120	57-160	mg/L
Sodium (Na), dissolved	35	600	200-830	mg/L
Percent sodium	35	64	51-77	percent
Sodium-adsorption ratio	35	9.9	4.5-15	---
Potassium (K), dissolved	35	9.7	3.8-14	mg/L
Bicarbonate (HCO_3)	34	650	271-1130	mg/L
Carbonate (CO_3)	35	10	0-100	mg/L
Sulfate (SO_4), dissolved	35	1400	590-2000	mg/L
Chloride (Cl), dissolved	35	15	5.5-27	mg/L
Fluoride (F), dissolved	35	1.1	.3-2.0	mg/L
Silica (SiO_2), dissolved	35	7.0	.8-22	mg/L
Dissolved solids (calculated)	34	2560	1060-3370	mg/L
Nitrite plus nitrate, total as N	35	.04	.00-.32	mg/L
Nitrogen, ammonia, total as N	35	.11	.00-.86	mg/L
Nitrogen, total organic as N	35	.76	.33-1.8	mg/L
Nitrogen, total kjeldahl as N	35	.87	.46-1.8	mg/L
Phosphorus, total as P	35	.05	.00-.12	mg/L
Suspended sediment	34	79	17-214	mg/L

	(DISSOLVED)		(TOTAL)		
PROPERTY	NO. OF ANALYSES	VALUE OR RANGE	NO. OF ANALYSES	VALUE OR RANGE	UNITS
Aluminum	7	10-100	9	100-1400	µg/L
Arsenic	7	1-3	11	1-6	µg/L
Beryllium	7	0-10	11	0-<10	µg/L
Boron	35	220-970	---	---	µg/L
Cadmium	7	0-2	11	0-20	µg/L
Chromium	7	0	11	0-40	µg/L
Copper	7	0-4	11	<10-60	µg/L
Iron	35	0-270	11	370-2000	µg/L
Lead	7	0-14	11	4-100	µg/L
Lithium	7	40-73	11	30-90	µg/L
Manganese	7	0-450	10	20-500	µg/L
Mercury	7	.0-.1	11	.0-.6	µg/L
Molybdenum	7	1-9	11	2-12	µg/L
Nickel	7	1-6	11	0-50	µg/L
Selenium	6	0-2	11	0-1	µg/L
Vanadium	7	.0-<9.0	---	---	µg/L
Zinc	7	0-430	9	10-260	µg/L

load, and analytical values for Redwater River at Circle (station 7).

difference in ion concentration for February samples. A high flow in early February 1975 had a diluting effect on the ensuing sample. High-flow samples were absent but, by comparison to similar drainages, a sodium concentration below 50 percent of the cations would be expected. The sulfate concentration would also decrease during high flow but not as significantly.

Dissolved-solids concentration did not correlate well with seasonal or discharge changes because of the lack of high discharges. The average concentration, 2,560 mg/L, was the highest in the study area. Many of the dissolved minerals are introduced by ground-water inflow and dissolution of salts precipitated by evaporation along the river banks.

The pH and dissolved oxygen varied with the seasons and water temperature. The pH ranged from 7.6 to 8.2 during the winter months and accompanying ice cover. Dissolved-oxygen saturation decreased from a year-round average of 82 percent to an average of 61 percent during the winter months.

Nitrogen and phosphorus were relatively low for all samples. Organic nitrogen was dominant over the inorganic form (fig. 13). Cattle excretion and plant decay were probably the major sources of nutrients. The Circle sewage lagoon is downstream from this site and, therefore, had no effect on the samples.

A dissolved-manganese concentration of 450 μg/L was sampled on December 21, 1976, which is higher than sampled at other sites. Although manganese is not known to deteriorate the water for drinking, it can precipitate as manganese oxide and cause black stains. The recommended limit for manganese in water used for irrigation is 200 μg/L (Environmental Studies Board, 1972).

The Redwater River is used for irrigation and stock watering. The sodium hazard is normally low, but the salinity hazard is very high because of the dissolved constituents (fig. 13). As a result, irrigation is limited to periods when streamflow consists primarily of direct runoff. The average dissolved-solids concentration is only slightly below the recommended limit for poultry, 2,860 mg/L. This limit is usually exceeded in the fall and winter.

Suspended-sediment load showed fair correlation with discharge (fig. 13). The average sediment concentration was 79 mg/L, which would have been higher if high flows had been sampled.

Redwater River near Vida

The sampling site (station 8) is 400 feet downstream from East Redwater River and 17 miles upstream from the mouth (fig. 1). The river channel at the site is about 120 feet wide and 8 feet deep and the bottom is a mixture of mud, sand, and gravel (see photograph, front cover). Much of the area downstream from Circle is shale of the Lebo Shale Member of the Fort Union Formation. Through erosion much of this area has a badland topography. The station is near the contact between the Lebo Shale and Tullock Members. Of the 1,974 mi^2 in the drainage, approximately 4,536 acres (7.09 mi^2) is irrigated.

Snowmelt and summer rainstorms are the major sources of flow in the Redwater River. February through April are the months of major runoff (fig. 14). The rainy period during June and July that produces discharges of short duration generally dissipates during August. Flow is also sustained by tributaries, such as Cow Creek, that have ground-water inflow. The average daily discharge of the Redwater River at the gage was 57.8 ft^3/s for 1976. During some years the river has periods of no flow.

Sodium and sulfate ions dominate the Redwater River near Vida, as at Circle. Comparison of a high-flow sample of June 13, 1976, with a mean-flow sample of October 15, 1975, shows a threefold difference in the major-ion concentration (bar graph, fig. 15). During high flows the percentage of calcium was double the average of 8.3 percent. For the same flows magnesium and bicarbonate increased but not as significantly.

Dissolved-solids concentration and discharge had a correlation coefficient of -0.65. Minimum concentrations occurred during samplings when the

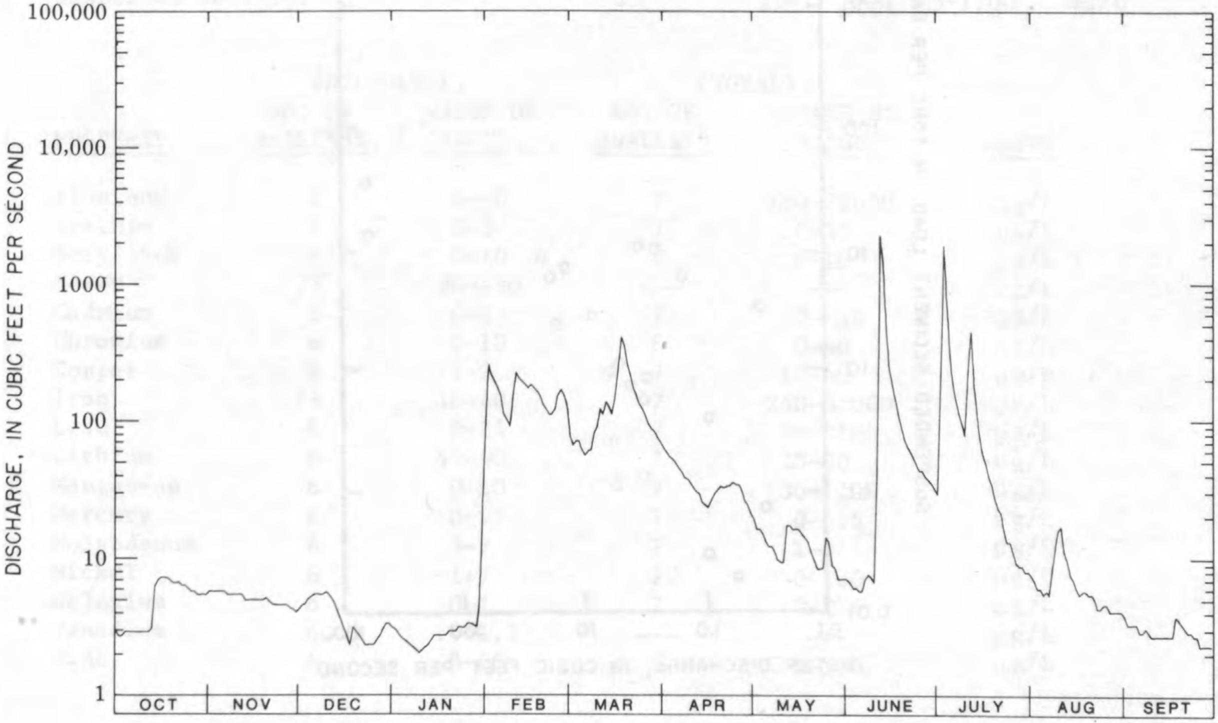
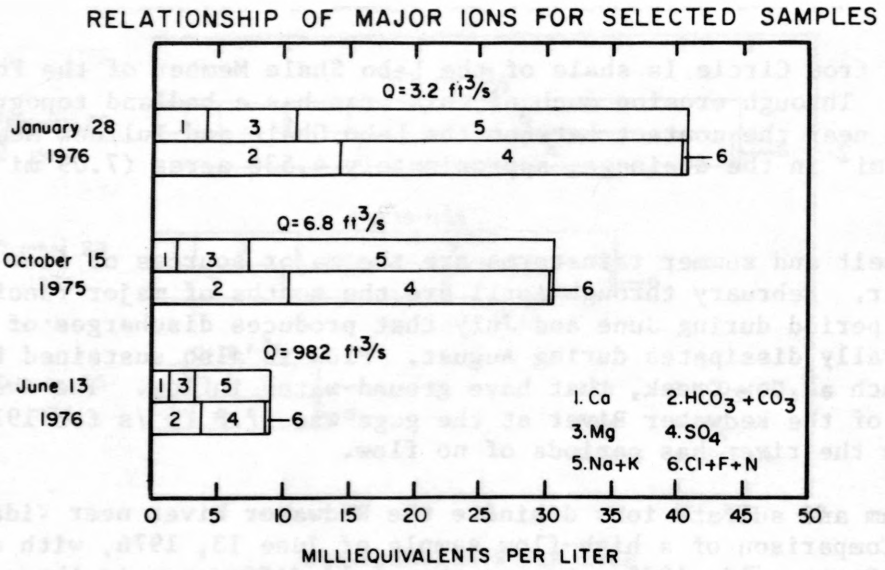


Figure 14.--Hydrograph of stream discharge for Redwater River near Vida, 1976 water year.



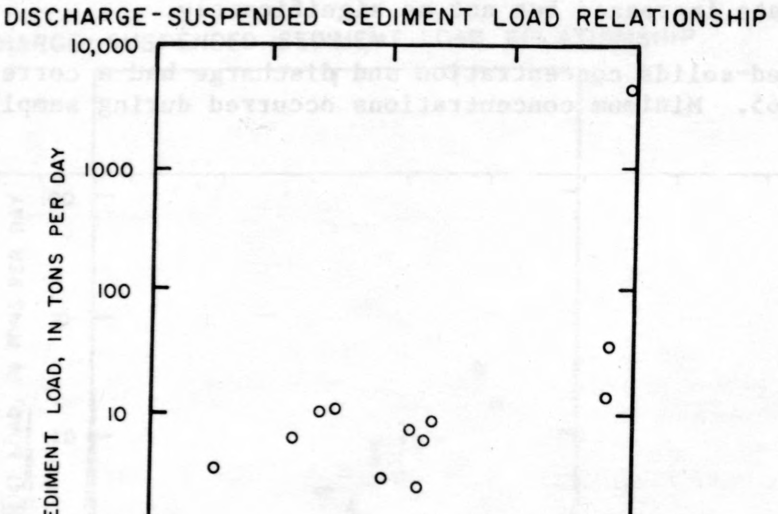


Figure 15.--Relationships of major ions, discharge, suspended-sediment

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	23		.34-982	ft^3/s
Specific conductance (at 25°C)	23	2930	812-4250	μmhos/cm
pH	23	8.5	7.8-8.9	units
Temperature, water	23	9.4	.0-25.0	°C
Turbidity	23	63	3-1000	JTU
Dissolved oxygen, percent saturation	23	90	67-113	percent
Biochemical oxygen demand	23	2.6	.4-7.1	mg/L
Calcium (Ca), dissolved	23	49	26-79	mg/L
Magnesium (Mg), dissolved	23	73	18-99	mg/L
Sodium (Na), dissolved	23	550	110-810	mg/L
Percent sodium	23	72	62-80	percent
Sodium-adsorption ratio	23	11	4.1-17	---
Potassium (K), dissolved	23	9.4	7.1-12	mg/L
Bicarbonate (HCO_3)	23	620	212-925	mg/L
Carbonate (CO_3)	22	13	.0-72	mg/L
Sulfate (SO_4), dissolved	23	1100	250-1600	mg/L
Chloride (Cl), dissolved	23	12	3.0-19	mg/L
Fluoride (F), dissolved	23	.6	.2-.7	mg/L
Silica (SiO_2), dissolved	23	5.2	.8-8.9	mg/L
Dissolved solids (calculated)	23	2080	531-2940	mg/L
Nitrite plus nitrate, total as N	23	.08	.01-.74	mg/L
Nitrogen, ammonia, total as N	23	.08	.00-.63	mg/L
Nitrogen, total organic as N	23	.86	.32-5.0	mg/L
Nitrogen, total kjeldahl as N	23	.94	.14-4.4	mg/L
Phosphorus, total as P	23	.08	.00-.72	mg/L
Suspended sediment	23	154	15-1700	mg/L

PROPERTY	(DISSOLVED) NO. OF ANALYSES	(DISSOLVED) VALUE OR RANGE	(TOTAL) NO. OF ANALYSES	(TOTAL) VALUE OR RANGE	UNITS
Aluminum	6	0-40	7	180-22000	μg/L
Arsenic	6	0-3	7	0-35	μg/L
Beryllium	6	0-10	7	0-10	μg/L
Boron	23	80-480	---	---	μg/L
Cadmium	6	0-1	7	0-<10	μg/L
Chromium	6	0-10	6	0-40	μg/L
Copper	6	1-2	7	10-40	μg/L
Iron	23	10-40	7	240-35000	μg/L
Lead	6	0-24	7	36-<100	μg/L
Lithium	6	50-80	7	20-80	μg/L
Manganese	6	0-50	7	30-1100	μg/L
Mercury	6	.0-.1	7	.0-<.5	μg/L
Molybdenum	6	3-7	7	1-6	μg/L
Nickel	6	1-7	7	0-100	μg/L
Selenium	6	0-1	7	0-2	μg/L
Vanadium	6	.0-1.2	---	---	μg/L
Zinc	6	0-20	7	0-130	μg/L

load, and analytical values for Redwater River near Vida (station 8).

discharge exceeded 160 ft^3/sec. The maximum transport of dissolved solids, 1,410 tons/day, was measured on June 13, 1976, when the dissolved-solids concentration was 531 mg/L and the discharge was 982 ft^3/sec. This value is the highest dissolved-solids load measured in the study area during the sampling period. Average dissolved-solids concentration was 2,080 mg/L.

The pH was lowest during the winter months, ranging from 7.8 to 8.4. During the summer months the pH values were generally greater than 8.6; the average for the year was 8.5. The percent saturation of dissolved oxygen also decreased during the winter months, presumably because of ice cover. Turbidity increased to 1,000 JTU during the period of runoff from rainfall on June 13, 1976, but not during high flows in February or March 1976.

Total organic nitrogen was the major nutrient present. Runoff in June 1976 contained the highest total nitrogen concentration, 5.7 mg/L, of which 4.4 mg/L was organic nitrogen and 0.7 mg/L was nitrite plus nitrate. The remaining samples were below 1.6 mg/L total nitrogen. The average phosphorus concentration, 0.08 mg/L, was lower than normally occurred at most other sites.

Dissolved trace-element concentrations were relatively low throughout the sampling period (fig. 15). The total iron and aluminum concentrations reached highs of 35,000 mg/L and 22,000 mg/L, respectively, during June 1976. Boron concentrations were below the average concentration that occurred in the other drainages.

The water is classified as normally having a very high salinity hazard and medium sodium hazard (fig. 3). Even during periods of high flow the salinity hazard is high, although the sodium hazard becomes low. The water is suitable for stock consumption, but the concentrations are considerably above the recommended limits for dissolved solids and sulfate when considered for human consumption.

Suspended sediment and discharge had a correlation coefficient of 0.98. Runoff from rainfall June 13, 1976, shows the potential erosion characteristics in the Redwater basin. Comparison of the sediment concentration for the June 1976 rain, 1,700 mg/L, to the concentration for the February 24 and March 22, 1976, runoff from snowmelt, 32 mg/L and 75 mg/L, shows how important ground conditions are to sediment discharge. The sediment load transported as a result of the direct runoff from rainfall was 4,510 tons/day (fig. 15).

Burns Creek near Savage

Burns Creek is the only stream in the study area that flows into the Yellowstone River. Its three tributaries flow through valleys that range from badland topography to grassy slopes. Along much of Burns Creek black shale, gray siltstone, and sandstone of the Fort Union Formation are exposed. The sampling site (station 9) is about 1 mile upstream from the mouth in an area underlain by the Tullock Member of the Fort Union Formation. The drainage area upstream from the station is 233 mi^2. Land use is mostly for grazing and dryland farming; 46 acres (0.07 mi^2) is presently irrigated.

The streamflow hydrograph for 1976 (fig. 16) shows the high discharge that resulted from snowmelt in February and March, the only months when discharge was consistently greater than 10 ft^3/s. The major runoff of Burns Creek is from snowmelt in late winter and early spring. Peaks in the late spring and summer result from direct runoff from local rains. Most of the year, however, flow is less than 5 ft^3/s and is sustained by ground-water contribution. Both snowmelt and rainfall recharge aquifers along streams and tend to prolong flow. Sampled discharges ranged from 0.32 to 63 ft^3/s.

At Burns Creek the cations and anions varied seasonally with respect to each other. The sodium concentration exceeded the other cations except during one high discharge on February 9, 1976, when it was less than the magnesium concentration (fig. 17). Generally, the calcium concentration

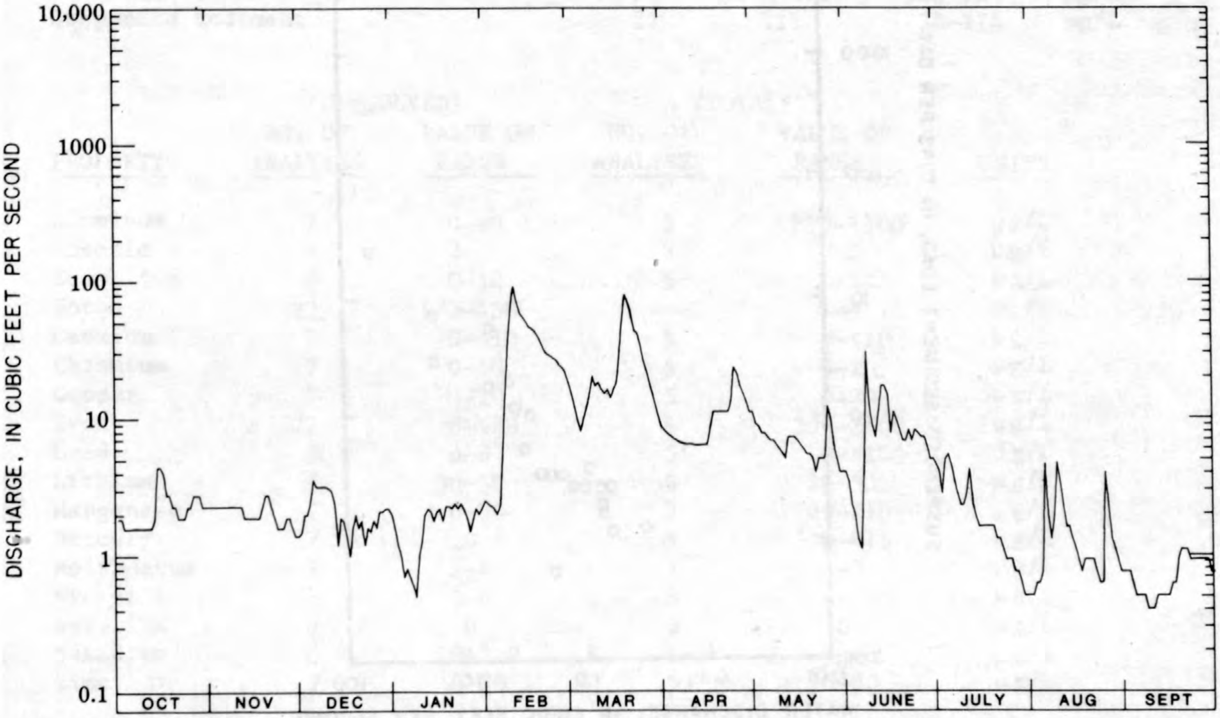


Figure 16.--Hydrograph of stream discharge for Burns Creek near Savage, 1976 water year.

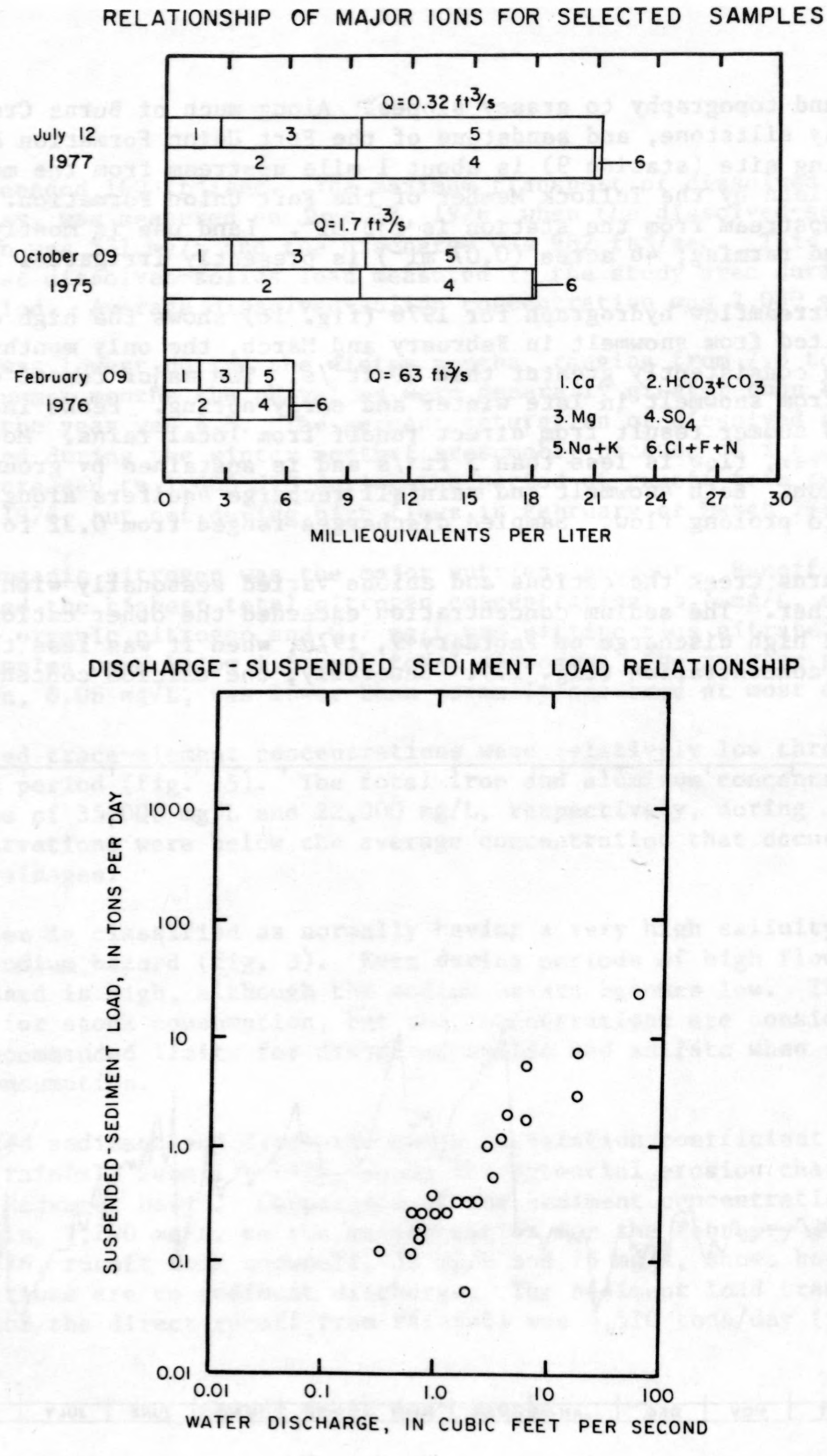


Figure 17.--Relationships of major ions, discharge, suspended-sediment

PROPERTY	NO. OF ANALYSES	MEAN	RANGE	UNITS
Discharge (Q)	22		.32-63	ft^3/s
Specific conductance (at 25°C)	22	1650	640-2250	μmhos/cm
pH	22	8.4	8.0-8.8	units
Temperature, water	22	10.6	.0-30.0	°C
Turbidity	22	30	3-80	JTU
Dissolved oxygen, percent saturation	22	96	70-114	percent
Biochemical oxygen demand	21	1.8	.2-6.8	mg/L
Calcium (Ca), dissolved	22	61	31-90	mg/L
Magnesium (Mg), dissolved	22	77	29-100	mg/L
Sodium (Na), dissolved	22	210	55-280	mg/L
Percent sodium	22	48	37-56	percent
Sodium-adsorption ratio	22	4.1	1.7-5.6	---
Potassium (K), dissolved	22	8.4	5.6-11	mg/L
Bicarbonate (HCO_3)	22	540	218-610	mg/L
Carbonate (CO_3)	22	7	0-36	mg/L
Sulfate (SO_4), dissolved	22	450	140-640	mg/L
Chloride (Cl), dissolved	22	6.5	3.6-8.6	mg/L
Fluoride (F), dissolved	22	.5	.2-.7	mg/L
Silica (SiO_2), dissolved	22	11	6.8-16	mg/L
Dissolved solids (calculated)	22	1090	382-1420	mg/L
Nitrite plus nitrate, total as N	22	.06	.00-.15	mg/L
Nitrogen, ammonia, total as N	22	.03	.00-.10	mg/L
Nitrogen, total organic as N	22	.58	.09-3.3	mg/L
Nitrogen, total kjeldahl as N	22	.61	.09-3.4	mg/L
Phosphorus, total as P	22	.04	.00-.14	mg/L
Suspended sediment	22	111	54-174	mg/L

PROPERTY	(DISSOLVED) NO. OF ANALYSES	(DISSOLVED) VALUE OR RANGE	(TOTAL) NO. OF ANALYSES	(TOTAL) VALUE OR RANGE	UNITS
Aluminum	7	0-20	5	100-1300	μg/L
Arsenic	6	0-2	5	0-2	μg/L
Beryllium	7	0-10	5	0-10	μg/L
Boron	22	170-450	---	---	μg/L
Cadmium	7	0-<10	5	0-<10	μg/L
Chromium	7	0-10	5	0-10	μg/L
Copper	7	0-20	5	0-20	μg/L
Iron	22	0-120	5	300-2500	μg/L
Lead	7	0-8	5	0-<100	μg/L
Lithium	7	30-50	5	20-50	μg/L
Manganese	7	0-30	5	20-110	μg/L
Mercury	7	.0	5	0-<.5	μg/L
Molybdenum	7	2-4	5	1-5	μg/L
Nickel	7	2-6	5	4-<50	μg/L
Selenium	7	0	5	0	μg/L
Vanadium	6	.0-2.2	---	---	μg/L
Zinc	7	0-20	5	10-50	μg/L

load, and analytical values for Burns Creek near Savage (station 9).

increased in the fall and winter and decreased in the spring and summer. Magnesium percentages in the cation balances were constant during the flow cycle. Much the same variation was noticed with the anions. The sulfate concentration increased during the spring and summer; however, it was less than the bicarbonate concentration in the fall and winter.

Dissolved-solids concentration decreased with increased discharge. On February 9, 1976, the minimum concentration of 382 mg/L occurred at a near peak flow of 63 ft^3/s. The low concentration resulted from direct runoff from snowmelt over frozen ground. Seventeen of the 22 samples were within 20 percent of 1,090 mg/L, the average dissolved-solids concentration.

The lowest pH, 8.0, occurred in the winter and the highest, 8.8, during the summer. This seasonal trend of pH was noticed in other drainages. Dissolved oxygen averaged 96 percent of saturation and ranged from 70 to 114 percent. The high average saturation probably resulted from the algae growth on the firm cobble bottom at the sample site. The lower saturations occurred during ice-cover periods.

Nutrient concentrations were low, as at the other stations in the study area. Nitrogen and phosphorus concentrations were greatest during the two highest flows sampled--February 9 and March 9, 1976. Nitrogen was associated with organic matter, as indicated by the fact that kjeldahl nitrogen constituted the highest concentration of nitrogen present. The association of nitrogen with sediment that might be expected was not a consistent relation. The maximum BOD concentration of 6.8 mg/L was associated with the high-flow period for 1975. Fecal material from livestock was observed near the sampling site.

Total and dissolved trace-element concentrations were low for all samples (fig. 17). Maximum dissolved aluminum and manganese concentrations were lower than normal when compared with other streams in the study area. Total concentrations were also low; maximum aluminum and iron concentrations were at least 10 times smaller than for most other drainages.

Major uses of water from Burns Creek are for irrigation and stock watering. The sodium-adsorption ratio indicated a low sodium hazard and the specific conductance a high salinity hazard for irrigation uses (fig. 3). The maximum dissolved-solids concentration of 1,420 mg/L was below the recommended limit for livestock watering. However, the average concentrations of dissolved solids and sulfate exceeded the recommended limits for human consumption.

Suspended-sediment concentration was low throughout the sampling period, probably owing to a firm channel bottom, vegetation that stabilized the banks, and high flow over frozen ground during the winter. Barren shale slopes could be an ample sediment source during intense summer rainstorms. Figure 17 shows a relatively good correlation for the lower values of discharge and sediment load. The usefulness of the relationship between discharge and load is hindered by a lack of high-discharge samples.

SUMMARY

In October 1975, the U.S. Geological Survey established a network of nine data-collection stations to monitor the quality of water in potential coal-mining areas of east-central Montana. Stations were monitored on the Redwater River and Big Dry, Little Dry, Timber, Nelson, Prairie Elk, Sand, and Burns Creeks. All the streams except Burns Creek flow directly or indirectly to the Missouri River; Burns Creek is a tributary to the Yellowstone River. Streamflow is perennial in the lower Redwater River and Prairie Elk and Burns Creek and intermittent in the upper Redwater River and the other five streams studied.

Big Dry Creek contains water dominated by sodium and sulfate ions, with bicarbonate ion generally comprising 35 percent or more of the anions. Flow was observed four times during the sampling period as a result of spring snowmelt or summer rains; discharge ranged from 0.20 to 7.4 ft^3/s. Concentrations of dissolved solids ranged from 628 to 1,540 mg/L and averaged 1,090 mg/L. Concentrations of nutrients and most trace elements were generally low.

Little Dry Creek contains water of the sodium sulfate type during low-flow conditions, but bicarbonate concentration increases to about 50 percent of the anions during periods of high flow. Measured discharge during the study ranged from 0.12 to 224 ft^3/s. The highest observed dissolved-solids concentration of 2,460 mg/L was sampled at the time of lowest observed flow. Even though many of the total trace elements were near maximum concentrations for the study area, the concentrations were not unusually high.

Water in Timber Creek is of the sodium sulfate type. The variation in water composition during the study was small, probably because of the limited range of discharges sampled, 0.76 to 21 ft^3/s. Dissolved-solids concentration, although high (1,180-3,840 mg/L) when compared with samples from other streams, seemed to be affected by type of runoff (rainfall versus snowmelt) rather than volume of discharge. Trace-element concentrations were low except for boron, which ranged from 430 to 1,200 μg/L.

Nelson Creek drains an area of 100 mi^2 and is the smallest basin studied in the investigation. As a result of the short duration of peak flows, no discharges greater than 7.7 ft^3/s were sampled. Water is of the sodium sulfate type. Nelson Creek had the highest sodium and sulfate concentrations (1,200 and 2,700 mg/L, respectively) sampled in the study area. Dissolved-solids concentration ranged from 528 to 4,570 mg/L. Trace-element concentrations were low, except for boron, which ranged from 120 to 910 μg/L and averaged 420 μg/L.

Although Prairie Elk Creek water is strongly dominated by sodium, the lowest concentration (43 mg/L) in the study area was sampled here. Bicarbonate is the dominant anion. Sampled discharges ranged from 0.06 to 1,170 ft^3/s. Discharge and dissolved-solids concentration had a poor inverse correlation. Dissolved trace-element concentrations were relatively low compared to total concentrations.

Sand Creek, like Prairie Elk Creek, contains water of the sodium bicarbonate type during most flows. However, during two of the three highest flows, sulfate comprised at least 60 percent of the anions, probably as a result of overland flow in the upper drainage. Dissolved-solids concentration (212-2,480 mg/L) varied inversely with discharge (0.20-165 ft^3/s). Nutrient concentrations were generally low but increased with higher sediment concentrations and discharges.

The Redwater River is monitored by two water-quality stations--one about mid-drainage and one 17 miles upstream from the mouth. Water throughout the basin is predominantly sodium sulfate and does not vary significantly with season or discharge. The upper drainage had smaller discharge and therefore higher dissolved-solids concentration than the lower drainage. Average dissolved-solids concentration of water in the upper drainage (2,560 mg/L) was higher than for other streams in the study area. Nutrient and trace-element concentrations were generally low.

Sampled discharges for Burns Creek ranged from 0.32 to 63 ft^3/s, and dissolved-solids concentration ranged from 382 to 1,420 mg/L. The water type was generally sodium sulfate during the spring and summer and sodium bicarbonate during the fall and winter. Nutrient and trace-element concentrations were low. Maximum aluminum and iron concentrations were about 10 times smaller than for most other drainages.

Periods of high flow from spring snowmelt and early summer rains are the only times when streams in east-central Montana carry water that is suitable for irrigation. When flow is present, the water is good for livestock watering. The water quality of these prairie streams has resulted largely from natural processes and has been only slightly affected by man's activities.

SELECTED REFERENCES

Colby, B. R., and Hembree, C. H., 1955, Computations of total sediment discharge, Niobrara River near Colby, Nebraska: U.S. Geological Survey Water-Supply Paper 1357, 187 p.

Environmental Studies Board, 1972, Water quality criteria, 1972: National Academy of Sciences and National Academy of Engineering report, 594 p.

Hem, J. D., 1970, Study and interpretation of the chemical characteristics of natural water [2d ed]: U.S. Geological Survey Water-Supply Paper 1473, 363 p.

Knapton, J. R., and McKinley, P. W., 1977, Water quality of selected streams in the coal area of southeastern Montana: U.S. Geological Survey Water-Resources Investigations 77-80, 145 p.

McKee, J. E., and Wolf, H. W., 1963, Water quality criteria [2d ed]: California State Water Quality Control Board Publication 3-A, 548 p.

Montana Water Resources Board, 1970, Water resource survey, Dawson County: Montana Water Resources Board report, 43 p.

_____1971, Water resource survey, McCone County: Montana Water Resources Board report, 51 p.

U.S. Department of Agriculture, 1930, Climatic summary of the United States, sec. 11, southeastern Montana: 3 p.

U.S. Environmental Protection Agency, 1975, National interim primary drinking water regulations: Federal Register, v. 40, no. 248, Dec. 24, Part IV, p. 59566-59588.

_____1977, National secondary drinking water regulations (proposed): Federal Register, v. 42, no. 62, Mar. 31, Part I, p. 17143-17147.

U.S. Geological Survey, 1974, Stripping coal deposits of the Northern Great Plains, Montana, Wyoming, North Dakota, and South Dakota: U.S. Geological Survey Miscellaneous Field Studies Map MF-590, 1 sheet.

_____issued annually, Water resources data for Montana: U.S. Geological Survey water-data report.

U.S. Salinity Laboratory Staff, 1954, Diagnosis and improvement of saline and alkali soils: U.S. Department Agriculture Handbook 60, 160 p.

Van Lewen, M. C., and King, N. J., 1971, Prospects for developing stockwater supplies from wells in northeastern Garfield County, Montana: U.S. Geological Survey Water-Supply Paper 1999-F, p. F1-F38.

Weeth, H. J., Haverland, L. H., and Cassard, D. W., 1960, Some effects of salt water on growing cattle: Journal of Animal Science, v. 19, p. 961.

Table 1.--Station descriptions

(Number to left of station name is the same as shown on fig. 1; number to right is formal USGS station number. Station descriptions are in the same order described in the report.)

Station 1 BIG DRY CREEK AT JORDAN, MT (06130680)

LOCATION.--Lat 47°18'56", long 106°54'33", in SW1/4 NE1/4 SW1/4 sec.17, T.18 N., R.38 E., Garfield County, Hydrologic Unit 10040105, at bridge on State Highway 200 at Jordan.

Station 2 LITTLE DRY CREEK NEAR VAN NORMAN, MT (06130950)

LOCATION.--Lat 47°20'22", long 106°21'47", in NE1/4 NE1/4 NE1/4 sec.9, T.18 N., R.42 E., Garfield County, Hydrologic Unit 10040106, at bridge on State Highway 200, 0.8 mi (1.3 km) upstream from mouth, 1.5 mi (2.4 km) southeast of Van Norman.

Station 3 TIMBER CREEK NEAR VAN NORMAN, MT (06131120)

LOCATION.--Lat 47°24'20", long 106°10'25", in E1/2 sec.13, T.19 N., R.43 E., McCone County, Hydrologic Unit 10040104, at bridge on State Highway 24, and 11.8 mi (19.0 km) northeast of Van Norman.

Station 4 NELSON CREEK NEAR VAN NORMAN, MT (06131200)

LOCATION.--Lat 47°32'08", long 106°09'11", in SW1/4 NW1/4 sec.36, T.21 N., R.43 E., McCone County, Hydrologic Unit 10040104, on left bank at upstream side of bridge on State Highway 24, 1.5 mi (2.4 km) upstream from Fort Peck Lake, and 19 mi (30 km) northeast of Van Norman.

Station 5 PRAIRIE ELK CREEK NEAR OSWEGO, MT (06175540)

LOCATION.--Lat 47°59'56", long 105°52'00", in SE1/4 SE1/4 sec.14, T.26 N., R.45 E., McCone County, Hydrologic Unit 10060001, on left bank 75 ft (23 m) downstream from bridge on FAS 528, 1.0 mi (1.6 km) upstream from mouth and 4 mi (6 km) south of Oswego.

Station 6 SAND CREEK NEAR WOLF POINT, MT (06175580)

LOCATION.--Lat 48°00'52", long 105°42'34", in SE1/4 SE1/4 SE1/4 sec.12, T.26 N., R.46 E., McCone County, Hydrologic Unit 10060001, on county road bridge, 2.8 mi (4.5 km) upstream from mouth and 6.5 mi (10.5 km) southwest of Wolf Point.

Station 7 REDWATER RIVER AT CIRCLE, MT (06177500)

LOCATION.--Lat 47°24'51", long 105°34'30", in SW1/4 SW1/4 sec.11, T.19 N., R.48 E., McCone County, Hydrologic Unit 10060002, on left bank at Circle, 1.0 mi (1.6 km) upstream from Horse Creek, and at mile 79.6 (128 km).

Station 8 REDWATER RIVER NEAR VIDA, MT (06177825)

LOCATION.--Lat 47°54'07", long 105°12'54", in SW1/4 sec.24, T.25 N., R.50 E., McCone County, Hydrologic Unit 10060002, on right bank at downstream side of bridge on FAS Highway 201, 400 ft (122 m) downstream from East Redwater River and 13.7 mi (22.0 km) northeast of Vida post office.

Station 9 BURNS CREEK NEAR SAVAGE, MT (06329200)

LOCATION.--Lat 47°22'20", long 104°25'46", near center of west line of sec.26, T.19 N., R.57 E., Richland County, Hydrologic Unit 10100004, on right bank 1,000 ft (305 m) upstream from bridge on State Highway 16, 1 mi (2 km) upstream from mouth, and 7 mi (11 km) southwest of Savage.