SURFACE- AND GROUND-WATER QUALITY IN THE OWL CREEK BASIN, NORTH-CENTRAL WYOMING

By Kathy Muller Ogle

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 91-4108

Prepared in cooperation with the

NORTHERN ARAPAHO TRIBE

U.S. DEPARTMENT OF THE INTERIOR

March 3, 1849

Cheyenne, Wyoming

1992

U.S. DEPARTMENT OF THE INTERIOR

MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

District Chief
U.S. Geological Survey
2617 E. Lincolnway, Suite B
Cheyenne, Wyoming 82001

Copies of this report may be
purchased from:

U.S. Geological Survey
Open-File Reports-ESIC
P.O. Box 25425
Denver, Colorado 80225

CONTENTS

Page

Abstract........ 1
Introduction........ 2
  Purpose and scope........ 2
  Description of area........ 4
    Location........ 4
    Climate and vegetation........ 4
    Topography and drainage........ 5
    Geology........ 5
  Data collection........ 8
  Acknowledgments........ 8
Surface-water quality........ 9
  Upper basin segment........ 16
    Variability of water quality........ 20
    Variability of streamflow........ 21
  Middle basin segment........ 22
  Lower basin segment........ 26
Ground-water quality........ 29
  Arapaho Ranch alluvial aquifer........ 32
  Bedrock aquifers........ 44
    Absaroka Volcanic Supergroup........ 44
    Cody Shale........ 48
    Frontier Formation........ 48
    Lower Cretaceous to Jurassic rocks........ 51
    Tensleep Sandstone and Amsden Formation........ 52
    Madison Limestone and Darby Formation........ 52
    Upper Ordovician to Middle Cambrian rocks........ 53
Summary and conclusions........ 54
Selected references........ 56
Supplemental data........ 59

PLATE

Plate 1. Map showing geology and chemical composition of water from selected wells and springs in the Owl Creek basin, north-central Wyoming........ In Pocket

FIGURES

Figure 1. Map showing location of Owl Creek basin in Wyoming........ 3
2. Map showing location of streamflow-gaging stations and surface-water sampling sites in Owl Creek basin........ 6
3. Graph showing period of record of surface-water data collection at U.S. Geological Survey streamflow-gaging stations........ 11
4. Map showing dissolved-solids concentrations in water samples collected September 22 and 23, 1986, at selected surface-water sampling sites in Owl Creek basin........ 12

FIGURES--Continued

Page

5. Map showing modified Stiff diagrams of water samples collected September 22 and 23, 1986, at selected surface-water sampling sites in Owl Creek basin.................. 14

6-14. Graphs showing:
  6. Relation between dissolved-solids concentration and specific conductance for water samples from the upper basin segment.. 18
  7. Concentrations of dissolved solids and major ions in water samples from streams in the upper basin segment and corresponding contaminant levels in U.S. Environmental Protection Agency (EPA) Drinking-Water Regulations.. 19
  8. Temporal variation of average monthly specific conductance at two surface-water-quality stations on South Fork Owl Creek in the upper basin segment....... 21
  9. Average monthly streamflow at site 22 on North Fork Owl Creek in the upper basin segment, 1963-72............ 23
  10. Flow-duration curve for site 22 on North Fork Owl Creek in the upper basin segment, 1963-72.................. 23
  11. Average monthly streamflow at site 8 on South Fork Owl Creek in the upper basin segment, 1960-84............ 24
  12. Flow-duration curve for site 8 on South Fork Owl Creek in the upper basin segment, 1960-84.................. 24
  13. Relation between dissolved-solids concentration and specific conductance for water samples from the middle basin segment................................. 26
  14. Concentrations of dissolved solids and major ions in water samples from streams in the middle basin segment and corresponding contaminant levels in U.S. Environmental Protection Agency (EPA) Drinking-Water Regulations.. 27

15. Photograph showing salt incrustation in the lower basin segment near junction of Wyoming Highways 170 and 120...... 28

16. Graph showing relation between dissolved-solids concentration and specific conductance for water samples from the lower basin segment.. 30

17. Graph showing concentrations of dissolved solids and major ions in water samples from streams in the lower basin segment and corresponding contaminant levels in U.S. Environmental Protection Agency (EPA) Drinking-Water Regulations.. 31

18-20. Maps showing:
  18. Location and selected data for wells completed in and springs issuing from the Arapaho Ranch alluvial aquifer, March and June 1989........................ 33
  19. Dissolved-solids concentrations in water samples from wells completed in and springs issuing from the Arapaho Ranch alluvial aquifer, March and June 1989... 39
  20. Modified Stiff diagrams of water samples from wells completed in and springs issuing from the Arapaho Ranch alluvial aquifer, March and June 1989.......... 40

FIGURES--Continued

Page

21. Graph showing relation between dissolved-solids concentration and specific conductance for water samples from the Arapaho Ranch alluvial aquifer.......................... 41
22. Graph showing concentrations of dissolved solids and major ions in water samples from wells completed in and springs issuing from the Arapaho Ranch alluvial aquifer and corresponding contaminant levels in U.S. Environmental Protection Agency (EPA) Drinking-Water Regulations......... 42

TABLES

Table 1. Location and station name of surface-water sampling sites..... 10
2. Statistical summary of discharge measurements and chemical analyses of water samples from streams in the upper, middle, and lower basin segments.................................. 17
3. Statistical summary of specific conductance by month at two surface-water-quality stations on South Fork Owl Creek in the upper basin segment................................... 20
4. Records of wells completed in and springs issuing from the Arapaho Ranch alluvial aquifer............................ 34
5. Statistical summary of chemical analyses of water samples from wells completed in and springs issuing from the Arapaho Ranch alluvial aquifer............................ 37
6. Discharge measurements and chemical analyses of water samples from wells completed in and springs issuing from the Arapaho Ranch alluvial aquifer............................ 38
7. Trace-element and radiochemical analysis of a water sample from spring 1-A issuing from the Arapaho Ranch alluvial aquifer.. 43
8. Records of wells completed in and springs issuing from bedrock aquifers.. 45
9. Discharge measurements and chemical analyses of water samples from wells completed in and springs issuing from bedrock aquifers.. 49
10. Discharge measurements and chemical analyses of water samples from the upper basin segment............................. 60
11. Discharge measurements and chemical analyses of water samples from the middle basin segment............................ 62
12. Discharge measurements and chemical analyses of water samples from the lower basin segment............................. 64

CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	By	To obtain
inch	25.4	millimeter
foot	0.3048	meter
mile	1.609	kilometer
square mile	2.590	square kilometer
acre	0.4047	hectare
gallon per minute	3.785	liter per minute
cubic foot per second	0.02832	cubic meter per second

Temperature can be converted to degrees Fahrenheit (^{0}F) or degrees Celsius (^{0}C) by the following equations:

$$^{0}F = 9/5\ (^{0}C) + 32$$

$$^{0}C = 5/9\ (^{0}F - 32)$$

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

Abbreviations

BLM	U.S. Bureau of Land Management
EPA	U.S. Environmental Protection Agency
MCL	maximum contaminant level
SMCL	secondary maximum contaminant level
USGS	U.S. Geological Survey
mg/L	milligram per liter
µg/L	microgram per liter
µS/cm	microsiemens per centimeter at 25 degrees Celsius

SURFACE- AND GROUND-WATER QUALITY IN THE OWL CREEK BASIN, NORTH-CENTRAL WYOMING

By Kathy Muller Ogle

ABSTRACT

Water quality of surface water and ground water in the Owl Creek basin is characterized and compared to the U.S. Environmental Protection Agency (EPA) maximum contaminant levels (MCL) or secondary maximum contaminant levels (SMCL) for concentrations of sulfate, chloride, fluoride, dissolved solids, and nitrate. Water samples from two sources--streams in the upper basin segment of Owl Creek basin and springs issuing from a bedrock aquifer in the Absaroka Volcanic Supergroup--have concentrations less than the associated MCL or SMCL.

Surface-water quality in Owl Creek basin is separated into three basin segments. That separation is based on differences in the following: dissolved-solids concentrations, water type, and relation of dissolved-solids concentration to specific conductance. Only concentrations in water samples from streams in the upper basin segment are less than the MCL or SMCL. In the middle and lower basin segments, the averages of dissolved-solids concentrations of water samples exceed the SMCL. There is a distinct linear relation between dissolved-solids concentration and specific conductance in each basin segment.

Concentrations of selected constituents in water samples from the Arapaho Ranch alluvial aquifer and selected bedrock aquifers also are compared to the associated MCL or SMCL. The average dissolved-solids concentration in water samples from the Arapaho Ranch alluvial aquifer exceeds the associated MCL by more than two times, primarily because of large concentrations of sodium, alkalinity, and sulfates. A strong linear relation exists between dissolved-solids concentration and specific conductance in the Arapaho Ranch alluvial aquifer.

Selected bedrock aquifers are evaluated. Only concentrations of dissolved constituents in samples from the Absaroka Volcanic Supergroup in Owl Creek basin are equal to or less than the associated MCL or SMCL. Limited water-quality analyses are available for the other potential aquifers: Cody Shale, Frontier Formation, Lower Cretaceous to Jurassic rocks, Tensleep Sandstone and Amsden Formation, Madison Limestone and Darby Formation, and Upper Ordovician to Middle Cambrian rocks. Concentrations of some constituents in these potential aquifers exceed the MCL or SMCL. Water samples from the Lower Cretaceous to Jurassic rocks unit, however, have lower concentrations of most constituents than samples from the overlying Frontier Formation and the underlying Tensleep Sandstone and Amsden Formation unit. Water samples from water-yielding units of the Lower Cretaceous to Jurassic rocks unit have concentrations that slightly exceed the MCL or SMCL. If substantial areal variability exists, this unit potentially may have localities where concentrations are equal to or less than the MCL or SMCL.

Water-quality analyses available to evaluate the Tensleep Sandstone and Amsden Formation, Madison Limestone and Darby Formation, and Upper Ordovician to Middle Cambrian rocks primarily are from oil-field production wells and may not be representative of these units as a whole. On the basis of the limited data, no firm comparisons can be made of concentrations of dissolved constituents in water from the Tensleep Sandstone and Amsden Formation, Madison Limestone and Darby Formation, or Upper Ordovician to Middle Cambrian rocks to the associated MCL or SMCL.

INTRODUCTION

Water quality limits the use of water for drinking in much of Owl Creek basin in north-central Wyoming. Surface water, in the middle and lower reaches of Owl Creek where most of the residents live, generally is not suitable for a drinking-water supply because of large concentrations of sulfates and dissolved solids. Likewise water from the alluvial aquifer generally is unsuitable as a drinking-water source because of large concentrations of sulfates and dissolved solids. Information regarding water quality in deeper bedrock aquifers in Owl Creek basin is limited because of the paucity of wells completed in those aquifers, but the available data indicate that the water usually is of marginal quality for use as drinking water.

The water from many household wells in the basin contain concentrations of sulfates and dissolved solids that exceed the EPA secondary maximum contaminant levels (SMCL)[1] (U.S. Environmental Protection Agency, 1990). Residents either drink water that exceeds EPA standards, haul water from the town of Thermopolis (fig. 1), or use small-scale treatment systems. The Northern Arapaho Tribe owns Arapaho Ranch in Owl Creek basin and expends considerable resources hauling water for the ranch's operation from Thermopolis. The U.S. Geological Survey (USGS), in cooperation with the Northern Arapaho Tribe, began an investigation in 1989 to describe the chemical quality of surface and ground water in Owl Creek basin.

Purpose and Scope

This report describes the chemical quality of surface and ground water in the Owl Creek basin and compares the concentrations of selected constituents to EPA Drinking-Water Regulations (U.S. Environmental Protection Agency, 1990). Chemical quality is determined by analysis of surface- and ground-water samples for major ions and dissolved solids. Concentrations of sulfate, chloride, fluoride, dissolved solids, and nitrate are compared to the EPA maximum contaminant levels (MCL)[2] or secondary maximum contaminant levels for those constituents. When the concentrations in the samples are less than the

---

[1] SMCL is a nonenforceable, aesthetically based maximum level for contaminants in public drinking-water supplies.

[2] MCL is an enforceable, health-based maximum level for contaminants in public drinking-water supplies.

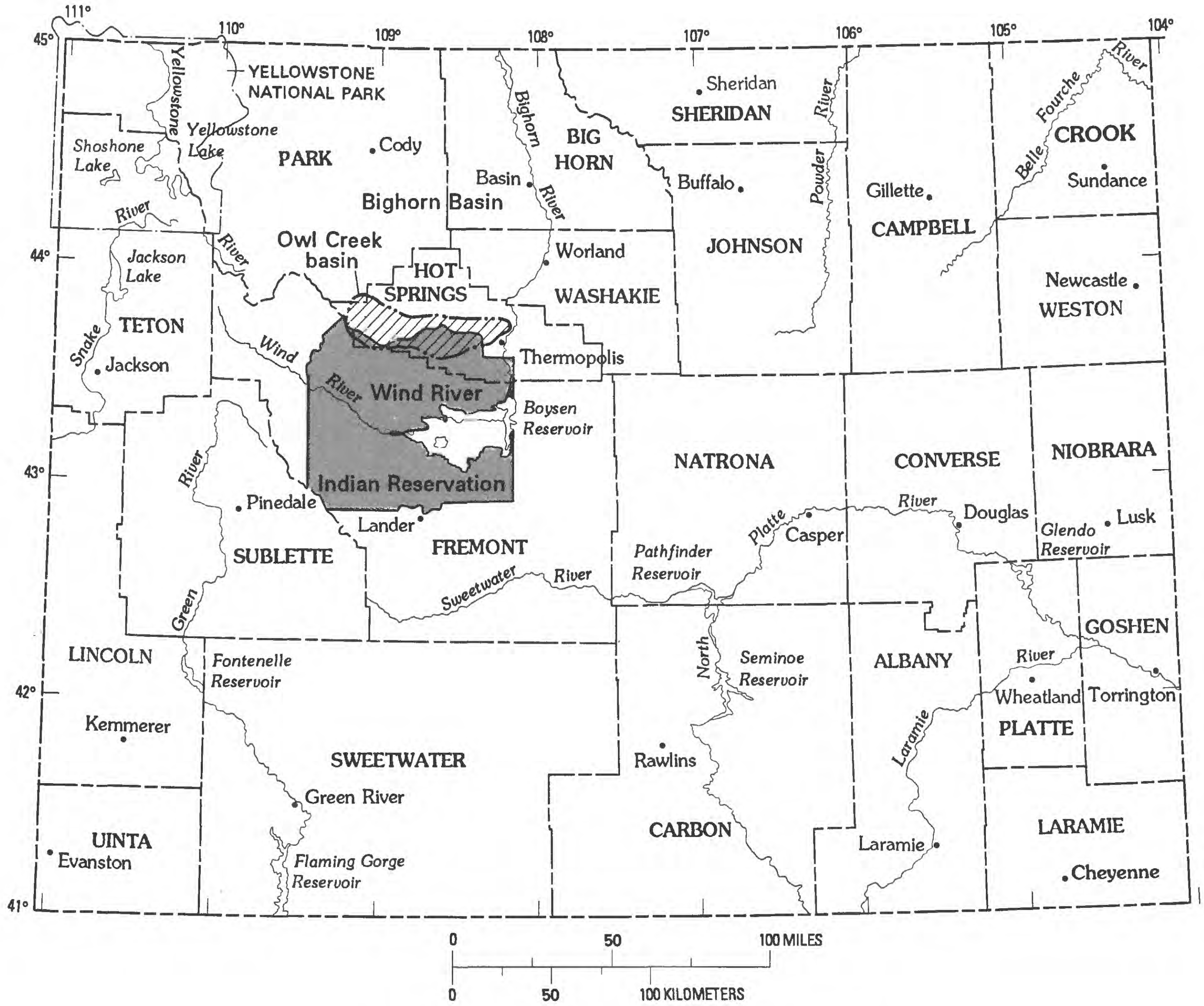


Figure 1.--Location of Owl Creek basin in Wyoming.

MCL or SMCL for all major constituents, the water discharge is evaluated to determine if a minimum quantity of water is available. Because the alluvial aquifer had been evaluated in previous studies, an area designated as the Arapaho Ranch alluvial aquifer was selected for more intensive study.

Description of Area

The Owl Creek basin is complex and diverse in many aspects. Land ownership in the basin is held by the Wind River Indian Reservation, private individuals, and public agencies. Climate and vegetation is variable primarily because the topographic relief is more than 8,000 feet. Both topography and drainage are affected by the complex geology of the basin.

Location

The Owl Creek basin, in north-central Wyoming, trends in an east-west direction and is west of Thermopolis (fig. 1). Most of the basin is in Hot Springs County, but a small strip in the southwest is in Fremont County. South of Owl Creek and South Fork Owl Creek, the basin is on the Wind River Indian Reservation. To the north of those streams, the land is owned by private individuals, U.S. Forest Service, U.S. Bureau of Land Management, and the State of Wyoming. The drainage area of the basin is 509 square miles upstream of the streamflow-gaging station on Owl Creek near Lucerne (site 46, fig. 2).

Climate and Vegetation

Climate in Owl Creek basin varies primarily because of the range in altitude from 4,300 feet above sea level near the mouth of Owl Creek to 12,518 feet at Washakie Needles (pl. 1). The climate is semiarid in the lower parts of the valley, changing to a cold, humid environment in the mountains. The following discussion of climate in Owl Creek basin is based primarily on Martner (1986).

On the basis of data from 1951-80, the average annual precipitation in Owl Creek basin ranges from 12 inches near the mouth to 40 inches in the high Absaroka Range in the far western part of the basin. Snowfall ranges from an average annual total of 40 inches near the Arapaho Ranch to 150 inches in the Washakie Needles area (fig. 2) during that same period. The greatest average monthly snowfall is in March and April.

The native vegetation in Owl Creek basin is diverse. Peterson and others (1987, p. 8-9) identify four types of vegetative aspect (visually dominant type of vegetation)--forest, grass, brush, and barren. Fallat and others (1987) mapped the following land types: evergreen coniferous forest, brush-dominated rangeland, mixed rangeland, barren land, and irrigated cropland.

Irrigated cropland primarily is located on the bottomland and bench deposits (pl. 1). The primary source of water for this irrigated cropland is surface water diverted from North Fork Owl Creek, South Fork Owl Creek, Owl Creek, and limited diversions from major tributaries to those streams.

Anchor Reservoir, a large water-storage facility in the Owl Creek basin, is constructed on the South Fork Owl Creek. This reservoir, because of leakage, only stores a limited amount of water.

Topography and Drainage

The topographic relief of the area is dominated by three features: the Owl Creek Mountains in the south, the volcanic rocks of the Absaroka Range in the west, and the valley of Owl Creek and its major tributaries (pl. 1). The large east-west uplift of the Owl Creek Mountains is modified by numerous anticlinal, domal, and synclinal folds. Depending on the erodibility of the sediments, these structural features provide varied relief in the southern half of the study area.

The Absaroka Range represents the remnants of plateaus built of pyroclastic rocks (Love, 1939, p. 3). These deposits of volcanic and sedimentary materials are being eroded by Owl Creek and its uppermost tributaries. There are numerous landslide features in the Absaroka volcanic deposits (Sundell, 1980, p. 89).

The Owl Creek valley and the valleys of its tributaries narrow, and in some places form canyons, where geological anticlinal structures are crossed. Where soft shales and easily erodible rocks are exposed, the valley widens. In addition to alluvial deposits in the valley, areally extensive alluvial fans and scattered pediment deposits also occur in Owl Creek basin (Cooley and Head, 1982, p. 20-25). Some terrace deposits, remnants of the Owl Creek floodplain during earlier parts of the Quaternary time (Berry and Littleton, 1961, p. 8), are in the valley.

Owl Creek drains an elongated basin at the southern end of the Bighorn River basin. Owl Creek flows generally from west to east. The main stem of Owl Creek begins in the central part of the basin at the confluence of North Fork and South Fork Owl Creek. North Fork Owl Creek extends along the northern edge of the basin, where the creek and its tributaries drain an area overlain by the Absaroka Volcanic Supergroup of Tertiary (Eocene) age. South Fork Owl Creek drains a more extensive area. It flows first to the southwest then turns northwest, where it drains a complicated melange of sedimentary and volcanic rocks. Middle Fork Owl Creek drains a small local area upstream of Anchor Dam. Owl Creek, North Fork Owl Creek, and South Fork Owl Creek all are classified on U.S. Geological Survey maps as perennial. Middle Fork Owl Creek is intermittent. Along the middle and lower reaches of Owl Creek, the areas on either side are drained by intermittent, ephemeral, and perennial tributaries. The major drainages are Mud Creek and Red Creek, which are perennial.

Geology

The geology of Owl Creek basin is complex. Thirty geologic units were mapped by Love and others (1979) on the Thermopolis 1^0 by 2^0 quadrangle preliminary geologic map, which includes most of the Owl Creek basin. For purposes of this report, these units were combined into 14 hydrogeologic units (pl. 1). In addition to the number of geologic units, the geologic structure in the basin is complex. Twenty-nine synclines and anticlines, 33 faults and 5 thrust faults are shown on plate 1 (1:100,000 scale). Many small-scale features observed in the field can not be shown on a map of this scale.

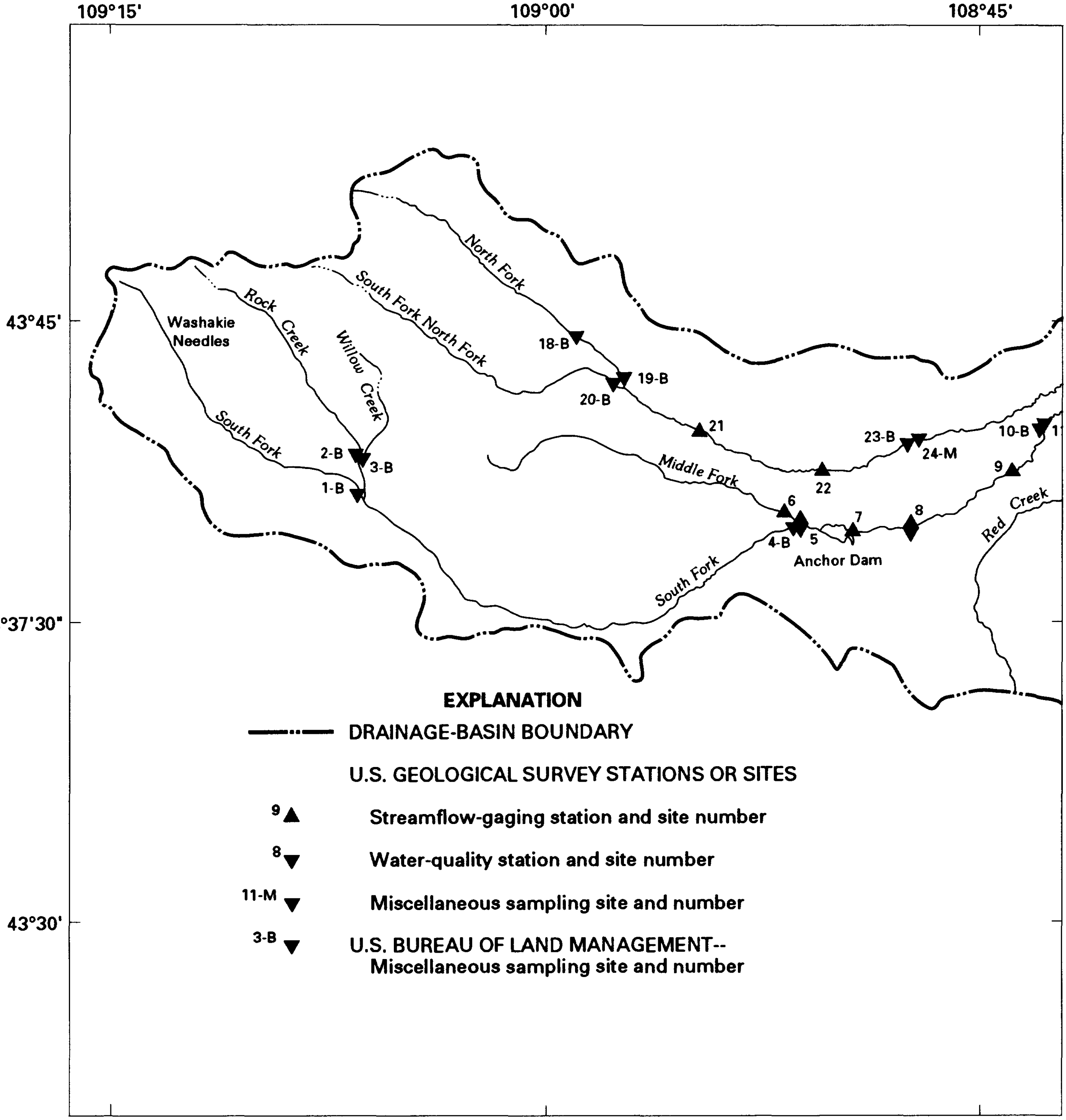
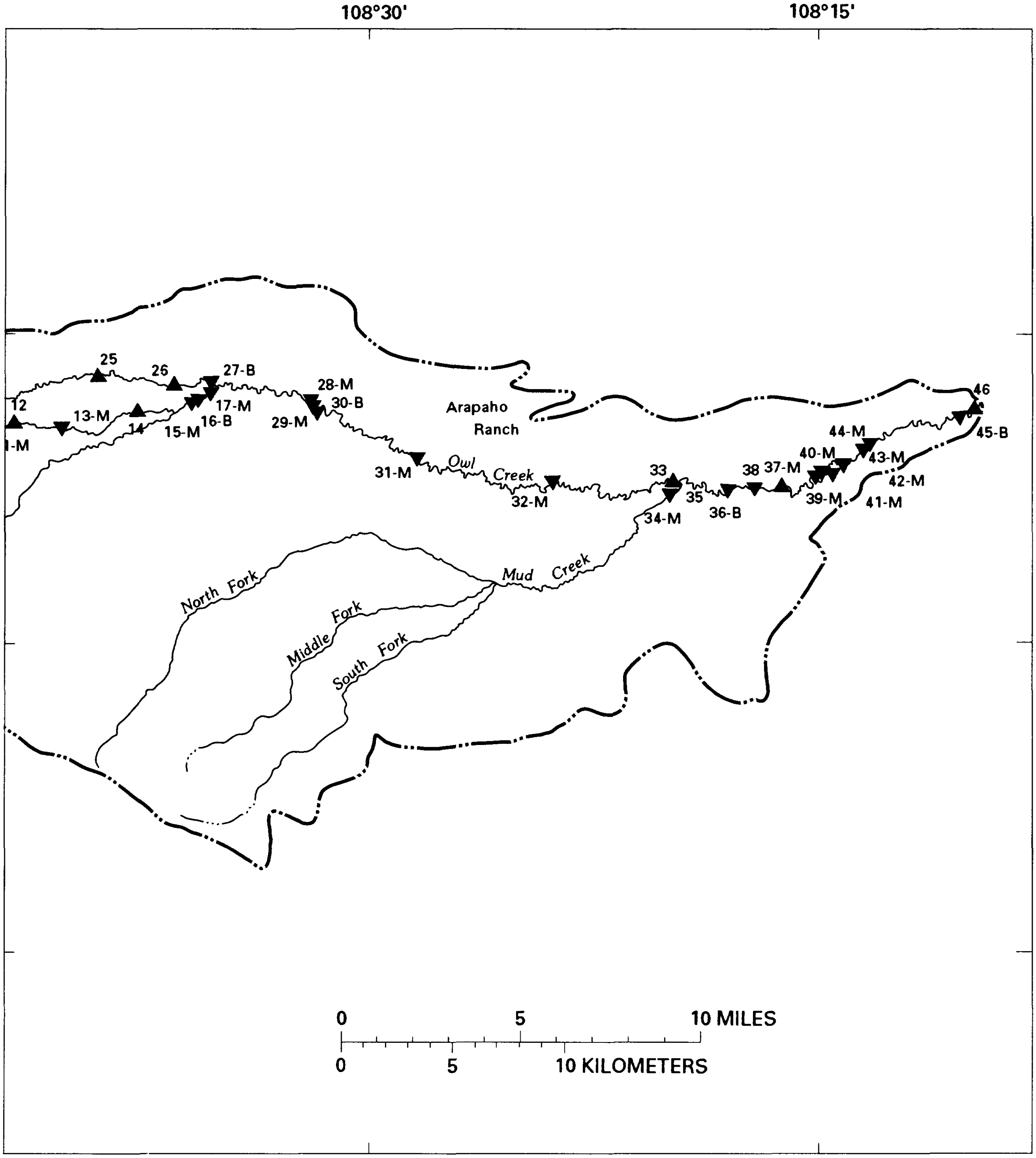


Figure 2.--Location of streamflow-gaging stations and



surface-water sampling sites in Owl Creek basin.

Both igneous and sedimentary rocks are exposed in Owl Creek basin (Love, 1939, p. 10). The oldest rocks in the area are Precambrian igneous and metamorphic rocks. From the Paleozoic Era, rocks representing the Cambrian, Ordovician, Devonian, Mississippian, Pennsylvanian, and Permian Periods are present. Triassic, Jurassic, and Cretaceous rocks from the Mesozoic Era are found in Owl Creek basin. From the Cenozoic Era, both Tertiary and Quaternary Periods are represented. The only major Period missing from the geological record is the Silurian.

Data Collection

Streamflow measurements were made and samples of surface water for chemical analysis were collected in the following manner. Streamflow was measured at sampling sites on sections of the stream that were straight and unobstructed. Areas upstream of the sampling site were evaluated to determine that any inflow was mixed adequately. Then a width- and depth-integrated water sample was collected at the site. Properties of water such as pH, temperature, and specific conductance were measured onsite, and, as appropriate, samples were filtered onsite using a membrane filter with a pore diameter of 0.45 micrometer. Handling and preserving procedures were followed, and all samples were analyzed by the USGS National Water Quality Laboratory at Arvada, Colo., using standard USGS methodology.

Water level and discharge were measured and water samples were collected from wells and springs in the following manner. If well construction allowed, the depth to water was measured using a steel tape and was adjusted to the depth below land surface. Land-surface altitude for the well or spring was determined onsite from a 1:24,000 scale USGS topographic map. The depth to water was converted to a water-level altitude estimate. If the site was suitable for water sampling, the well was pumped until onsite measurements of pH, temperature, and specific conductance had stabilized. Whenever possible, pressure tanks were bypassed. After the properties measured onsite stabilized, a representative sample was collected. Water samples were collected from springs at the discharge point. Samples which required filtration were filtered onsite using a membrane filter with a pore diameter of 0.45 micrometer. Handling and preserving procedures were followed and all samples were analyzed by the USGS National Water Quality Laboratory at Arvada, Colo. A discharge measurement was made at all springs, and, when appropriate, at wells. The flow was measured using a graduated container and a stop watch. Flow measurements were repeated at each site until two measurements were within approximately 2 percent. Discharge for springs with multiple discharge areas was estimated.

Acknowledgments

The assistance and support of the Northern Arapaho Tribe; Dr. Catherine Vandermoer, Director, Wind River Environmental Quality Council; and the U.S. Bureau of Indian Affairs are gratefully acknowledged. The use of water-quality data and files from Mr. William Wilson, U.S. Bureau of Land Management, and Mr. Glenn Taucher, U.S. Bureau of Reclamation, is appreciated.

Access to wells and assistance by Mr. Ronald Hoffman, ranch manager for the Arapaho Ranch and by residents of Owl Creek basin were most helpful. Mr. Gary Collins of the Arapaho Tribe gave generously of his time in directing

the project to an effective start. In addition, assistance with sample collection provided by Mr. Daniel Ortez and Mr. Meldon Hill is gratefully acknowledged.

SURFACE-WATER QUALITY

Surface-water quality in Owl Creek basin is characterized by a progressive downstream increase in dissolved-solids concentration. Cooley and Head (1982, p. 1) concluded that this increase was caused primarily by irrigation return flows, with some basin segments affected by inflow from tributaries and from ground-water discharge from alluvial deposits. The upstream reaches of North Fork and South Fork Owl Creek generally contain small concentrations of dissolved materials. Berry and Littleton (1961, p. 43) reported concentrations of dissolved solids of 108 mg/L for South Fork Owl Creek (upstream from Anchor Dam) and 190 mg/L for North Fork Owl Creek (from the west edge of their report area, probably in R.101 W.), during low flow in September 1947. Also, they (p. 43) determined that dissolved-solids concentration increased downstream and attributed this to ground-water inflow and the use and re-use of water from Owl Creek for irrigation.

Surface-water data for the Owl Creek basin were compiled. There were three primary sources of data: data collected at USGS streamflow-gaging stations; data collected at miscellaneous sites during USGS investigations, including this study; and data collected by the U.S. Bureau of Land Management (BLM). These sampling sites are listed in table 1 and their locations shown in figure 2.

Fifteen streamflow-gaging stations were operated by the USGS in Owl Creek basin between 1910 and 1989 (fig. 3). Water-quality data have been collected at two of the USGS streamflow-gaging stations (sites 5 and 8, fig. 2) near Anchor Dam. In addition, miscellaneous water-quality data have been collected throughout Owl Creek basin by the USGS. These miscellaneous sampling sites, along with the sites sampled as part of this study, are designated in table 1 and figure 2 by an M in the site number. Water samples have been collected at a total of 17 sites as part of USGS miscellaneous studies in Owl Creek basin.

BLM collected surface-water quality and streamflow data at selected sites throughout Owl Creek basin in 1977, 1979, and 1982 through 1987. These data consist primarily of instantaneous flow measurements, onsite measurements of pH, temperature, and specific conductance, and concentrations of major ions and trace elements. These sampling sites are designated by a B in the site number in table 1 and figure 2.

The Owl Creek drainage basin can be subdivided into three basin segments with differing surface-water quality (fig. 4). Each basin segment has a distinct average range of dissolved-solids concentration, water type, and relation between dissolved-solids concentration and specific conductance. Bar graphs of dissolved-solids concentrations (fig. 4) and modified Stiff diagrams of major ions (fig. 5) were constructed from September 1986 data to give an overview of the variability of surface-water quality on a 2-day period during low flow in the basin. Linear relations between paired specific conductance values and dissolved-solids concentrations were developed for each basin segment.

Table 1.--Location and station name of surface-water sampling sites

[Site number: B, U.S. Bureau of Land Management miscellaneous site; M, U.S. Geological Survey (USGS) miscellaneous site; no letter, USGS established site]

Site number	Location (degrees, minutes, seconds)		Station name	USGS Station number
	Latitude	Longitude		
1-B	43 40 35	109 06 25	South Fork Owl Creek above Rock Creek	
2-B	43 41 39	109 06 29	Rock Creek above Willow Creek	
3-B	43 41 38	109 06 25	Willow Creek at mouth	
4-B	43 39 56	108 51 20	South Fork Owl Creek at gaging station above Anchor Reservoir	
5	43 39 53	108 52 02	South Fork Owl Creek near Anchor	06260000
6	43 40 00	108 52 00	Middle Fork Owl Creek above Anchor Reservoir	06260200
7	43 39 50	108 49 27	Anchor Reservoir	06260300
8	43 39 57	108 47 34	South Fork Owl Creek below Anchor Reservoir	06260400
9	43 41 00	108 44 00	South Fork Owl Creek above Curtis Ranch north of Thermopolis	06260500
10-B	43 42 30	108 42 52	South Fork Owl Creek above Embar	
11-M	43 42 29	108 42 55	South Fork Owl Creek near Embar Ranch	
12	43 43 00	108 42 00	South Fork Owl Creek at Curtis Ranch near Thermopolis	06261000
13-M	43 42 50	108 40 19	South Fork Owl Creek at Embar Ranch	
14	43 43 00	108 38 00	South Fork Owl Creek near Thermopolis	06261500
15-M	43 43 26	108 35 59	South Fork Owl Creek near mouth near Arapaho Ranch	
16-B	43 43 21	108 35 46	South Fork Owl Creek near mouth	
17-M	43 43 36	108 35 28	South Fork Owl Creek at mouth near Arapaho Ranch	
18-B	43 44 33	108 58 48	North Fork Owl Creek above Meadow Creek	
19-B	43 43 28	108 57 24	North Fork above South Fork North Fork Owl Creek	
20-B	43 43 23	108 57 30	South Fork North Fork Owl Creek	
21	43 42 00	108 55 00	North Fork Owl Creek near Anchor	06262000
22	43 41 21	108 50 24	North Fork Owl Creek above Basin Ranch near Anchor	06262300
23-B	43 41 59	108 47 33	North Fork Owl Creek above Rattlesnake Creek	
24-M	43 42 04	108 47 32	North Fork Owl Creek above Rattlesnake Creek near Anchor Dam	
25	43 44 00	108 39 00	North Fork Owl Creek at Crann Ranch near Thermopolis	06262500
26	43 44 00	108 36 00	North Fork Owl Creek near Thermopolis	06263000
27-B	43 43 49	108 35 13	North Fork Owl Creek near mouth	
28-M	43 43 21	108 31 59	Owl Creek at Highway 174	
29-M	43 43 26	108 32 02	Owl Creek near Hamilton Dome	
30-B	43 43 27	108 32 05	Owl Creek at Arapaho Ranch	
31-M	43 42 07	108 28 17	Owl Creek at Middleton School	
32-M	43 41 28	108 23 34	Owl Creek near Thompson Reservoir #1 near Thermopolis	
33	43 41 31	108 19 22	Owl Creek above Mud Creek near Thermopolis	06263300
34-M	43 41 04	108 20 05	Mud Creek at mouth near Thermopolis	

Table 1.--Location and station name of surface-water sampling sites--Continued

Site number	Location (degrees, minutes, seconds) Latitude	Longitude	Station name	USGS Station number
35	43 41 00	108 20 00	Mud Creek near Thermopolis	06263500
36-B	43 41 06	108 18 04	Owl Creek at Highway 120	
37-M	43 41 12	108 16 08	Owl Creek 0.5 mile below Eagle Draw near Thermopolis	
38	43 41 09	108 18 08	Owl Creek near Thermopolis	06264000
39-M	43 41 34	108 15 04	Owl Creek 3.1 mile below Eagle Draw near Thermopolis	
40-M	43 41 29	108 14 54	Owl Creek 1.7 mile above Meeteetse Draw near Thermopolis	
41-M	43 41 37	108 14 35	Owl Creek 1.0 mile above Meeteetse Draw near Thermopolis	
42-M	43 41 52	108 14 11	Owl Creek below Meeteetse Draw near Thermopolis	
43-M	43 42 06	108 13 35	Owl Creek above Sunnyside Lane near Thermopolis	
44-M	43 42 08	108 13 30	Owl Creek at Sunnyside Lane near Thermopolis	
45-B	43 42 56	108 10 30	Owl Creek at Highway 20	
46	43 43 00	108 11 00	Owl Creek near Lucerne	06264500

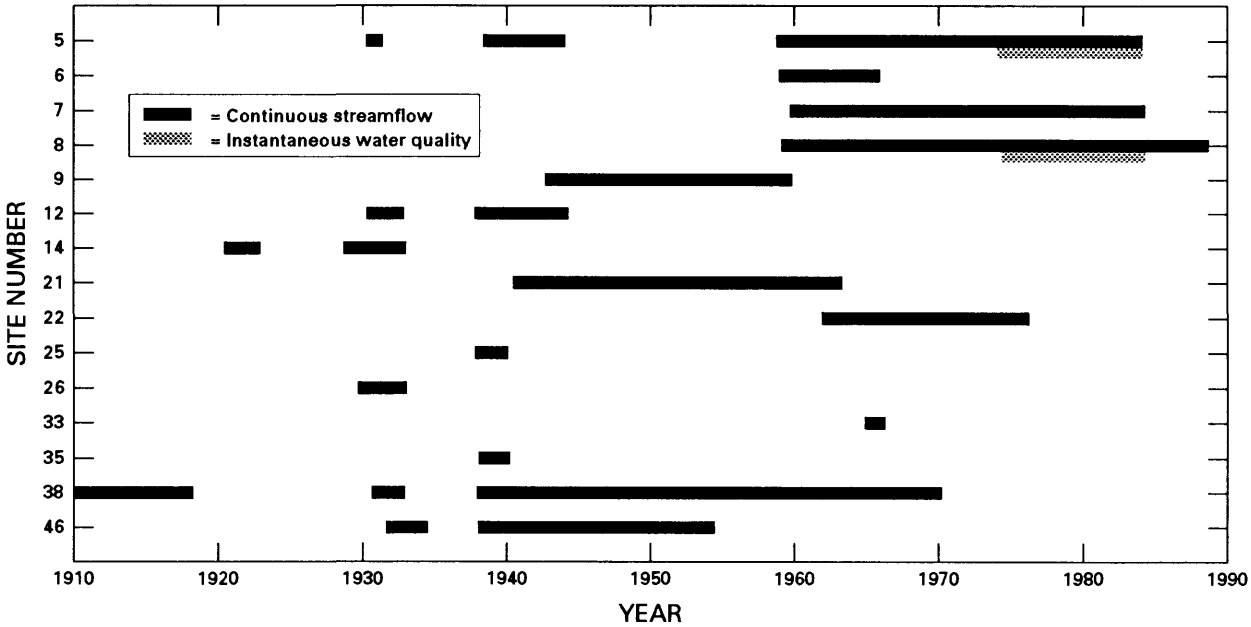


Figure 3. -- Period of record of surface-water data collection at U.S. Geological Survey streamflow-gaging stations.

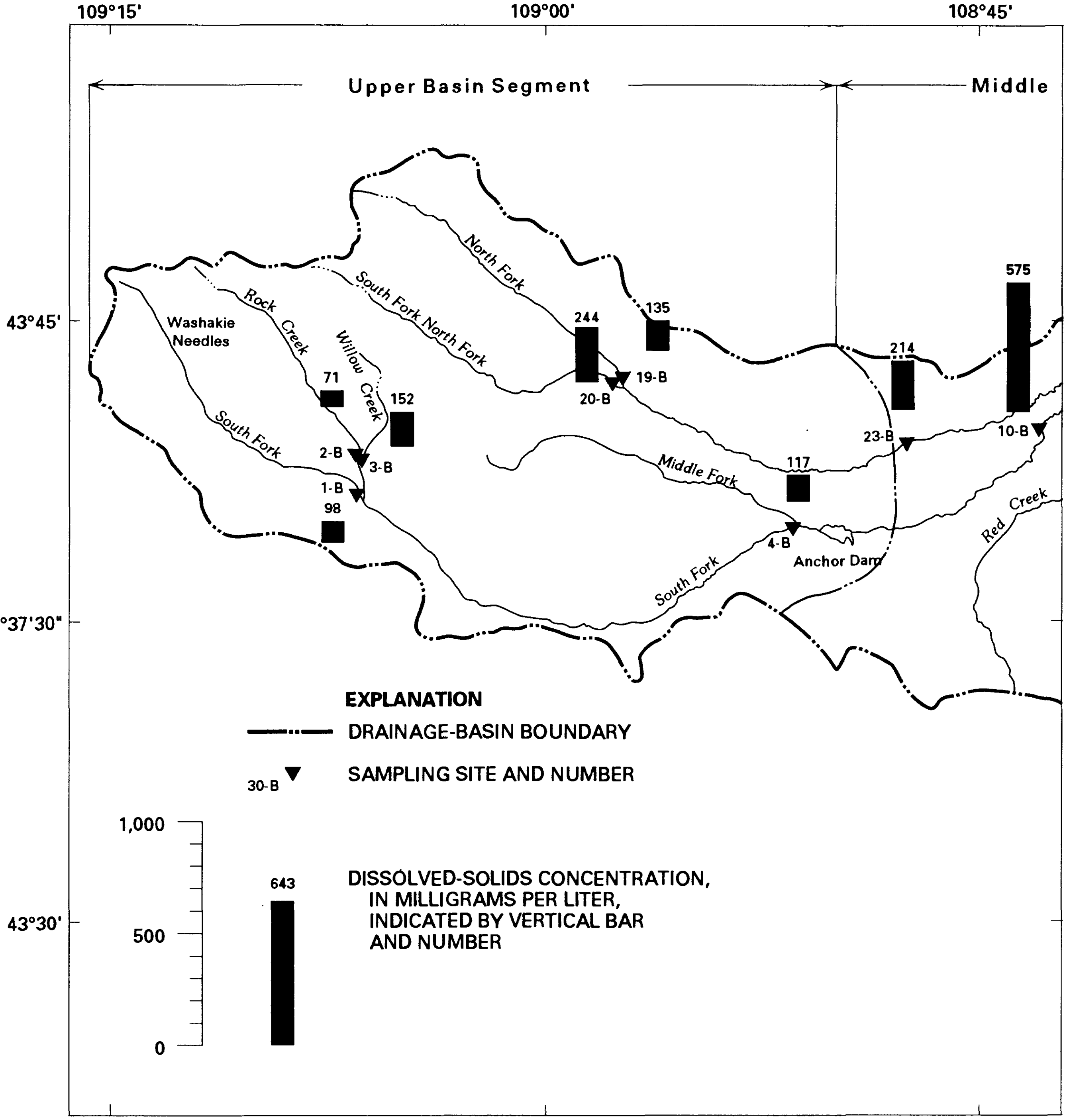
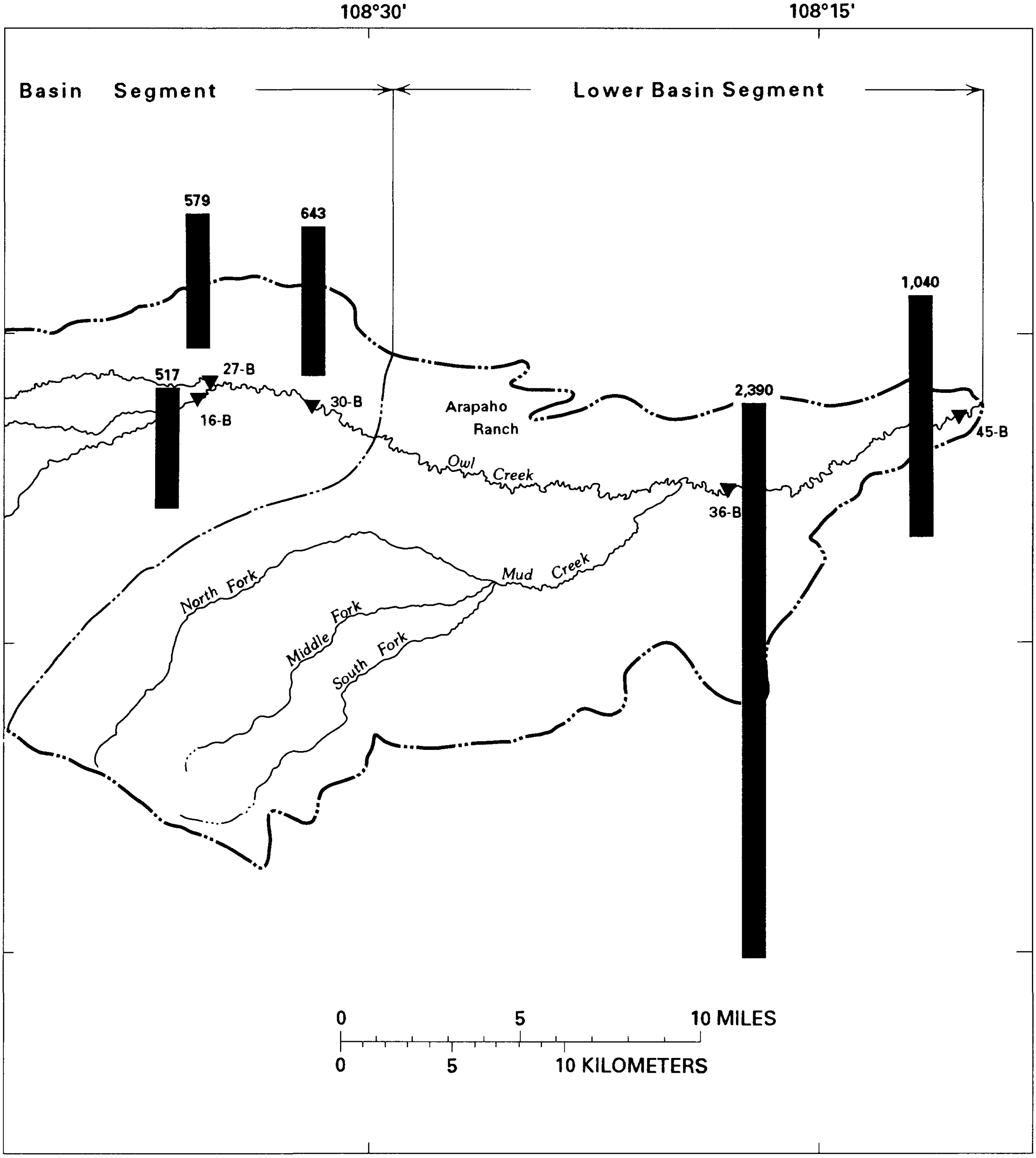


Figure 4.--Dissolved-solids concentrations in water samples collected September



22 and 23, 1986, at selected surface-water sampling sites in Owl Creek basin.

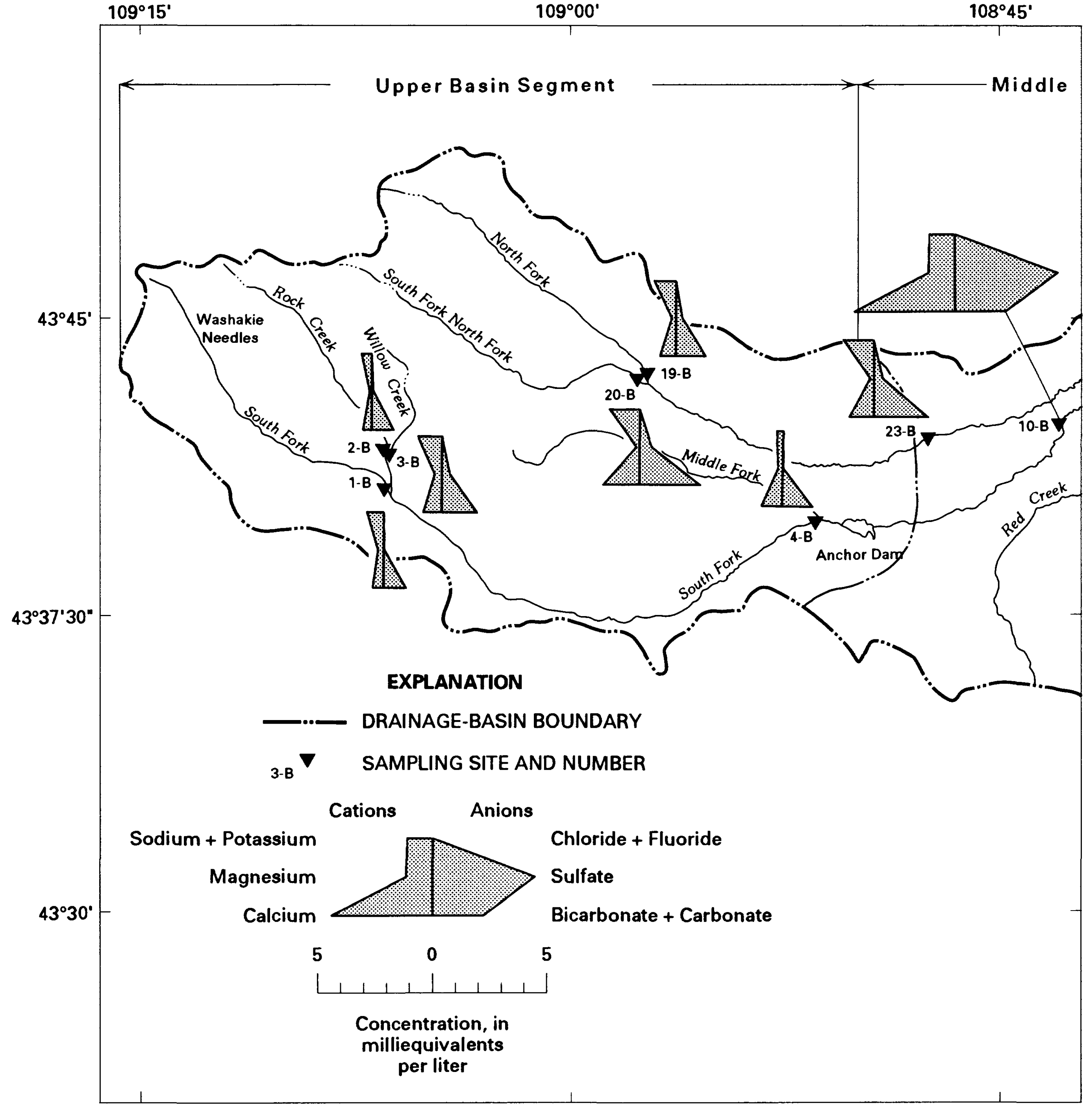
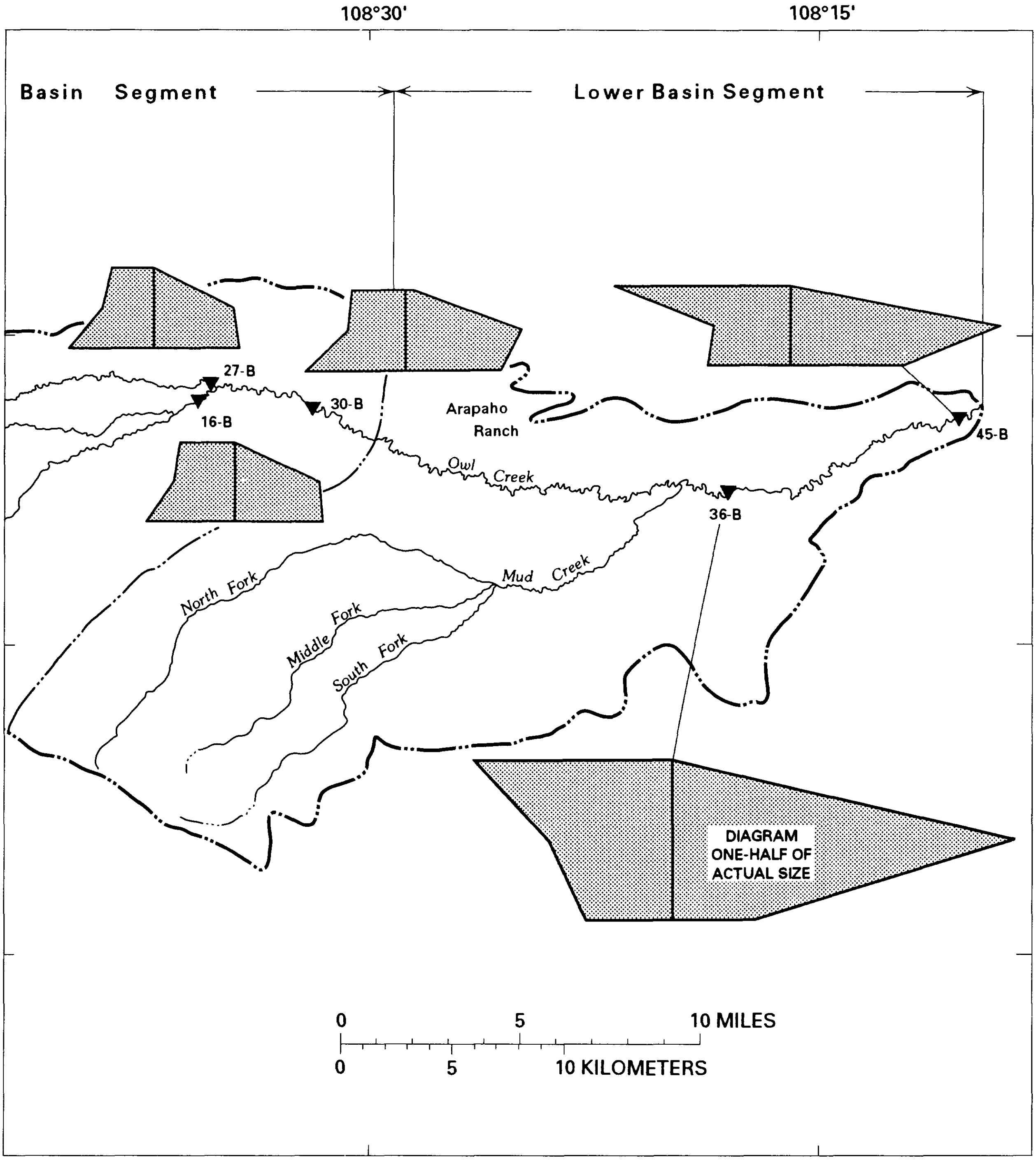


Figure 5.--Modified Stiff diagrams of water samples collected September 22



and 23, 1986, at selected surface-water sampling sites in Owl Creek basin.

Upper Basin Segment

In the upper basin segment, both North Fork Owl Creek and South Fork Owl Creek flow out of high mountains. In the headwaters, both creeks drain an area overlain by the Absaroka Volcanic Supergroup (Wiggins, Tepee Trail, and Aycross Formations of Eocene age). Downstream both creeks drain a more complex assemblage of geological formations (pl. 1).

Water quality of streams in the upper basin segment is characterized as having small concentrations of most major ions. Specific conductance generally is less than 350 μS/cm, and the average dissolved-solids concentration is 171 mg/L for all samples collected from streams in this basin segment. Modified Stiff diagrams were used as a graphical tool to analyze water quality type. Modified Stiff diagrams are plots of the major-ion concentrations in milliequivalents per liter. Their shapes indicate the dominance of ions in the water samples; different shapes indicate different water types. The shapes of the modified Stiff diagrams in figure 5 indicate that the sodium and calcium cations are equally represented and bicarbonate is the dominant anion in the upper basin segment. These data are comparable to the results found by Miller and Drever (1977, p. 288) in their study of chemical weathering in the drainage basin of the North Fork Shoshone River. They found sodium and calcium were the major cations, and bicarbonate was the major anion. Although the basin studied by Miller and Drever (1977, p. 286) is about 50 miles north of Owl Creek basin, the bedrock materials are the same andesitic volcanic rocks present in the upper basin segment of Owl Creek. In the upper basin segment, water in North Fork Owl Creek contains slightly greater concentrations of bicarbonate and calcium and generally has a slightly greater concentration of dissolved solids than the water in South Fork Owl Creek.

In this upper basin segment, there is a gradual increase in the concentration of dissolved solids as the water moves downstream (fig. 4). The September 22-23, 1986 data indicate that South Fork Owl Creek only has a small increase in concentration of dissolved solids from 71 mg/L at the upper-most monitoring site (2-B) to 117 mg/L at the farthest downstream monitoring site (4-B). However, in samples collected during that same 2-day period in North Fork Owl Creek, the concentration of dissolved solids increased from 135 mg/L at site 19-B to 214 mg/L at site 23-B.

In general, the water from streams in the upper basin segment has small concentrations of all major ions and dissolved solids. The average and range of the major-ion concentrations, dissolved-solids concentrations, and specific conductance for water samples collected in this upper basin segment are presented in table 2. The individual chemical analyses are listed in table 10 (at back of report).

Concentrations of dissolved solids in surface-water samples were plotted as a function of specific conductance (fig. 6) to determine if a relation could be developed that would enable future concentrations of dissolved solids to be estimated from specific conductance values. A linear-regression analysis using the least-squares method resulted in the relation that is described by the following equation:

$$DS = 8.35 + 0.742\,(C) \qquad (1)$$

where DS = dissolved-solids concentration, in milligrams per liter; and
C = specific conductance, in microsiemens per centimeter at 25 degrees Celsius.

Table 2.--Statistical summary of discharge measurements and chemical analyses of water samples from streams in the upper, middle, and lower basin segments

[ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; <, less than detection limit. For samples with concentrations less than the detection limit, the average was estimated using log-probability regression (Helsel and Cohn, 1988)]

Statistic	Discharge, instantaneous (ft^3/s)	Specific conductance (µS/cm)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Bicarbonate, HCO_3 (mg/L)	Carbonate, CO_3 (mg/L)	Sulfate, dissolved (mg/L)	Chloride, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Dissolved solids, calculated, sum of constituents (mg/L)	Nitrate, dissolved as N (mg/L)
						Upper basin segment							
Average	10	185	16	3.8	27	2	87	1	38	2.4	0.1	171	0.30
Range	<1-50	58-348	1.2-150	0.0-27	6.0-170	0.0-5	33-200	0-15	2.8-650	1.0-11	<0.1-0.4	52-1,190	0.00-1.6
Number of samples	27	32	38	38	38	38	36	34	38	38	31	38	28
						Middle basin segment							
Average	4.8	576	70	23	58	3	190	5	220	5.0	0.2	566	0.31
Range	<0.50-11	120-1,800	27-148	7.0-49	14-240	1-5	92-300	0-24	49-780	1.0-19	0.1-0.4	181-1,505	0.09-1.7
Number of samples	9	23	14	14	14	14	13	13	14	14	13	14	11
						Lower basin segment							
Average	4.6	2,200	190	106	346	6	350	1	1,400	22	0.6	2,340	2.9 [1](.13)
Range	<0.5-10.4	650-4,400	71-321	13-240	169-611	4-11	280-460	0-10	480-2,500	13-42	0.4-0.8	1,040-4,070	0.07-22
Number of samples	5	16	8	8	8	8	8	8	8	8	8	8	8

[1] Average without inclusion of large value of 22 mg/L.

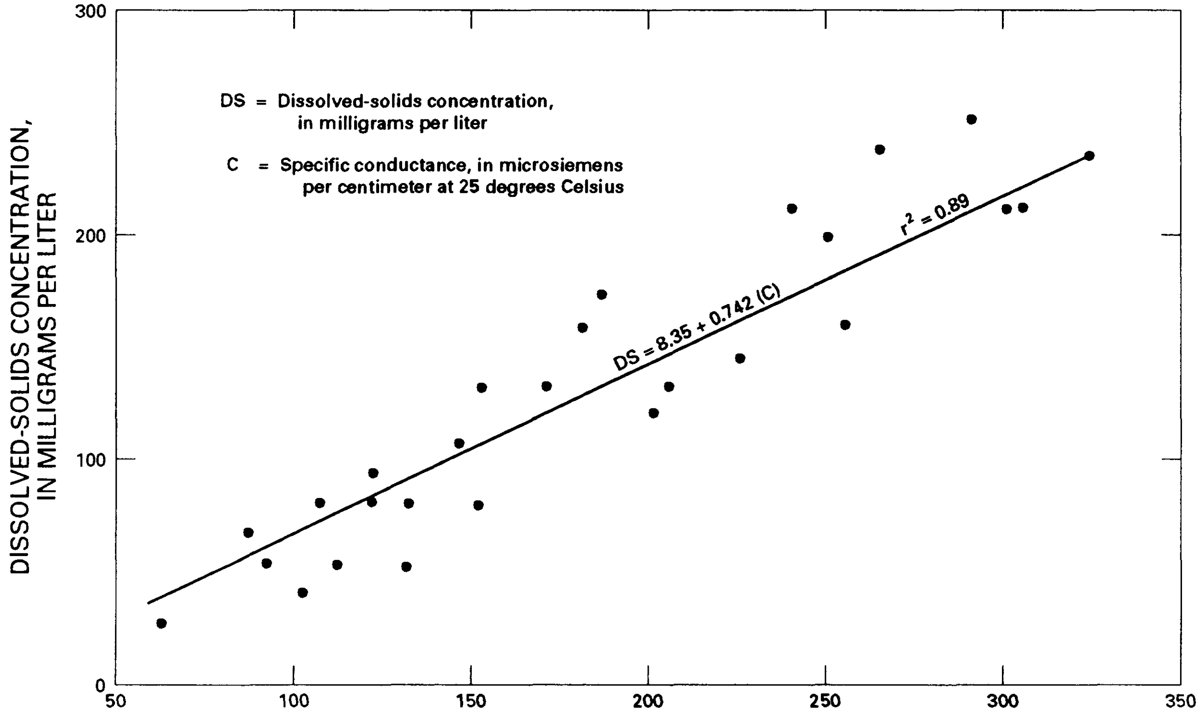


Figure 6. -- Relation between dissolved-solids concentration and specific conductance for water samples from the upper basin segment.

This relation is within the expected ratio of dissolved-solids concentration to specific conductance for the analysis of natural water (Hem, 1985, p. 67). The coefficient of determination (r-squared) is 0.89, indicating that the regression equation (eq. 1) explains 89 percent of the variation in dissolved-solids concentrations. The standard error of estimate is 20 mg/L.

The average concentrations of sulfate, chloride, fluoride, dissolved solids, and nitrate (as nitrogen) in water samples from the upper basin segment are equal to or less than their associated SMCL and MCL. However, the maximum concentrations of sulfate and dissolved solids exceed the associated SMCL. The maximum concentrations of sulfate and dissolved solids occurred in the sample collected in July 1979 at site 23-B during low flow. The second-largest concentration of each of these two constituents is less than their SMCL. The average and range of concentrations of dissolved solids and the major ions are compared to their respective SMCL or MCL in figure 7.

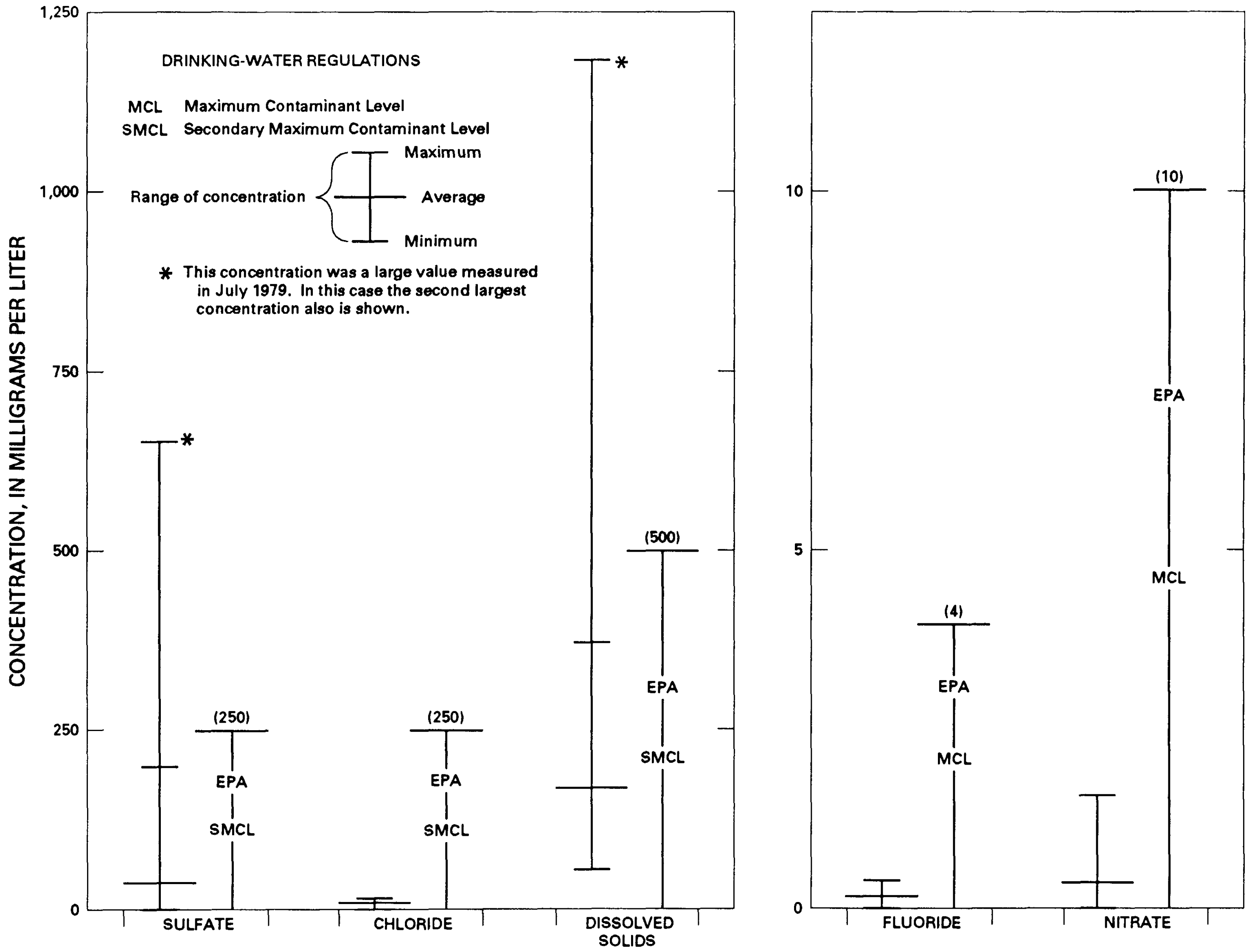


Figure 7.--Concentrations of dissolved solids and major ions in water samples from streams in the upper basin segment and corresponding contaminant levels in U.S. Environmental Protection Agency (EPA) Drinking-Water Regulations.

Concentrations of the selected constituents in most water samples from the upper basin segment of Owl Creek basin were less than the MCL or SMCL. Therefore, additional analysis was performed for this basin segment to assess seasonal variability of surface-water quality and adequacy of flow to meet a hypothetical need of 0.01 cubic feet per second.

Variability of Water Quality

Two streamflow-gaging stations (sites 5 and 8, fig. 2), in the upper basin segment have been operated for several years, and specific conductance was measured at those two sampling sites. The data were used to assess seasonal variability. Between 1974 and 1986, 118 measurements of specific conductance were made at site 5, and 98 were made at site 8. These data were grouped by month for each station, and the average, range, and number of samples were calculated (table 3). The average monthly specific conductance for 1974-86 at each site is plotted in figure 8. The seasonal pattern of water-quality changes is similar for each site even though specific conductance of water samples at site 8 has the potential to be affected by the releases of water from Anchor Reservoir.

Table 3.--Statistical summary of specific conductance by month at two surface-water-quality stations on South Fork Owl Creek in the upper basin segment

[Concentrations, in microsiemens per centimeter at 25 degrees Celsius]

Statistic	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
Site 5 (1974-85)												
Average	143	176	180	164	201	186	162	115	90	100	116	151
Range	114-180	140-220	160-205	110-190	170-280	170-200	125-200	65-180	58-125	66-175	80-165	130-180
Number of samples	12	10	9	5	9	7	8	12	16	11	11	8
Site 8 (1974-86)												
Average	141	174	228	187	190	193	167	132	100	104	125	155
Range	39-188	54-205	200-260	180-195	170-210	170-240	117-270	80-170	62-155	68-165	80-170	140-185
Number of samples	12	9	6	3	5	7	6	7	15	10	9	9

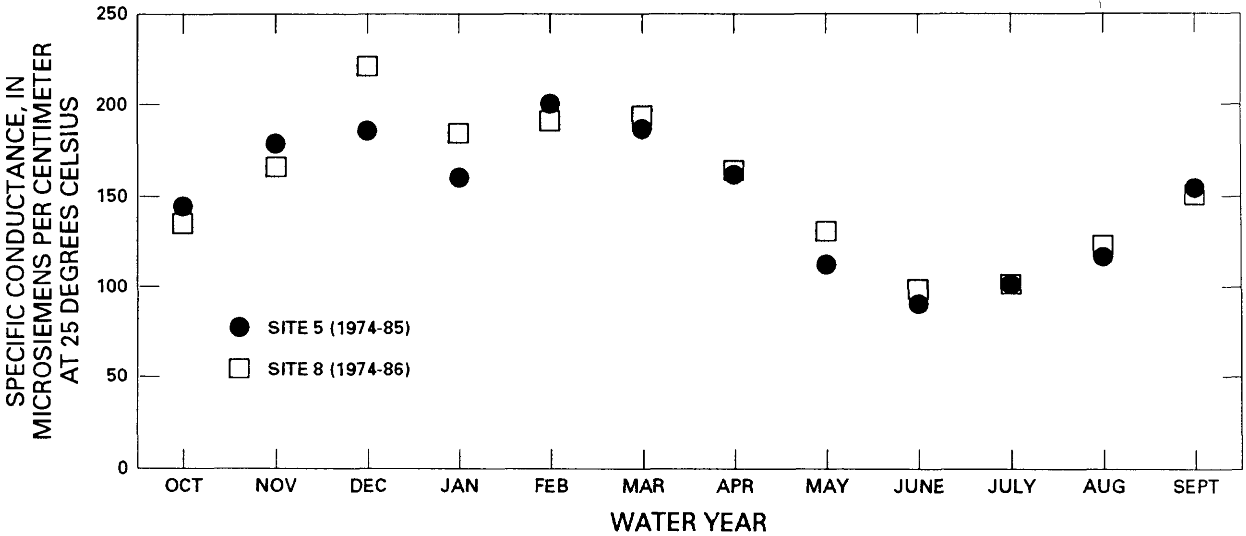


Figure 8. -- Temporal variation of average monthly specific conductance at two surface-water-quality stations on South Fork Owl Creek in the upper basin segment.

Seasonal variability was examined using monthly variation in specific-conductance measurements. Water samples taken at these sites in November through March generally have specific-conductance measurements between 150 to 225 μS/cm. Water samples taken in the months of May through August generally have specific-conductance measurements that range from 75 to 125 μS/cm. From the relation of dissolved solids to specific conductance developed for the upper basin segment, a specific conductance of 663 μS/cm would correlate to an approximate concentration of 500 mg/L for dissolved solids, the SMCL. Even with seasonal variability, none of the average monthly values of specific conductance calculated between 1974 and 1968 exceeded that threshold value of 663 μS/cm.

Variability of Streamflow

The variability of streamflow in North Fork Owl Creek and South Fork Owl Creek was examined to determine if adequate flow exists to meet a hypothetical discharge of about 0.01 cubic feet per second. Records of streamflow were analyzed at two stations, site 22 on the North Fork Owl Creek and site 8 on the South Fork Owl Creek below Anchor Dam.

The streamflow characteristics of North Fork Owl Creek at site 22 for 1963-72 were analyzed by Peterson (1988, p. 100-101). As indicated in figure 9, the smallest average monthly streamflows (average of the average monthly streamflows for a particular month during the period of record) occur in November, December, January, and February. The minimum monthly streamflow (minimum average monthly streamflow for a particular month during the period of record) were examined over the same period of record (Peterson, 1988, p. 100); minimum streamflows for February, September, and October were 0.00 cubic foot per second which is less than the hypothetical discharge of 0.01 cubic foot per second. During the 10-year period of record, the daily average streamflow (average streamflow for a given day) was 0.01 cubic foot per second or greater 90 percent of the time (fig. 10).

Streamflow characteristics of South Fork Owl Creek at site 8 for 1960-84 were analyzed by Peterson (1988, p. 94-95). The average monthly streamflow is given in figure 11. The smallest average monthly streamflows during 1960-84 occurred in December, January, and February. The minimum monthly streamflow during the period of record was 0.00 cubic foot per second during January, February, March, and December (Peterson, 1988, p. 94) which is less than the hypothetical discharge of 0.01 cubic foot per second. The flow-duration curve (fig. 12) shows that over the same 24-year period, the daily average streamflow exceeded 0.01 cubic foot per second 90 percent of the time.

Middle Basin Segment

Surface-water quality in streams in the middle basin segment of Owl Creek basin (fig. 4) is characterized by an increase in specific conductance and a tripling of the average dissolved-solids concentration compared to the upper basin segment (table 2). The streams in the middle basin segment drain an area of complex geology (pl. 1). The alluvial deposits are underlain by the Cody Shale and Frontier Formation of Cretaceous age. South Fork Owl Creek and Red Creek flow across and receive runoff from outcrops of the Chugwater and Dinwoody Formations of Triassic age and of the Phosphoria Formation and related rocks of Permian age. Agricultural development is greater in the middle basin segment than in the upper basin segment. The development primarily consists of irrigated meadows for hay crops and irrigated fields for small grains. The water applied to the fields is surface water diverted primarily from Owl Creek, North Fork Owl Creek, and South Fork Owl Creek.

As compared to the upper basin segment, surface-water samples indicate a general increase in most of the major ions in the middle basin segment. Average concentrations of bicarbonate and sodium double, average concentration of calcium increases four times, and average concentrations of magnesium and sulfate increase by a factor of six over the concentrations in samples from streams in the upper basin segment. The specific conductance in the middle basin segment ranges from 120 to 1,800 μS/cm. The average and range of the major ions, dissolved solids, and specific conductance in the middle basin segment--based on all water samples collected in that segment--are shown in table 2. Chemical analyses of water samples from streams in the middle basin segment are listed in table 11 (at back of report).

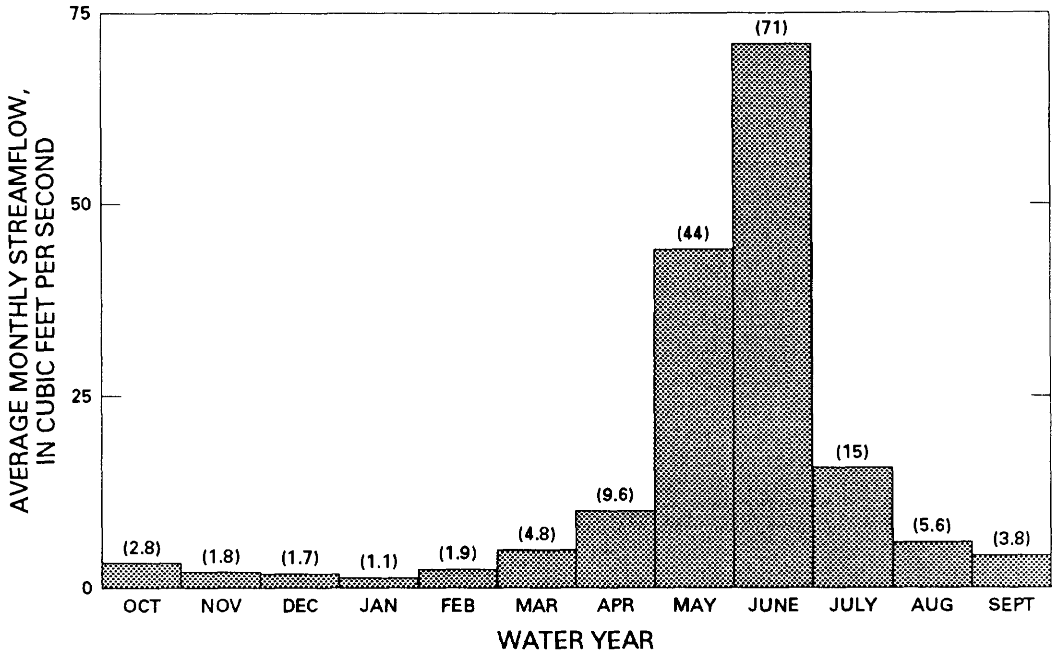


Figure 9. -- Average monthly streamflow at site 22 on North Fork Owl Creek in the upper basin segment, 1963-72 (modified from Peterson, 1988, p. 101).

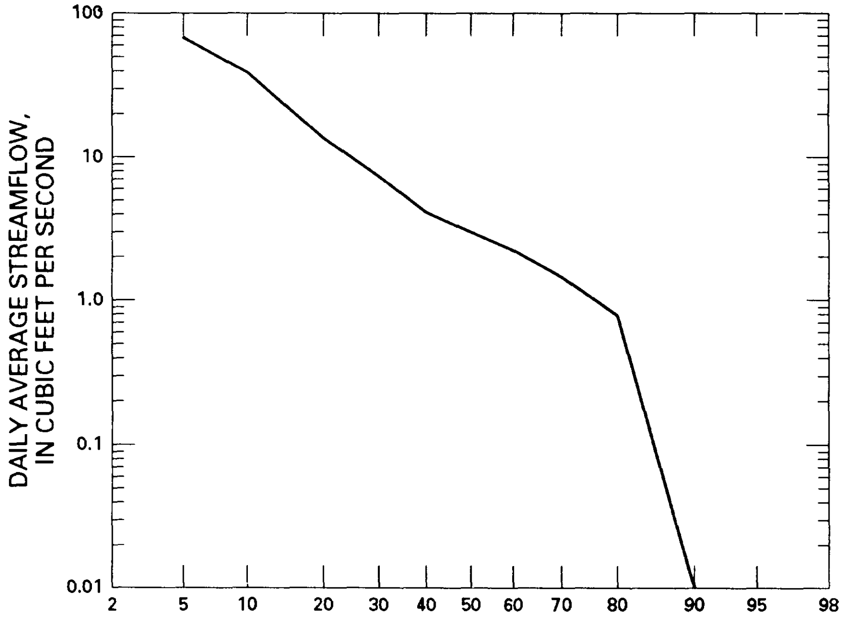


Figure 10. -- Flow-duration curve for site 22 on North Fork Owl Creek in the upper basin segment, 1963-72 (modified from Peterson, 1988, p. 101).

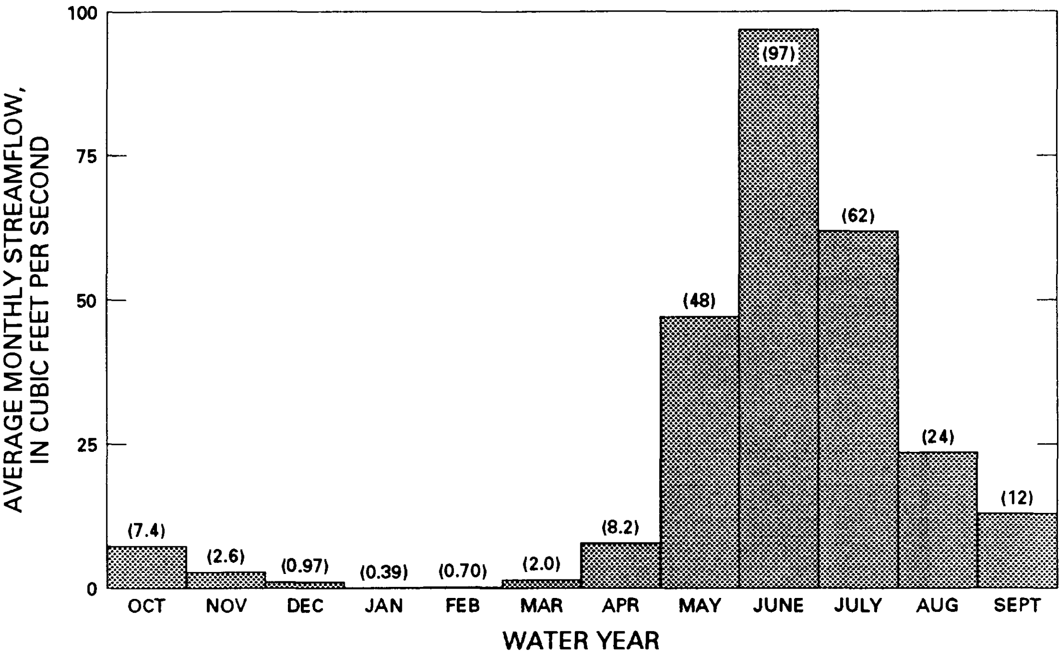


Figure 11. -- Average monthly streamflow at site 8 on South Fork Owl Creek in the upper basin segment, 1960-84 (modified from Peterson, 1988, p. 95).

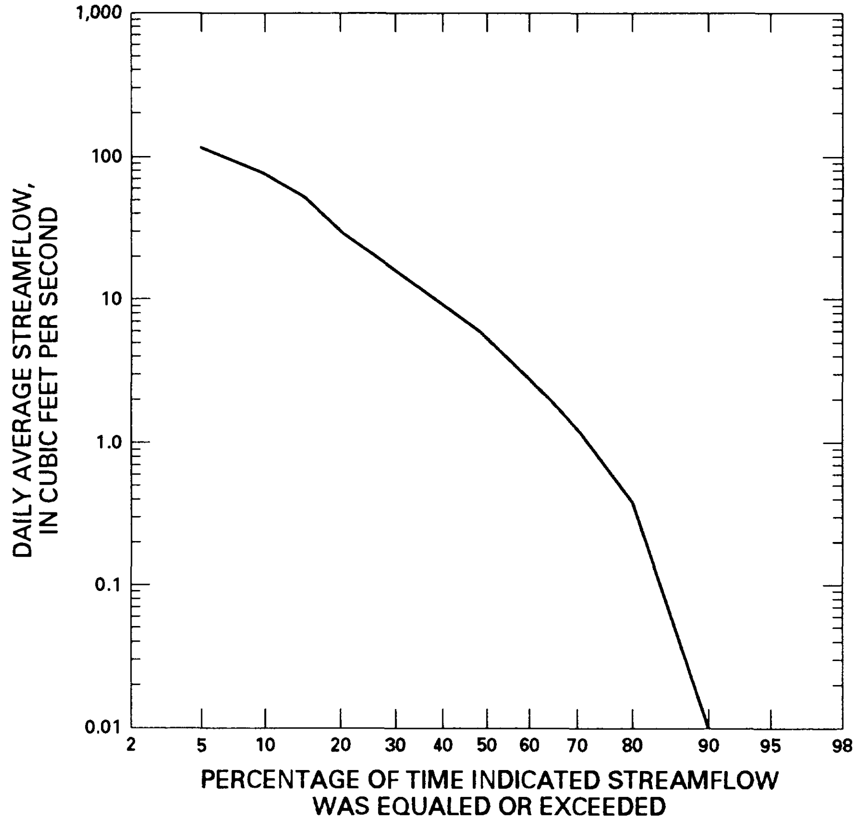


Figure 12. -- Flow-duration curve for site 8 on South Fork Owl Creek in the upper basin segment, 1960-84 (modified from Peterson, 1988, p. 95).

The shape of the modified Stiff diagrams (fig. 5) indicates that the chemical type of water in the middle basin segment differs from that of the upper basin segment. Calcium is the dominant cation, in contrast to the upstream basin segment where calcium and sodium were about equally distributed. Sulfate concentrations are much greater, and sulfate equals or exceeds bicarbonate as the dominant anion. There is an increase in average magnesium concentration from 3.8 mg/L in the upstream basin segment to 23 mg/L in the middle basin segment.

The data are inconclusive as to the cause of the changes in water quality in the middle basin segment, although geological material, ground-water inflow, irrigation return flow, or a combination of these factors are likely causes. Streams in the middle basin segment receive runoff from Chugwater, Dinwoody, and Phosphoria Formations, which are known to contain gypsum (calcium/magnesium sulfate). Small-yield springs were observed between sampling sites 28-M and 30-B (fig. 2) during work onsite in January 1989. The source of these springs could be either the alluvial aquifer or the bedrock aquifer. The increased concentration of major ions between the upper and middle basin segments is within the range of increases attributed to irrigation as reported by McGauhey (1968, p. 63-64), and irrigated acreage is greater in this segment than in the upper basin segment.

The dissolved-solids concentrations average 566 mg/L for all water samples collected from streams in the middle basin segment. More apparent is the increase in average concentration of dissolved solids in streams by a factor of three, as compared to the upper basin segment.

Pairs of dissolved-solids concentrations and specific conductance readings for streams in the middle basin segment were plotted (fig. 13). When a linear regression analysis using the least-squares method was performed on the data, the relation was described by the equation

$$DS = -29.3 + 0.810\ (C) \qquad (2)$$

where DS = dissolved-solids concentration, in milligrams per liter; and
C = specific conductance, in microsiemens per centimeter at 25 degrees Celsius.

This relation is in the upper range of the common ratio of dissolved solids to specific conductance for the analysis of natural water reported in Hem (1985, p. 67), indicating large concentrations of sulfate ions. This is confirmed by the individual ion concentrations of sulfate in water samples. The coefficient of determination of 0.94 indicates that 94 percent of the variation in dissolved-solids concentration is explained by this relation (eq. 2). The standard error of estimate is 89 mg/L.

When the averages and ranges of all data available for the middle basin segment are compared to the associated MCL or SMCL, the average values for dissolved-solids concentrations exceed the associated SMCL of 500 mg/L. The concentrations of major ions and dissolved solids are compared to the associated MCL and SMCL in figure 14.

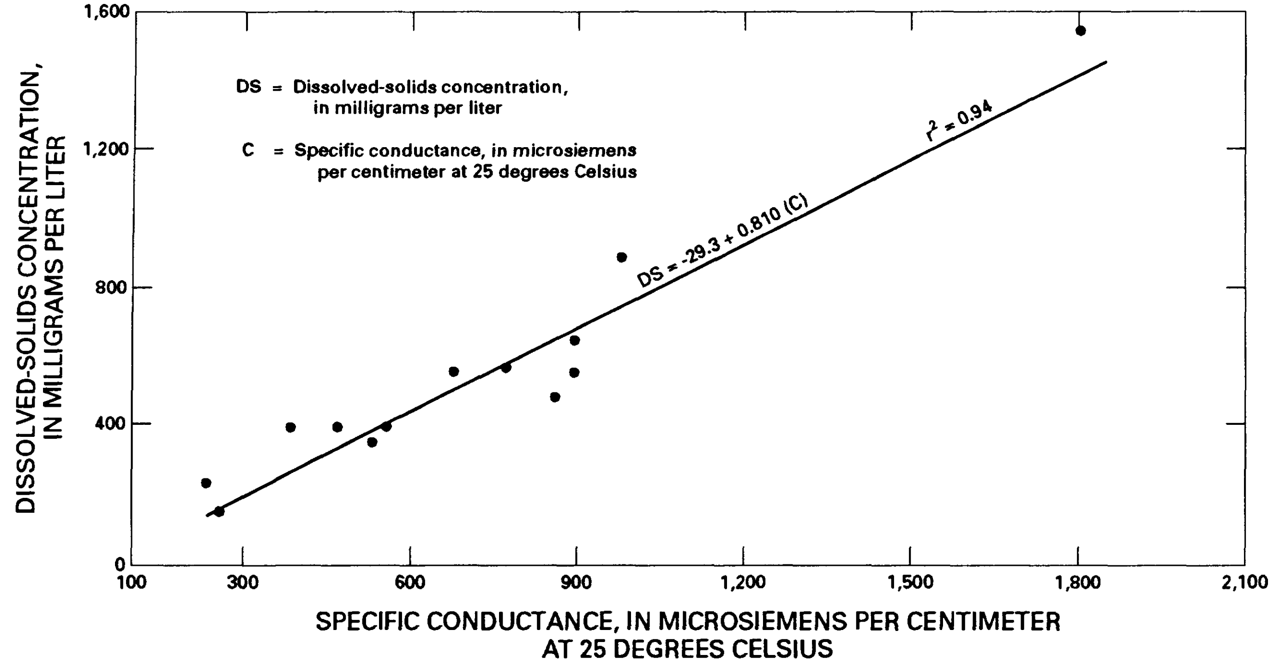


Figure 13. -- Relation between dissolved-solids concentration and specific conductance for water samples from the middle basin segment.

Lower Basin Segment

In the lower basin segment, Owl Creek receives runoff from the Cody Shale and Frontier Formation in addition to contributions from Mud Creek, which drains a large area of predominately Lower Cretaceous to Jurassic rocks. Agricultural development with surface-water diversions for irrigation continues in the upper half of the lower basin segment. Incrustation of saline soils can be observed along Wyoming Highway 170 near the junction with Wyoming Highway 120, (pl. 1) as shown in figure 15.

Specific conductance and dissolved-solids concentrations in stream samples in the lower basin segment (fig. 4) are variable. Specific conductance ranges from 650 to 4,400 μS/cm with an average value of 2,200 μS/cm. For dissolved-solids concentration the range is 1,040-4,070 mg/L. The average dissolved-solids concentrations for all samples from streams is 2,340 mg/L. The average and range of specific conductance and of concentrations of major ions and dissolved solids, based on all water samples collected in the lower basin segment, are summarized in table 2.

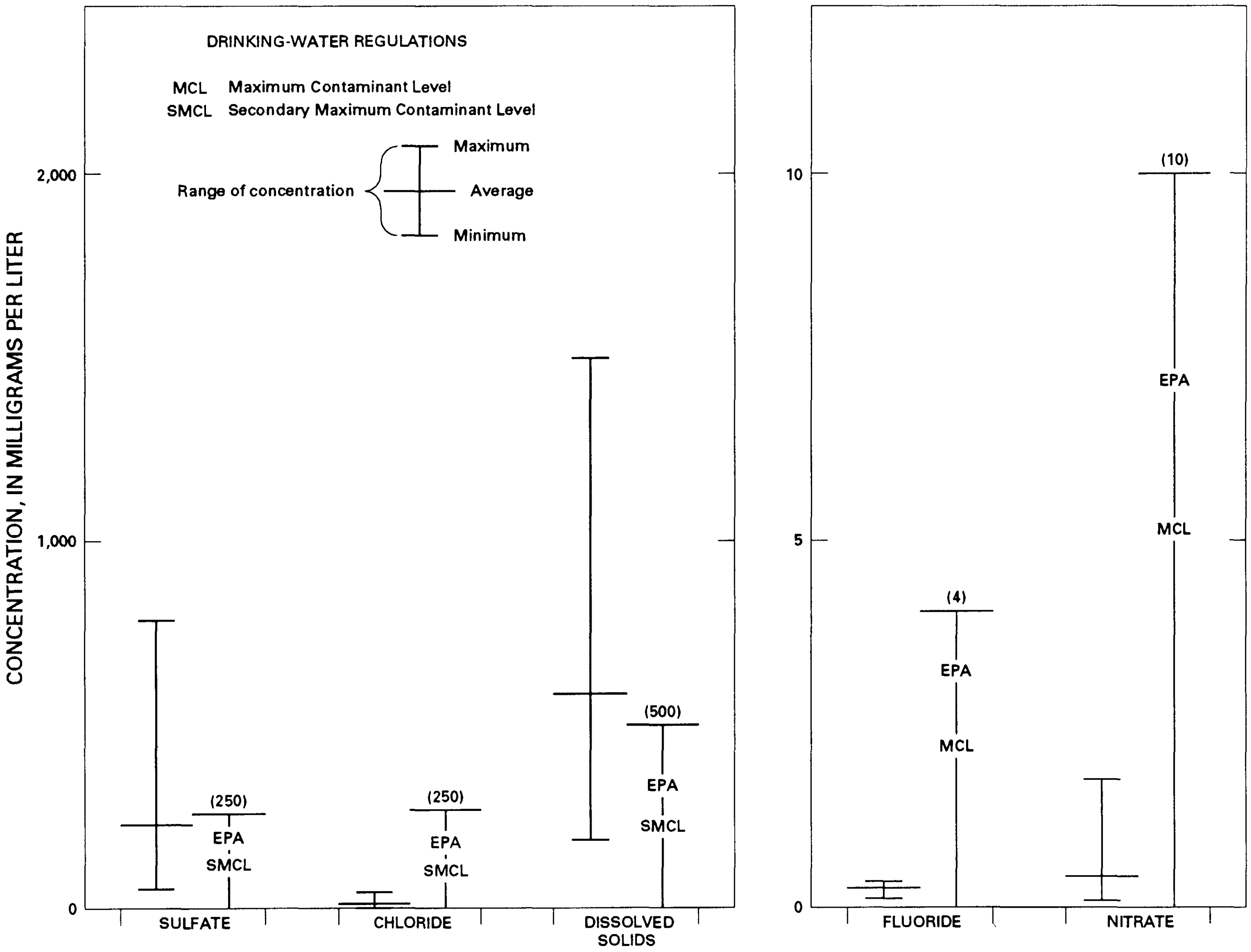


Figure 14.--Concentrations of dissolved solids and major ions in water samples from streams in the middle basin segment and corresponding contaminant levels in U.S. Environmental Protection Agency (EPA) Drinking-Water Regulations.

Figure 15.--Salt incrustation (outlined areas) in the lower basin segment near junction of Wyoming highways 170 and 120.

In general, the water samples from streams in the lower basin segment have larger concentrations of most major ions and dissolved solids than in either the upper or middle basin segments. Average sulfate and sodium concentrations of water samples from streams increased by a factor of 6, and magnesium increased by a factor of 5 in the lower basin segment when compared to the middle basin segment (table 2). The individual analyses in the lower basin segment are shown in table 12 in the back of the report. On the basis of the shape of the modified Stiff diagrams of water quality in the lower basin segment in figure 5, it is apparent that in this segment the water is dominated by sodium and sulfate ions. The sodium cation is dominant in this lower basin segment, whereas the calcium cation is dominant in the middle basin segment. The sulfate anion is more dominant in the lower basin segment than in the middle basin segment, where sulfate and bicarbonate are about evenly distributed.

In samples collected on September 23, 1986, the dissolved-solids concentration at site 36-B (2,390 mg/L) was substantially greater than at site 30-B (643 mg/L) (fig. 4). Farther downstream, the dissolved-solids concentrations decreased from 2,390 mg/L at site 36-B to 1,040 mg/L at site 45-B. This change probably is because of the effects of return flow from supplemental irrigation water diverted from the Bighorn River. This supplemental irrigation is permitted for application to about 6,000 acres between sites 36-B and

45-B. The Lucerne pumping station delivers water from the Bighorn River to irrigated areas along Owl Creek below site 36-B. Peterson and others (1987, p. 39) reported the average dissolved-solids concentration in the Bighorn River at a sampling site near the Lucerne pumping station's intake to be less than 500 mg/L. Return flows from lands irrigated with this diverted Bighorn River water might account for the decrease in dissolved-solids concentrations between sites 36-B and 45-B.

A plot of paired dissolved-solids concentrations and specific conductance measurements was prepared for water samples from the lower basin segment (fig. 16). From a linear regression analysis using the least-squares method, the relation is described by the equation

$$DS = -529 + 1.03\ (C) \qquad (3)$$

where DS = dissolved-solids concentration, in milligrams per liter; and
C = specific conductance, in microsiemens per centimeter at 25 degrees Celsius.

This relation is above the commonly found range of the ratio of dissolved solids to specific conductance for analysis of natural water (Hem, 1985, p. 67) and may be an indication of large gypsum or large silica concentrations (Ann Watterson, U.S. Geological Survey, oral commun., 1989). The coefficient of determination (r-squared) indicates that 96 percent of the variation in the dissolved-solids concentration can be explained by this relation (eq. 3). The standard error of estimate is 283 mg/L. It should be noted that only six points were available for this analysis of the lower basin segment.

Concentrations of sulfate, chloride, fluoride, dissolved solids, and nitrates in water samples from the lower basin segment are compared to their associated SMCL or MCL in figure 17. All concentrations of dissolved solids and sulfate exceed their associated SMCL. One dissolved-nitrate concentration of 22 mg/L as nitrogen, determined for a sample collected August 7, 1985 at site 45-B, exceeded the MCL of 10 mg/L as nitrogen. All other nitrate concentrations were considerably less than the MCL.

GROUND-WATER QUALITY

Ground-water quality in Owl Creek basin can be characterized as containing a large concentration of dissolved solids, generally greater than 500 mg/L. Larson (1984, p. 33) reported a median dissolved-solids concentration of 1,850 mg/L for ground-water samples collected in Hot Springs County, of which Owl Creek basin comprises 25 percent of the total area. Hot Springs County had the largest median dissolved-solids concentration of any county in Wyoming (Larson, 1984, p. 32). Berry and Littleton (1961, p. 41) determined ground water in the Owl Creek area to be highly mineralized; the dissolved-solids concentrations ranged from 1,830 to 11,600 mg/L (p. 41). Ground-water quality in Owl Creek basin for this report was analyzed in two sections: the alluvial aquifer and the bedrock aquifers.

The alluvial aquifer corresponds to the geologic deposits mapped as bottomland deposits on plate 1. The bottomland deposits containing the alluvial aquifer consist of floodplain alluvium, terrace deposits, alluvial fan deposits, and colluvial and pediment deposits that are in hydraulic

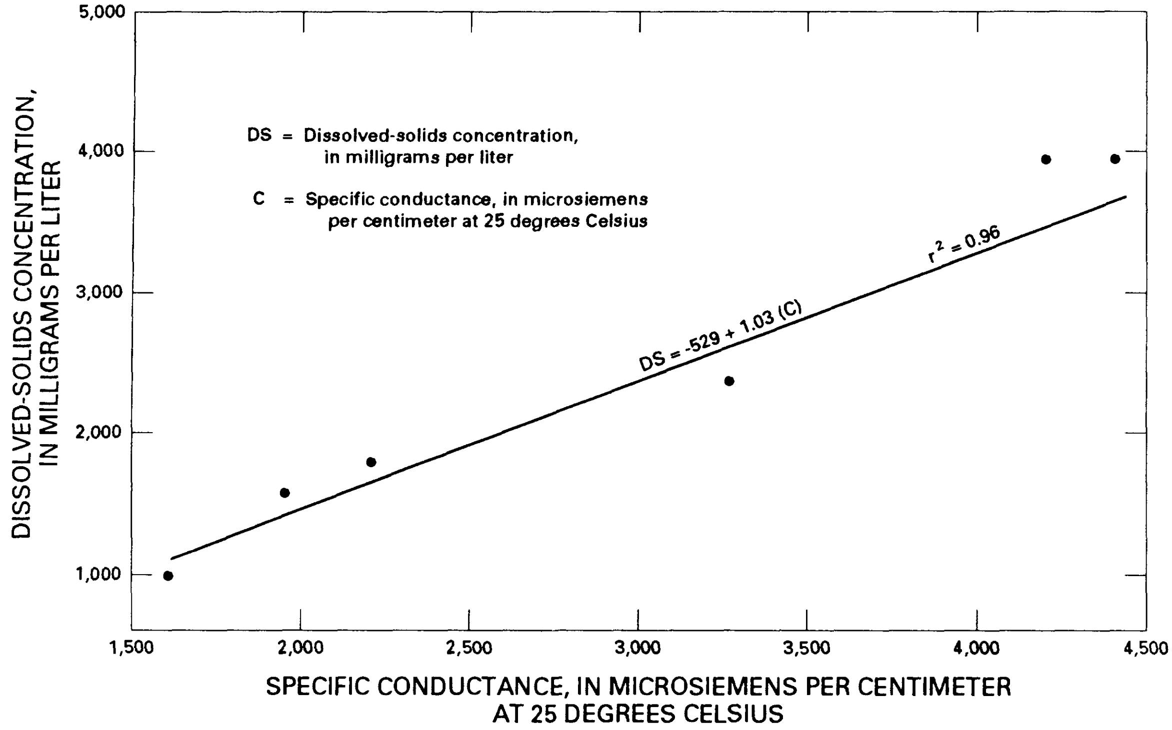


Figure 16. -- Relation between dissolved-solids concentration and specific conductance for water samples from the lower basin segment.

connection. Bench deposits (pl. 1), which are greater than 30 feet above the nearby stream, are assumed not to be in hydraulic interconnection with the alluvial aquifer. The bottomland deposits generally consist of clay, sand, and gravel; pebbles and cobbles are present locally. The thickness of these bottomland deposits ranges from about 20 to 40 feet along Owl Creek.

The alluvial aquifer is present along the main stem of Owl Creek and along the lower reaches of North Fork Owl Creek, Middle Fork Owl Creek, and South Fork Owl Creek. Its width varies from 1/4 mile along South Fork Owl Creek downstream from Anchor Dam to 1 1/2 miles along Owl Creek in the vicinity of Arapaho Ranch. The width in places is controlled by the geological structure; it decreases considerably at anticlinal structures. Where South Fork Owl Creek cuts a canyon through the Anchor anticline, the alluvial aquifer is absent. The alluvial aquifer is present but narrow along South Fork Owl Creek in the vicinity of the Owl Creek Anticline and along Owl Creek at the Thermopolis Anticline.

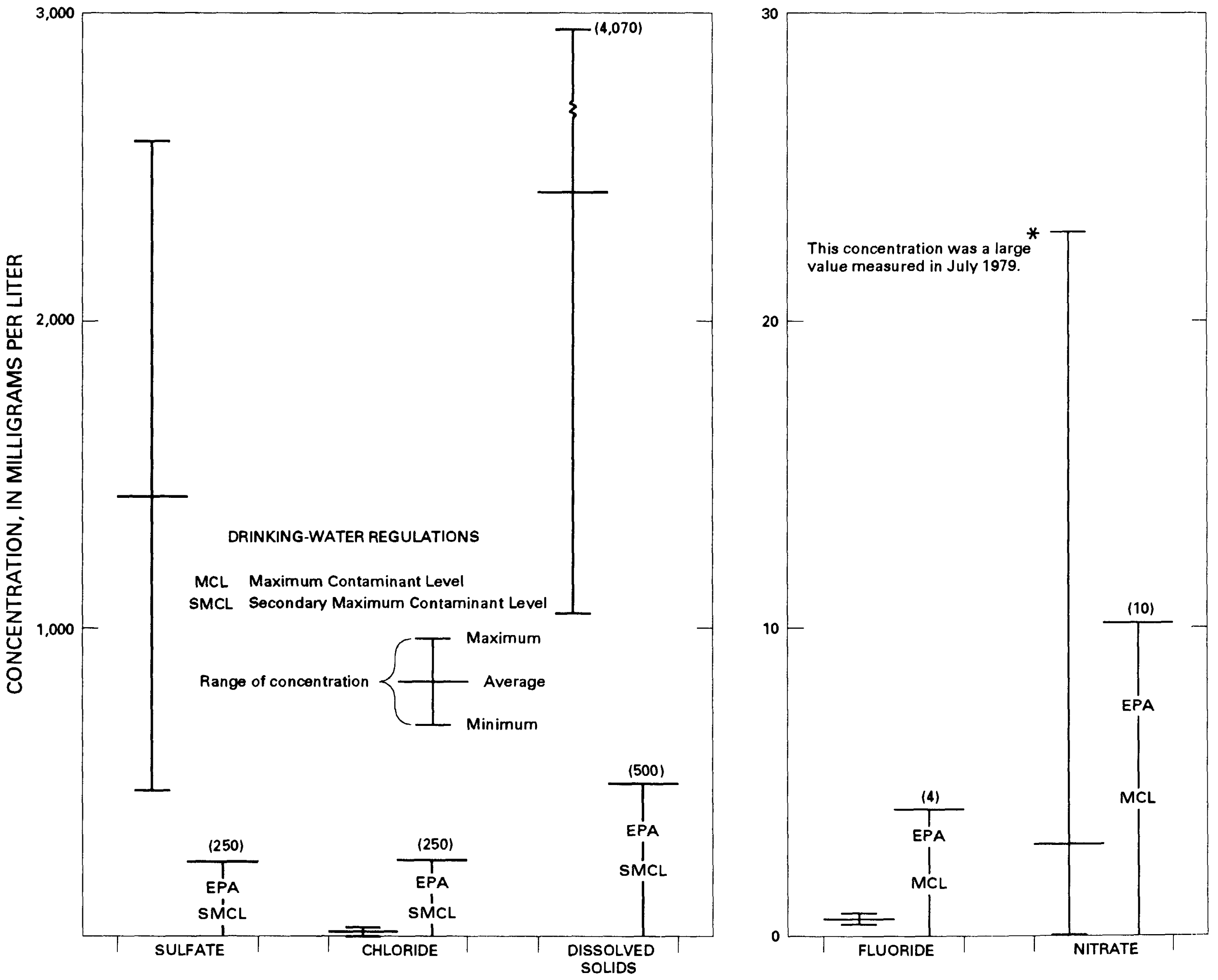


Figure 17.--Concentrations of dissolved solids and major ions in water samples from streams in the lower basin segment and corresponding contaminant levels in U.S. Environmental Protection Agency (EPA) Drinking-Water Regulations.

The alluvial aquifer is primarily a source for domestic and stock water. In the past, some attempts were made to develop the alluvial aquifer for irrigation, but developments are no longer operating. Cooley and Head (1982, p. 1) determined that the quality of water in the alluvial aquifer (defined in their report as the floodplain alluvium and part of the Arapaho Ranch terrace deposits, pl. 1) made its use undesirable or marginal for most purposes except stock watering.

Water in the alluvial aquifer contains large concentrations of dissolved solids. Berry and Littleton (1961, p. 45) listed two samples for the alluvium (defined in their report as deposits underlying the floodplains of the principal streams), with dissolved-solids concentrations of 2,010 and 2,540 mg/L.

Because the alluvial aquifer, as defined in this report, and aquifers in other alluvial deposits had been studied and water samples had been collected at selected sites in the alluvium by Berry and Littleton (1961) and by Cooley and Head (1982), a limited area of the alluvial aquifer--referred to in this report as the Arapaho Ranch alluvial aquifer--was selected for detailed study. The area selected extends from about 1 mile upstream of the confluence of North Fork Owl Creek and South Fork Owl Creek to about 4 miles downstream of the Arapaho Ranch (fig. 18).

Bedrock aquifers in this report are defined as all aquifers except the alluvial aquifer. Potential bedrock aquifers are numerous in Owl Creek basin. The geologic units in the basin have been combined (pl. 1) on the basis of their stratigraphic proximity and hydrologic characteristics. In each of these units, permeable stratigraphic zones might yield limited quantities of water. In this report, only aquifers that either have the potential to function as a water source over a large area of the basin or that are used as a water source in Owl Creek basin are examined.

Arapaho Ranch Alluvial Aquifer

Surface-resistivity measurements along Owl Creek in the vicinity of Arapaho Ranch indicated the alluvial aquifer to be from 19 to 44 feet in thickness (Cooley and Head, 1982, p. 28). From onsite investigations it was determined that in some areas wells are completed into a thickness of 60 feet of reported alluvial materials.

Fourteen wells completed in and two springs issuing from the Arapaho Ranch alluvial aquifer were inventoried. Their locations, depths to water, altitudes of water level, and depths of wells are shown in figure 18; records of wells and springs are listed in table 4. Static water levels were measured in January and March of 1989, with the exception of wells where access could not be gained until June 1989. Wells without listed depths were reported to be completed in the alluvial aquifer by the owner or tenant. In general, the water table in the Arapaho Ranch alluvial aquifer is from 7 to 37 feet below land surface. Samples for onsite and lab analyses of water quality also were obtained at the time the wells were inventoried.

The quality of water in the Arapaho Ranch alluvial aquifer varies greatly in both individual constituents and water types. The dissolved-solids concentrations in 10 samples from 7 sites averaged 1,352 mg/L and ranged from 708 to 2,210 mg/L. The mean and range of the specific conductance and concentrations

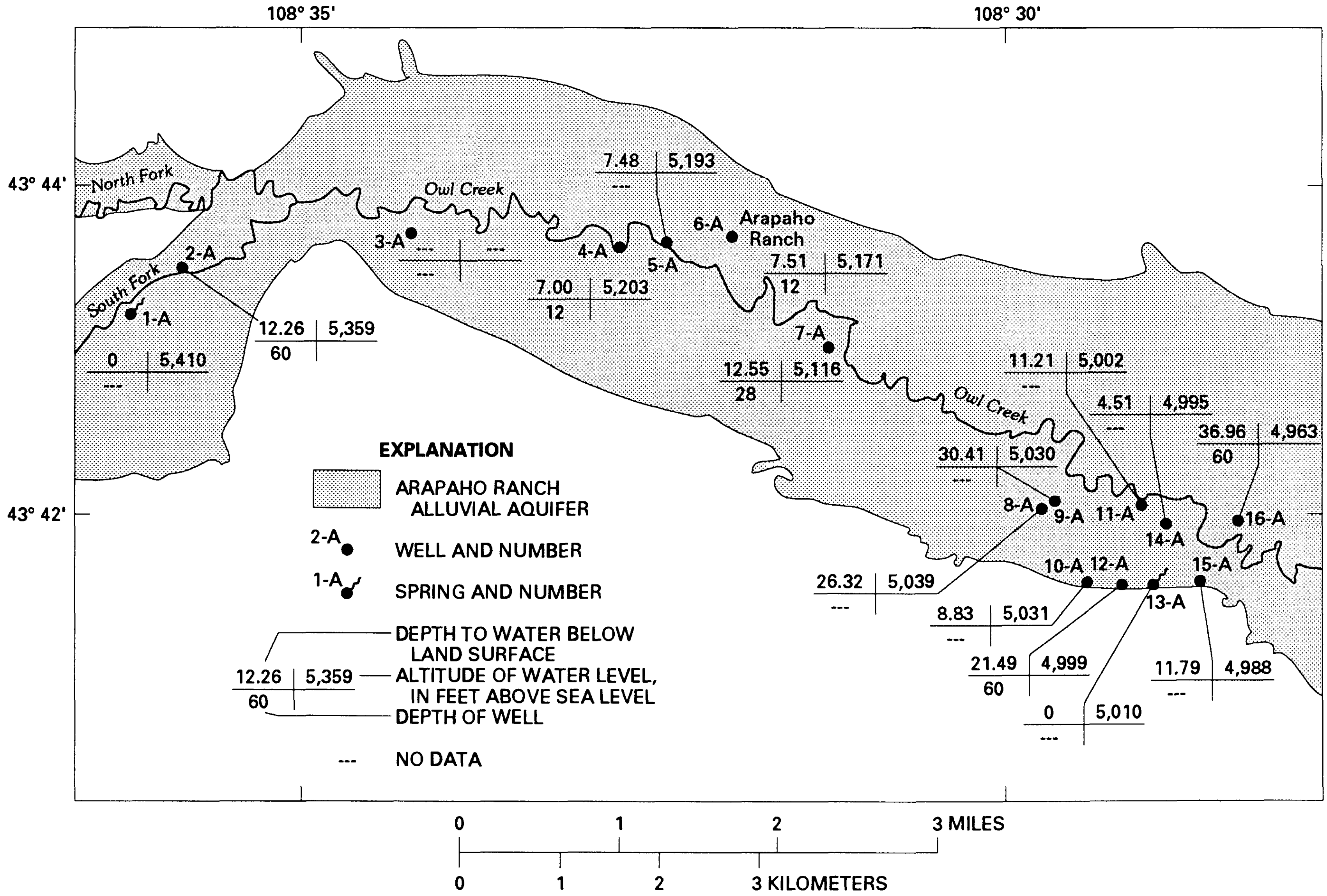


Figure 18.--Location and selected data for wells completed in and springs issuing from the Arapaho Ranch alluvial aquifer, March and June 1989.

Table 4.--Records of wells completed in and springs issuing from the Arapaho Ranch alluvial aquifer

[Use of water: D, domestic; S, stock; N, none. Water level: Depth to water below land surface; altitude: water level subtracted from surface altitude taken in the field from 1:24,000 topographic map. Remarks: W.Q. analysis, water-quality analysis is available in table 6. --, no data]

Site number (fig. 18)	Location (degrees, minutes, seconds)		Owner or tenant	Date of site visit	Well or spring	Well depth (feet)	Use of water	Water level		Remarks
	Latitude	Longitude						Depth to water (feet)	Altitude (feet above sea level)	
1-A	43 43 01	108 36 27	Arapaho Ranch	03-06-89 01-06-89 08-19-88	Spring	--	D, S	0	5,410	W.Q. analysis
2-A	43 43 28	108 35 56	Arapaho Ranch	06-22-89	Well	60	D	12.26	5,359	W.Q. analysis
3-A	43 43 40	108 34 12	Arapaho Ranch	06-23-89	Well	--	N	--	--	Not accessible for measurement or water-quality sampling
4-A	43 43 34	108 32 41	Arapaho Ranch	01-05-89	Well	12	D	7.00	5,203	Not accessible for water-quality sampling
5-A	43 43 35	108 32 21	Arapaho Ranch	01-05-89	Well	--	N	7.48	5,193	Not accessible for water-quality sampling
6-A	43 43 36	108 31 49	Arapaho Ranch	03-07-89 08-19-88	Well	12	S	7.51 7.94	5,171	W.Q. analysis
7-A	43 42 59	108 31 05	Mark Troxel	06-23-89	Well	28	D	12.55	5,116	W.Q. analysis
8-A	43 42 06	108 29 31	Robert Stewart	03-08-89	Well	--	D	26.32	5,039	W.Q. analysis
9-A	43 42 10	108 29 24	Robert Stewart	03-08-89	Well	--	D	30.41	5,030	Not accessible for water-quality sampling
10-A	43 41 42	108 29 09	Bill Daniels	03-07-89	Well	--	N	8.83	5,031	Not accessible for water-quality sampling
11-A	43 42 08	108 28 44	Bill Daniels	03-07-89	Well	--	N	11.21	5,002	Not accessible for water-quality sampling
12-A	43 41 41	108 28 54	Bill Daniels	03-07-89	Well	60	D, S	21.49	4,999	Bottom 17 ft may be completed in Cody Shale; W.Q. analysis
13-A	43 41 40	108 28 39	Bill Daniels	03-07-89	Spring	--	S	0	5,010	pH, temperature, and specific conductance measured

Table 4.--Records of wells completed in and springs issuing from the Arapaho Ranch alluvial aquifer--Continued

Site number (fig. 18)	Location (degrees, minutes, seconds)		Owner or tenant	Date of site visit	Well or spring	Well depth (feet)	Use of water	Water level		Remarks
	Latitude	Longitude						Depth to water (feet)	Altitude (feet above sea level)	
14-A	43 42 02	108 28 33	Middleton School	03-08-89	Well	--	N	4.51	4,995	
15-A	43 41 41	108 28 16	Bill Daniels	03-08-89	Well	--	N	11.79	4,988	
16-A	43 42 02	108 28 02	Fred and Margery Becker	03-07-89	Well	60	D	36.96	4,963	Used to irrigate small area around house; W.Q. analysis

of major ions, dissolved solids, and nitrate (as nitrogen) are listed in table 5 for all water samples in the Arapaho Ranch alluvial aquifer. The range of concentration of many of the major ions varies by one or two orders of magnitude (an order of magnitude is a tenfold difference). In addition, the individual measurements of specific conductance and concentrations of major ions, dissolved solids, and nitrate are listed in table 6. The distribution of dissolved-solids concentrations in water-quality samples collected from the Arapaho Ranch alluvial aquifer in March and June 1989 are shown in figure 19.

Modified Stiff diagrams of water samples from the Arapaho Ranch alluvial aquifer indicate the water generally is of the sodium, sulfate, and bicarbonate type (fig. 20). Although calcium, rather than sodium, is the dominate cation in two samples, the concentration of calcium and magnesium is highly variable. Chloride and fluoride consistently are present in small concentrations.

The variability of chemical composition of water in this aquifer has at least five potential causes: (1) undetected dual completion of wells in the Arapaho Ranch alluvial aquifer and the upper part of the underlying Cody Shale or Frontier Formation; (2) irrigation in the vicinity of the well or spring; (3) interconnection with surface water; (4) natural variability of the lithology of the Arapaho Ranch alluvial aquifer; or (5) leakage between the underlying aquifers and the Arapaho Ranch alluvial aquifer. Well 12-A may have a dual completion in both the Arapaho Ranch alluvial aquifer and the upper 17 feet of the Cody Shale. The modified Stiff diagram for a water sample from this well (fig. 20) has a similar shape to the modified Stiff diagrams of water samples from the Cody Shale (pl. 1). Spring 1-A and Well 7-A both lie in close proximity to the streams and may be affected by interconnection to surface water in the area. Water samples from these two sites have calcium, sulfate type water, and the surface water in this area is calcium, sulfate, bicarbonate type.

A linear regression of the relation between dissolved-solids concentration and specific conductance was developed for the Arapaho Ranch alluvial aquifer using the least-squares method. The relation is described by the equation

$$DS = -132 + 0.783\ (C) \tag{4}$$

where DS = dissolved-solids concentration, in milligrams per liter; and
C = specific conductance, in microsiemens per centimeter at 25 degrees Celsius.

The data used to develop this relation are plotted in figure 21. The ratio of 0.783 between dissolved-solids concentration and specific conductance measurements is at the larger end of the expected range for the analysis of natural water (Hem, 1985, p. 67). This larger ratio generally is associated with large sulfate concentrations such as those present in the Arapaho Ranch alluvial aquifer. The r-squared (coefficient of determination) value of 0.96 indicates a strong correlation between these variables. The standard error of estimate is 120 mg/L.

Table 5--Statistical summary of chemical analyses of water samples from wells completed in and springs issuing from the Arapaho Ranch alluvial aquifer

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; <, less than detection limit]

	Specific conductance (µS/cm)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Alkalinity, total as $CaCO_3$ (mg/L)	Sulfate, dissolved (mg/L)	Chloride, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Dissolved solids, calculated, sum of constituents (mg/L)	Nitrate, dissolved as N (mg/L)
Average	1,894	106	50	267	3.5	389	652	12	0.5	1,352	[1]0.62
Range	1,080-2,780	9.7-170	3.3-90	89-620	1.1-7.2	237-493	290-1,200	4.4-28	0.2-1.5	708-2,210	<0.10-5.3
Number of samples	10	10	10	10	10	10	10	10	10	10	10

[1] Concentrations in 6 of the 10 samples were less than the detection limit of 0.10 mg/L. Average concentration was estimated using log-probability regression (Helsel and Cohn, 1988).

Table 6.--Discharge measurements and chemical analyses of water samples from wells completed in and springs issuing from the Arapaho Ranch alluvial aquifer

[gal/min, gallons per minute; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; --, no data; <, less than detection limit]

Site number (fig. 19)	Date of sample	Discharge, instantaneous (gal/min)	Specific conductance (µS/cm)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Alkalinity, as $CaCO_3$ (mg/L)	Sulfate, dissolved (mg/L)	Chloride, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Dissolved solids, calculated, sum of constituents (mg/L)	Nitrate, dissolved as N (mg/L)
1-A	03-06-89	9.4	1,500	170	69	110	2.8	424	500	4.6	0.2	1,140	<0.10
	01-06-89	9.3	1,550	170	67	100	2.9	423	530	4.4	.2	1,150	< .10
	08-19-88	--	2,000	160	69	110	2.7	419	570	5.2	.2	1,190	< .10
2-A	06-22-89	--	1,075	25	7.1	210	1.8	263	290	6.5	.3	708	.59
6-A	03-07-89	--	2,240	82	62	380	7.2	514	760	16	.7	1,670	.16
	08-19-88	--	2,630	120	80	430	5.9	493	920	28	.6	2,520	< .10
7-A	06-23-89	--	1,200	110	43	89	1.1	237	380	5.9	.7	850	5.3
8-A	03-08-89	--	1,250	36	11	230	2.4	263	380	9.4	.4	835	.12
12-A	03-07-89	--	2,710	9.7	3.3	620	2.0	381	990	15	1.5	1,880	< .10
16-A	03-07-89	3.0	2,780	180	90	390	5.8	476	1,200	24	.5	2,210	< .10

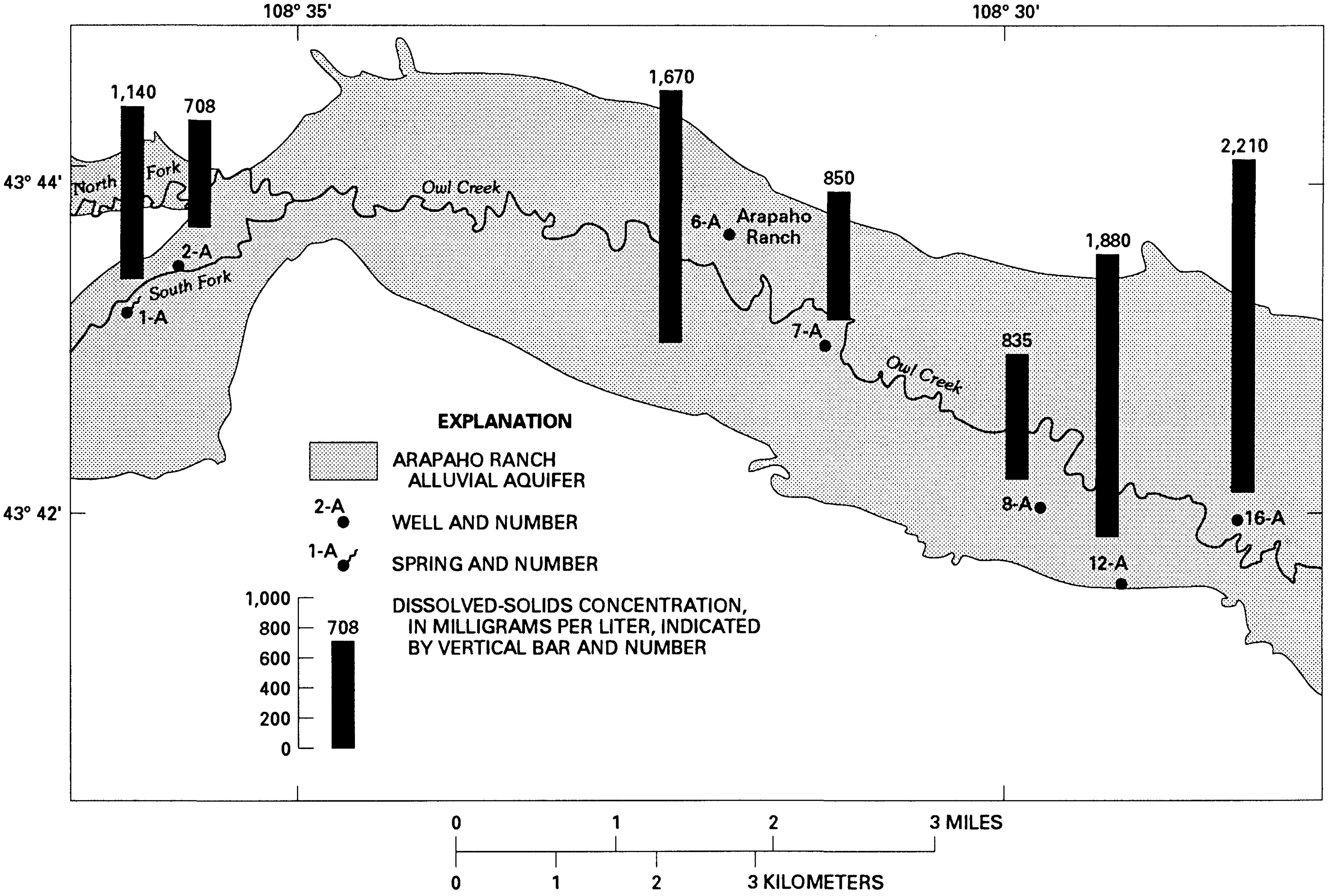


Figure 19.--Dissolved-solids concentrations in water samples from wells completed in and springs issuing from the Arapaho Ranch alluvial aquifer, March and June 1989.

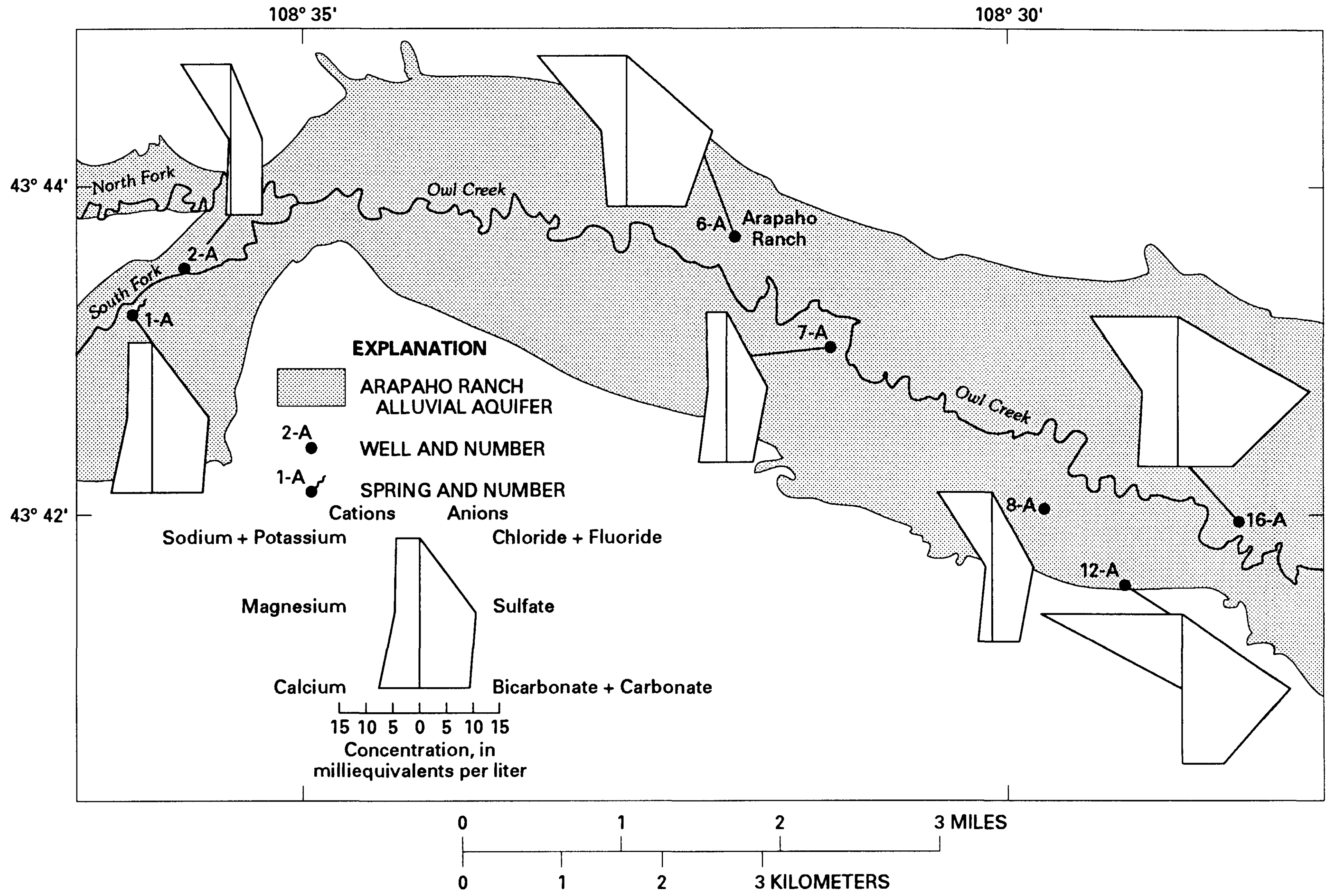


Figure 20.--Modified Stiff diagrams of water samples from wells completed in and springs issuing from the Arapaho Ranch alluvial aquifer, March and June 1989.

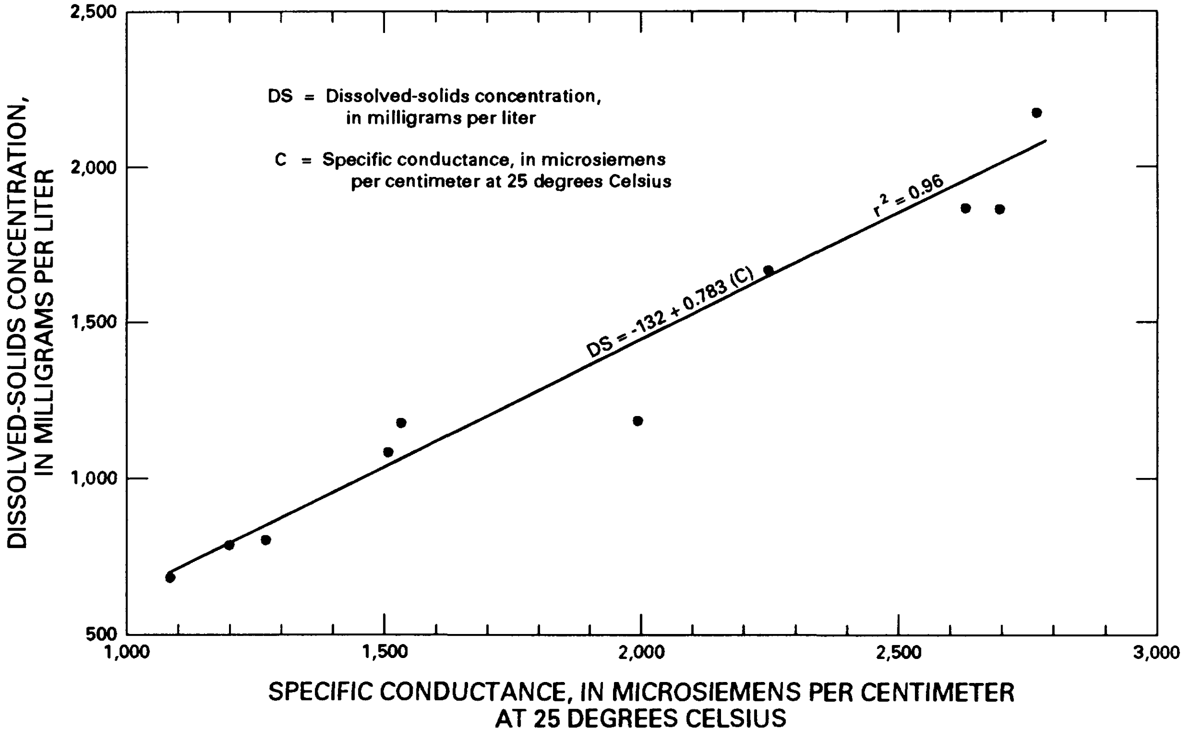


Figure 21. -- Relation between dissolved-solids concentration and specific conductance for water samples from the Arapaho Ranch alluvial aquifer.

The average and range of values calculated from the 10 water samples in the Arapaho Ranch alluvial aquifer were compared to the MCL or SMCL for sulfate, chloride, fluoride, dissolved solids, and nitrate. Dissolved-solids concentrations of all 10 water samples exceeded the SMCL of 500 mg/L, and the average value exceeded the SMCL by over two times, primarily because of large concentrations of sulfate, alkalinity, and sodium. Likewise, all sulfate concentrations exceeded the SMCL (250 mg/L), and the average sulfate concentration of 652 mg/L was more than twice the SMCL. All chloride concentrations were less than the SMCL (250 mg/L) and the average was an order of magnitude (tenfold) smaller. All fluoride and nitrate values also were less than the MCL. These comparisons are shown in figure 22.

Water samples were collected from spring 1-A and from well 12-A and were analyzed for the following selected herbicides: Dicamba (Banvel); picloram (Tordon); 2,4,5-TP (Silvex); 2,4-D; 2,4-DP; and 2,4,5-T. No concentrations of these herbicides were reported to exceed the detection limit of 0.01 μg/L. A water sample from Spring 1-A was analyzed for selected trace elements and radiochemicals. The results of these analyses and the appropriate MCL or SMCL are listed in table 7; only concentrations of manganese exceeded its standard.

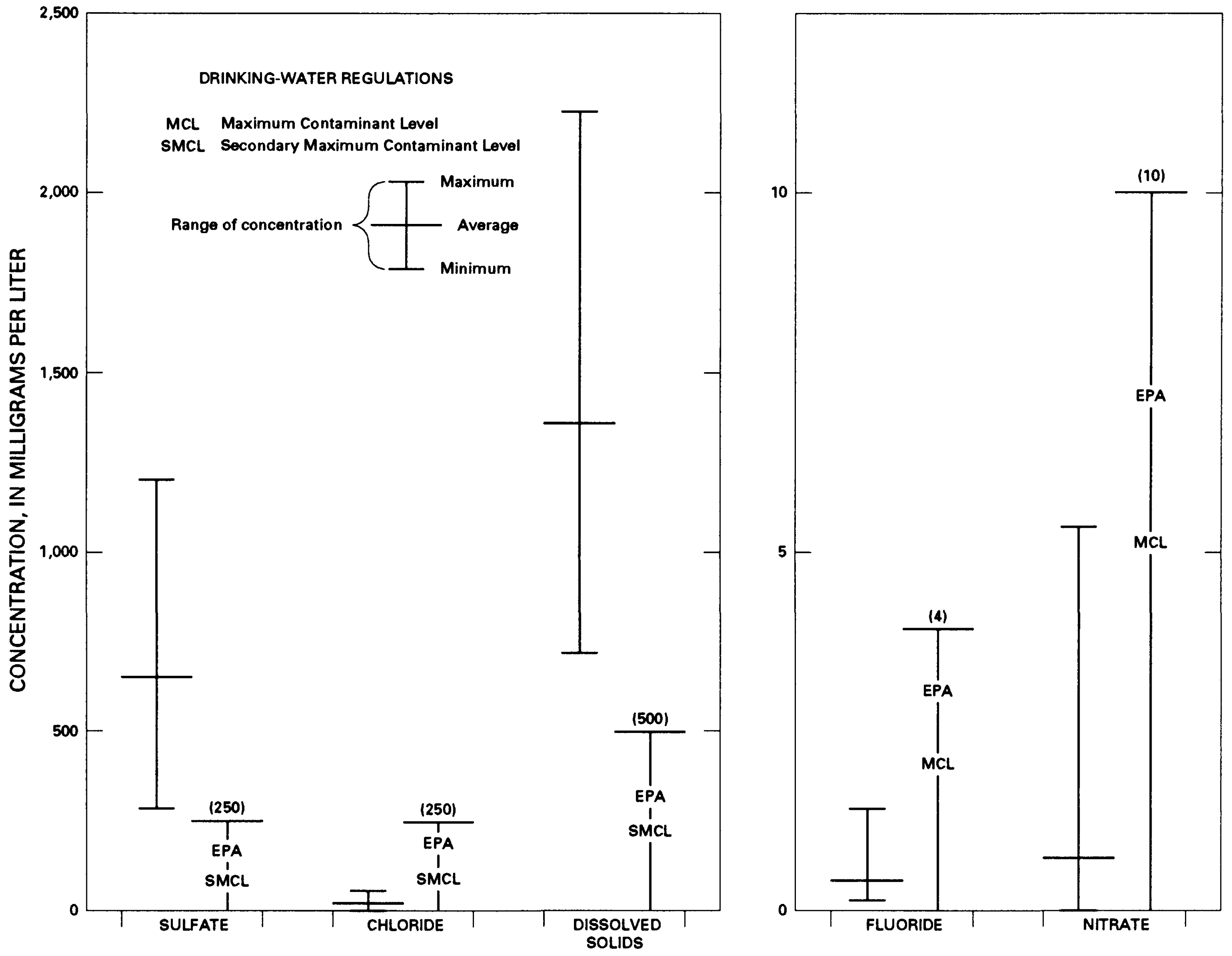


Figure 22.--Concentrations of dissolved solids and major ions in water samples from wells completed in and springs issuing from the Arapaho Ranch alluvial aquifer and corresponding contaminant levels in U.S. Environmental Protection Agency (EPA) Drinking-Water Regulations.

Table 7.--Trace-element and radiochemical analysis of a water sample from spring 1-A issuing from the Arapaho Ranch alluvial aquifer

[MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; μg/L, micrograms per liter; pCi/L, picocuries per liter; <, less than detection limit; --, no data]

Site number (fig. 19)	Date of sample	Arsenic, dissolved as As (μg/L)	Barium, dissolved as Ba (μg/L)	Beryllium, dissolved as Be (μg/L)	Cadmium, dissolved as Cd (μg/L)	Chromium, dissolved as Cr (μg/L)	Cobalt, dissolved as Co (μg/L)	Copper, dissolved as Cu (μg/L)	Iron, dissolved as Fe (μg/L)	Lead, dissolved as Pb (μg/L)
1-A	03-06-89	1	25	<0.5	<1	<5	<3	<10	89	<10
EPA MCL and SMCL		50 (MCL)	1,000 (MCL)	--	10 (MCL)	50 (MCL)	--	1,000 (SMCL)	300 (SMCL)	50 (MCL)

Site number (fig. 19)	Date of sample	Lithium, dissolved as Li (μg/L)	Manganese, dissolved as Mn (μg/L)	Mercury, dissolved as Hg (μg/L)	Molybdenum, dissolved as Mo (μg/L)	Nickel, dissolved as Ni (μg/L)	Selenium, dissolved as Se (μg/L)	Silver, dissolved as Ag (μg/L)	Strontium, dissolved as Sr (μg/L)	Vanadium, dissolved as V (μg/L)
1-A	03-06-89	44	120	<0.1	<10	<10	<1	<1.0	850	<6
EPA MCL and SMCL		--	50 (SMCL)	2 (MCL)	--	--	10 (MCL)	50 (MCL)	--	--

Site number (fig. 19)	Date of sample	Zinc, dissolved as Zn (μg/L)	Alpha, gross dissolved as U natural (μg/L)	Alpha, gross suspended total as U natural (μg/L)	Beta, gross dissolved as Cs-137 (pCi/L)	Beta, gross suspended total as Cs-137 (pCi/L)	Beta, gross dissolved as Sr/Y-90 (pCi/L)	Beta, gross suspended total as Sr/Y-90 (pCi/L)	Radium-226, dissolved, random method (pCi/L)	Uranium, natural dissolved as U (μg/L)
1-A	03-06-89	45	12	<0.4	5.5	0.9	3.6	0.9	0.04	8.2
EPA MCL and SMCL		5,000 (SMCL)	--	--	--	--	--	--	--	--

Bedrock Aquifers

The following geologic units were identified as containing potential bedrock aquifers in Owl Creek basin:

Absaroka Volcanic Supergroup (Wiggins, Tepee Trail, and Aycross Formations)
Cody Shale
Frontier Formation
Lower Cretaceous to Jurassic rocks
Tensleep Sandstone and Amsden Formation
Madison Limestone and Darby Formation
Upper Ordovician to Middle Cambrian rocks

Because of limited use of the bedrock aquifers for water supply in Owl Creek basin, few sampling sites were available. Four selected wells completed in and nine springs issuing from bedrock aquifers in the Owl Creek basin were inventoried and site visits were made. Existing analyses of samples from eight sites found in records and other published reports were compiled. Records for these sites in the bedrock aquifers are listed in table 8 and their locations are plotted on plate 1.

Previous studies of water quality in the bedrock aquifers of Owl Creek basin were limited to collection of samples from a few water wells completed in the Cody Shale and Frontier Formation, from oil-field production wells open to deeper geological units, and from geothermal wells. Berry and Littleton (1961, p. 44-45) reported a dissolved-solids concentration of 4,600 mg/L in a water sample from the Frontier Formation and 2,120 mg/L in a water sample from the Cody Shale. Cooley and Head (1982, p. 17) sampled one well in the Cody Shale that had a dissolved-solids concentration of 2,590 mg/L. Larson (1984, p. 32) found that in Hot Springs County (but not located in Owl Creek basin) the two wells with the smallest dissolved-solids concentrations, 420 and 479 mg/L, were from the Tensleep Sandstone. Spencer (1986, Appendix F) and Heasler (1985, p. 6) compiled data from various sources, primarily petroleum and geothermal wells. Information and results for each of the potential bedrock aquifers are discussed in the following sections.

Absaroka Volcanic Supergroup

On the basis of limited data, geologic units in the Absaroka Volcanic Supergroup seem to yield water containing small dissolved-solids concentrations. No data or previous investigations of the water resources of the Absaroka Volcanic Supergroup were found. Rocks from the Absaroka Volcanic Supergroup consist mainly of reworked volcaniclastic sediment, siltstone, sandstone, conglomerate, and breccia. Springs issue from some permeable zones in these units.

Water samples were collected from two springs originating from the Tepee Trail and Aycross Formations. The location of these two springs (sites 1-R and 2-R) are shown on plate 1, and the location descriptions are given in table 8. Both springs yielded water with small dissolved-solids concentrations when sampled in October 1989, 125 mg/L at spring 1-R and 143 mg/L at spring 2-R. Sulfate concentrations were less than 20 mg/L for

Table 8.--Records of wells completed in and springs issuing from bedrock aquifers

[Use of water: D, domestic; S, stock; N, none. Water level: Depth to water below land surface. Altitude: water level subtracted from surface altitude taken in the field from 1:24,000 topographic map. Remarks: W.Q. analysis, water-quality analysis is available in table 9; μS/cm, microsiemens per centimeter at 25 degrees Celsius; --, no data]

Site number (pl. 1)	Location (degrees, minutes, seconds)		Owner or tenant	Date of site visit	Well or spring	Well depth (feet)	Use of water	Water level		Remarks
	Latitude	Longitude						Depth to water (feet)	Altitude (feet above sea level)	
				Absaroka Volcanic Supergroup						
1-R	43 40 17	109 06 51	Wind River Indian Reservation	10-19-89	Barnes Spring	--	N	--	8,600	W.Q. analysis
2-R	43 41 30	109 04 19	Wind River Indian Reservation	10-18-89	Curry Creek Spring	--	N	--	8,950	W.Q. analysis
				Cody Shale						
3-R	43 41 38	108 28 03	Wind River Indian Reservation	09-17-76	Well	80	--	--	--	W.Q. analysis from Cooley and Head (1982)
4-R	43 42 39	108 12 46	Wind River Indian Reservation	07-22-46	Well	53	--	--	--	W.Q. analysis from Berry and Littleton (1961)
5-R	43 42 03	108 28 01	Fred Becker	03-07-89	Well	130	D	--	--	Site unsuitable for water-quality sampling
				Frontier Formation						
6-R	43 42 06	108 30 27	Arvin Thomas	01-05-89	Well	130	D	25.11	5,095	Well inaccessible for water-quality sampling
7-R	43 41 13	108 36 30	Wind River Indian Reservation	06-22-89	Blue Hill Spring	--	N	--	5,780	W.Q. analysis

Table 8.--Records of wells completed in and springs issuing from bedrock aquifers--Continued

Site number (pl. 1)	Location (degrees, minutes, seconds)		Owner or tenant	Date of site visit	Well or spring	Well depth (feet)	Use of water	Water level		Remarks
	Latitude	Longitude						Depth to water (feet)	Altitude (feet above sea level)	
				Frontier Formation--Continued						
8-R	43 41 29	108 33 32	Wind River Indian Reservation	06-21-89	Boghole Spring	--	N	--	5,390	Dry
9-R	43 42 29	108 32 10	Yonkee	03-07-89	Well	--	S	47.40	5,253	Specific conductance 4,900 μS/cm
10-R	43 42 27	108 32 00	Yonkee	03-07-89	Well	--	D	--	--	Specific conductance 4,700 μS/cm
11-R	43 41 02	108 35 34	Wind River Indian Reservation	06-21-89	Knight's Spring	--	N	--	5,740	W.Q. analysis
				Lower Cretaceous to Jurassic rocks						
12-R	43 40 30	108 34 55	Wind River Indian Reservation	06-21-89	Love Spring	--	N	--	5,860	W.Q. analysis; discharges from Mowry and Thermopolis Shales
13-R	43 35 22	108 27 23	Wind River Indian Reservation	06-22-89	Big Table Mountain Spring	--	N	--	5,980	Dry
14-R	43 38 28	108 34 16	Wind River Indian Reservation	06-21-89	Choke-cherry Spring	--	S	--	5,840	W.Q. analysis; discharges from Mowry and Thermopolis Shales
15-R	43 37 44	108 32 24	Wind River Indian Reservation	06-21-89	Iron Creek Spring	--	S	--	5,940	W.Q. analysis; discharges from Mowry and Thermopolis Shales

Table 8.--Records of wells completed in and springs issuing from bedrock aquifers--Continued

Site number (pl. 1)	Location (degrees, minutes, seconds)		Owner or tenant	Date of site visit	Well or spring	Well depth (feet)	Use of water	Water level		Remarks
	Latitude	Longitude						Depth to water (feet)	Altitude (feet above sea level)	
				Tensleep Sandstone and Amsden Formation						
16-R	43 41 36	108 18 33	--	--	Well	--	N	243-254	--	W.Q. analysis from Heasler (1985); completed in the Tensleep Sandstone
17-R	43 46 28	108 33 59	--	1964	Well[1]	--	--	--	--	Production W.Q. analysis from Spencer (1986); completed in the Tensleep Sandstone
18-R	43 46 06	108 34 33	--	1964	Well[1]	--	--	--	--	Production W.Q. analysis from Spencer (1986); completed in the Tensleep Sandstone
				Madison Limestone and Darby Formation						
19-R	43 46 17	108 34 02	--	1964	Well[1]	--	--	--	--	Production W.Q. analysis from Spencer (1986); completed in the Madison Limestone
20-R	43 46 12	108 34 38	--	1960	Well[1]	--	--	--	--	Production W.Q. analysis from Spencer (1986); completed in the Madison Limestone
				Upper Ordovician to Middle Cambrian rocks						
21-R	43 46 05	108 34 43	--	1970	Well[1]	--	--	--	--	Production W.Q. analysis from Spencer (1986); completed in the Bighorn Dolomite

---

[1] Oil-field production well.

both springs. The chemical analyses of the water samples for the springs are listed table 9. Modified Stiff diagrams (pl. 1) show the water to be of the sodium bicarbonate type. The concentrations in water samples collected from these two springs in October 1989 are less than the associated MCL or SMCL for sulfate (250 mg/L), chloride (250 mg/L), fluoride (4 mg/L), dissolved solids (500 mg/L), and nitrate (10 mg/L).

In October 1989, the discharge of each spring was about 1 gallon per minute. Individually these springs would not yield a discharge of 0.01 cubic foot per second. However, no well-yield data are available for the Absaroka Volcanic Supergroup in the Owl Creek basin.

Cody Shale

Permeable zones in the upper part of the Cody Shale sometimes are locally used to obtain water supplies. The upper part of the Cody Shale consists of discontinuous interbedded sandy shales and siltstones. In the lower part of the Cody Shale, marine shales are the predominate lithology. A water sample was collected from one well (well 5-R) completed in the Cody Shale as part of this study, for which only specific conductance was determined because of well-construction conditions. Water samples collected at two other wells (wells 3-R and 4-R) completed in Cody Shale were reported by Berry and Littleton (1961, p. 44), and by Cooley and Head (1982, p. 17). Records of those wells are listed in table 8, and their location is shown on plate 1.

Concentrations of selected constituents in water samples from wells were measured as follows: dissolved solids, 1,010 mg/L, well 3-R and 2,120 mg/L, well 4-R; sulfate, 550 mg/L, well 3-R and 1,120 mg/L, well 4-R; sodium, 240 mg/L, well 3-R; and sodium plus potassium, 674 mg/L, well 4-R (table 9). Modified Stiff diagrams for the two samples show the water to be sodium sulfate type (pl. 1). The concentrations in these two samples exceed SMCL for sulfates (250 mg/L) and dissolved solids (500 mg/L) by two to four times. Chloride concentrations are an order of magnitude less than the SMCL (250 mg/L), and fluoride concentrations are an order of magnitude less than the MCL (4 mg/L). Nitrate analyses were not available.

Frontier Formation

Water from the Frontier Formation is used in Owl Creek basin for stock and domestic purposes. The Frontier Formation consists predominantly of sandstone and sandy bentonitic shales. During this study, three wells completed in and three springs issuing from the Frontier Formation (sites 6-R through 11-R) were inventoried. Their locations are shown on plate 1. Records of the wells and springs are given in table 8. Well 6-R is completed in four water-bearing intervals of the Frontier Formation. This well was inaccessible for water sampling during site visits in January, March, June, and October 1989. The tenant, however, was interviewed, and she noted that the well was unsuitable as a drinking-water source and that water was being hauled to this site from Thermopolis. Specific conductance, temperature, and pH were measured at two other wells, 9-R and 10-R, which are completed in the Frontier Formation. The specific conductances were 4,900 μS/cm at 9-R and 4,700 μS/cm at 10-R (table 9). Because of well construction and operation, other analyses were not feasible at these two sites.

Table 9.--Discharge measurements and chemical analyses of water samples from wells completed in and springs issuing from bedrock aquifers

[gal/min, gallons per minute; μS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; --, no data; <, less than detection limit]

Site number (pl. 1)	Date of sample	Discharge, instantaneous (gal/min)	Specific conductance (μS/cm)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Alkalinity, total as $CaCO_3$ (mg/L)	Sulfate, dissolved (mg/L)	Chloride, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Dissolved solids, calculated, sum of constituents (mg/L)	Nitrate, dissolved as N (mg/L)
Absaroka Volcanic Supergroup													
1-R	10-19-89	1.5	180	9.6	1.0	30	0.3	72	17	0.8	0.2	125	0.25
2-R	10-18-89	1.2	202	7.6	2.4	37	.7	93	13	.8	.2	143	.31
Cody Shale													
3-R	09-17-76	--	1,430	59	23	240	3	^{1}222	550	15	.6	1,010	--
4-R	07-22-46	--	2,960	23	10	^{2}674	--	^{1}403	1,120	46	.6	2,120	--
5-R	03-07-89	--	1,330	--	--	--	--	--	--	--	--	--	--
Frontier Formation													
7-R	06-22-89	.57	2,340	180	70	270	8	181	1,200	3.2	1.5	1,860	<.10
9-R	03-07-89	--	4,900	--	--	--	--	--	--	--	--	--	--
10-R	03-07-89	--	4,700	--	--	--	--	--	--	--	--	--	--
11-R	06-21-89	1.2	2,350	180	69	290	11	306	1,100	6.3	1.7	1,860	<.10
Lower Cretaceous to Jurassic rocks													
12-R	06-21-89	.2	1,750	120	43	91	6	276	400	3.0	1.0	847	<.10
14-R	06-21-89	16	795	89	39	17	5	108	310	4.3	.9	542	<.10
15-R	06-21-89	4	1,070	130	56	24	6	167	440	4.6	1.0	778	.24

Table 9.--Discharge measurements and chemical analyses of water samples from wells completed in and springs issuing from bedrock aquifers--Continued

Site number (pl. 1)	Date of sample	Discharge, instantaneous (gal/min)	Specific conductance (µS/cm)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Alkalinity, total as $CaCO_3$ (mg/L)	Sulfate, dissolved (mg/L)	Chloride, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Dissolved solids, calculated, sum of constituents (mg/L)	Nitrate, dissolved as N (mg/L)
Tensleep Sandstone and Amsden Formation													
[3]16-R	--	--	--	280	61	253	43	--	646	287	3.0	--	--
[4]17-R	1964	--	4,082	507	96	[2]549	--	[1]4,400	1,047	414	--	3,321	--
[4]18-R	1964	--	5,000	484	131	[2]652	--	[1]1,040	1,340	580	--	3,759	--
Madison Limestone and Darby Formation													
[4]19-R	1964	--	3,226	361	102	[2]319	--	[1]878	593	480	--	2,287	--
[4]20-R	1960	--	--	484	124	[2]426	--	[1]1,173	936	500	--	3,047	--
Upper Ordovician to Middle Cambrian rocks													
[4]21-R	1970	--	4,210	616	122	284	160	[1]1,210	1,360	272	3.4	3,410	[5]0

[1] Bicarbonate plus carbonate.

[2] Sodium plus potassium.

[3] Data from Heasler (1985).

[4] Data from Spencer (1986).

[5] mg/L as nitrate.

Three springs discharging from the Frontier Formation were inventoried. Boghole Spring (8-R) was found to be dry during site visits in January and June 1989. In June 1989, the discharge of Blue Hill Spring (site 7-R) was 0.57 gallon per minute and of Knight's Spring (site 11-R) was 1.2 gallons per minute (table 9). Water samples were collected for analysis at both springs; the results are shown in table 9. The dissolved-solids concentration was 1,860 mg/L in water samples from both springs, calcium concentration was 180 mg/L at both springs, and sodium concentrations were 270 mg/L at site 7-R and 290 mg/L at site 11-R. Fluoride concentration was determined to be less than 2.0 mg/L at both springs. Modified Stiff diagrams (pl. 1) show the water as a sodium calcium sulfate type; sodium was the slightly more dominant cation.

Comparison of the analyses of water samples from springs 7-R and 11-R with SMCL or MCL indicate that the SMCL for dissolved solids (500 mg/L) is exceeded by more than three times, and the SMCL for sulfate (250 mg/L) is exceeded by more than four times. The chloride concentration, however, is less than the SMCL (250 mg/L), the fluoride concentration is less than its MCL (4 mg/L), and nitrate was undetected.

Lower Cretaceous to Jurassic Rocks

Prior to this study, little information has been available on the quality of water from aquifers in the Lower Cretaceous to Jurassic rocks in the basin. No wells completed in these rocks were found during the well record and literature search. The Lower Cretaceous to Jurassic rocks consist primarily of sandstone, siltstone, and shale with the presence of limestone, dolomite, gypsum, and marl increasing in the lower units. Four springs were inventoried for this study, and water samples were collected from the three springs (sites 12-R, 14-R, and 15-R) that were flowing on the date of sampling. The location of the springs is shown on plate 1, and records are listed in table 8.

Chemical analyses of the samples indicate that the quality of the water from the three springs in the Lower Cretaceous to Jurassic rocks is better than the quality of water from the overlying Cody Shale and Frontier Formation. The concentrations of dissolved solids in water samples from the three springs range from 542 to 847 mg/L, of calcium from 89 to 130 mg/L, and of sulfate from 310 to 440 mg/L. The chemical analyses are listed in table 9. Modified Stiff diagrams (pl. 1) show the water as a calcium sulfate type, in contrast to the chemical composition of the water in the overlying Frontier Formation, in which sodium is the dominant cation.

Comparison of the analyses of water samples from springs 12-R, 14-R, and 15-R with SMCL or MCL indicate that the SMCL (500 mg/L) is exceeded for dissolved-solids concentration by 42 to 347 mg/L, but by much less than in samples from the overlying aquifers. Likewise, sulfate concentrations exceed the SMCL (250 mg/L) by 60 to 190 mg/L. Chloride concentrations are less than the SMCL (250 mg/L), and fluoride concentrations are less than the MCL (4 mg/L). Nitrate was undetected at springs 12-R and 14-R and 0.24 mg/L at 15-R--all below the associated MCL of 10 mg/L.

Tensleep Sandstone and Amsden Formation

No water samples from the Tensleep Sandstone and Amsden Formation were collected during this study. The Tensleep Sandstone is predominantly fine- to medium-grained cemented sandstone that is massive and cross-bedded. The lower part of the Tensleep Sandstone contains discontinuous limestone and dolomite beds. The Amsden Formation consists of an upper limestone, a middle shale unit, and a lower sandstone. Three sample results were retrieved for wells 16-R, 17-R, and 18-R during the literature and records search. Locations of these samples are shown on plate 1, and the records of these wells are listed in table 8.

The dissolved-solids concentrations from water samples from the Tensleep Sandstone approach nearly 4,000 mg/L (Spencer, 1986, Appendix F; Heasler, 1985, p. 6). Chemical analyses of water samples are listed in table 9. Modified Stiff diagrams (pl. 1) of these two water samples show the water to be dominated about equally by the sodium and calcium cations; the water sample from well 17-R is dominated by the bicarbonate anion, while the water sample from well 18-R is dominated by the sulfate anion.

In all three samples, the sulfate and chloride concentrations exceed the SMCL (250 mg/L for each). The only fluoride concentration available (site 16-R) is 3.0 mg/L, below the MCL of 4.0 mg/L. Dissolved-solids concentrations for 17-R and 18-R exceeded the SMCL of 500 mg/L. No nitrate analysis was available.

The water-quality analyses of 17-R and 18-R are for water samples from oil-field production wells, and the analysis of 16-R is incomplete. Therefore, these data may not represent the potential of water in the Tensleep Sandstone to be used as drinking water. No water-quality data were available from the Amsden Formation. In the Bighorn Basin, the Tensleep Sandstone yields water containing dissolved-solids concentrations that range from 200 to 400 mg/L (Cooley, 1986, p. 50-53). In summarizing the analyses of 13 water samples collected from wells completed in the Tensleep Sandstone in Big Horn County, Earl Cassidy (U.S. Geological Survey, written commun., 1990) determined the average dissolved-solids concentration to be 708 mg/L and the range to be from 175 to 3,480 mg/L.

Madison Limestone and Darby Formation

No water samples were collected from the Madison Limestone and Darby Formation during this study. From well-record and literature searches data were recovered for two wells (wells 19-R and 20-R) producing oil-field production water from the Madison Limestone in the Hamilton Dome oil field. The location of these wells is given in table 8 and shown on plate 1. The Madison Limestone lithology can be divided into two parts. The upper part is predominantly limestone and dolomite with thin chert beds, often containing solution features. The lower part is a massive limestone and dolomite, which also contains thin chert beds. The Darby Formation consists of shale and siltstone underlain by dolomite and limestone.

The chemical analyses of water samples from these two wells indicate dissolved-solids concentrations in the range of 2,000 to 3,000 mg/L (Spencer, 1986, Appendix F). The chemical analyses are listed in table 9. Modified

Stiff diagrams (pl. 1) show the water to be dominated by the calcium cation with significant concentration of sodium present; the anions are about equally distributed among chloride, sulfate, and bicarbonate.

Concentrations of dissolved solids for wells 19-R and 20-R exceed the SMCL by four to six times, while the chloride concentrations exceed its SMCL by about two times and sulfate concentrations by about two to four times. While concentrations in these two water samples exceed the associated SMCL for sulfate (250 mg/L), chloride (250 mg/L), and dissolved solids (500 mg/L), they represent water from oil-field production wells at the Hamilton Dome oil field and may not be representative of overall water quality from the Madison Limestone. Neither fluoride nor nitrate analysis was available. Aquifers in the Madison Limestone and Bighorn Dolomite are used as drinking-water sources in the Bighorn Basin. Earl Cassidy (U.S. Geological Survey, written commun., 1990) determined the average dissolved-solids concentration of 21 water samples from the Madison Limestone and Bighorn Dolomite in the Bighorn Basin to be 844 mg/L and the range of dissolved-solids concentrations to be from 143 to 9,980 mg/L.

Upper Ordovician to Middle Cambrian Rocks

No water samples were obtained from the Upper Ordovician to Middle Cambrian rocks during this study. However, a chemical analysis of a water sample from one well (well 21-R) was found during the research of well records and literature for the area. This well is completed in the Bighorn Dolomite and is water from an oil-field production well at the Hamilton Dome oil field.

The Upper Ordovician to Middle Cambrian rocks include the Bighorn Dolomite, Gallatin Limestone, Gros Ventre Formation, and Flathead Sandstone. The Bighorn Dolomite consists of an upper part made up of massive and thin-bedded dolomite breccia or conglomerate near the base, and a lower part of massive dolomite and dolomitic limestone. The Gallatin Limestone consists of shale interbedded with pebbly limestone and sandstone. The Gros Ventre Formation consists of limestone interbedded with shale, limestone, and sandstone. The Flathead Sandstone consists of a sandstone with interbedded shale in the upper part. No samples were available from the Gallatin Limestone, the Gros Ventre Formation, or the Flathead Sandstone.

The well-record information for well 21-R is listed in table 8, and the well location is plotted on plate 1. The chemical analysis of water from the well (table 9) shows the dissolved-solids concentration to be 3,410 mg/L, with a calcium concentration of 616 mg/L (Spencer, 1986, Appendix F). A modified Stiff diagram shows the water type to be calcium sulfate.

The chloride concentration in the water sample from well 21-R exceeds the SMCL (250 mg/L) by 22 mg/L, dissolved solids (500 mg/L) by more than six times, and sulfate (250 mg/L) by more than five times. The fluoride concentration of 3.4 mg/L (Spencer, 1986, Appendix F) is less than the MCL of 4.0 mg/L. Nitrate was undetected. This is a water sample from an oil-field production well and might not be representative of water from the Bighorn Dolomite throughout Owl Creek basin. As previously discussed with regard to the Madison Limestone and Darby Formation, aquifers in the Bighorn Dolomite are used as drinking-water sources in the Bighorn Basin.

SUMMARY AND CONCLUSIONS

The quality of the water resources in the Owl Creek basin was assessed and compared to the maximum contaminant levels (MCL) and secondary maximum contaminant levels (SMCL) established by EPA Drinking-Water Regulations. Results of water-quality analyses from surface water and ground water in the area were compared to the associated MCL or SMCL for sulfate, chloride, fluoride, dissolved solids, and nitrate.

For assessing surface-water quality, the basin was separated into three segments on the basis of dissolved-solids concentration, water type, and relation of dissolved-solids concentration to specific conductance. Only water samples from the upper basin segment had concentrations below the associated MCL or SMCL for sulfate, chloride, fluoride, dissolved solids, and nitrate (as nitrogen). In the upper basin segment, average concentrations were sulfate 38 mg/L (SMCL = 250 mg/L), chloride 2.4 mg/L (SMCL = 250 mg/L), fluoride 0.1 mg/L (MCL = 4.0 mg/L), dissolved solids 171 mg/L (SMCL = 500 mg/L), and nitrate 0.30 mg/L (as nitrogen) (MCL = 10.0 mg/L). In the middle basin segment, the average dissolved-solids concentration exceeded the associated SMCL, while in the lower basin segment, the average and the range of both sulfate and dissolved-solids concentrations exceeded the SMCL. In the lower basin segment, one nitrate concentration exceeded the MCL.

Concentrations of selected dissolved constituents in the water samples from the Arapaho Ranch alluvial aquifer and selected bedrock aquifers were compared to the associated MCL or SMCL for sulfate, chloride, fluoride, dissolved solids, and nitrate (as nitrogen). The average dissolved-solids concentration in water from the Arapaho Ranch alluvial aquifer exceeded the SMCL by over two times, primarily because of large concentrations of sodium, alkalinity, and sulfate.

Few water-quality data were available for the bedrock aquifers. Of the bedrock aquifers evaluated in this study, only the Absaroka Volcanic Supergroup of Owl Creek basin was found to have concentrations at or below the associated MCL or SMCL. The two springs sampled in the Absaroka Volcanic Supergroup unit had concentrations of sulfate from 13 to 17 mg/L; chloride, 0.8 mg/L; fluoride, 0.2 mg/L; dissolved solids from 125 to 143 mg/L; and nitrate (as nitrogen) from 0.25 to 0.31 mg/L, all less than the associated MCL or SMCL.

Limited water-quality data available for the other potential aquifers--Cody Shale, Frontier Formation, Lower Cretaceous to Jurassic rocks, Tensleep Sandstone and Amsden Formation, Madison Limestone and Darby Formation, and Upper Ordovician to Middle Cambrian rocks--indicate that these units have concentrations of at least some constituents that exceed the MCL or SMCL being considered in this study. Water samples from the Lower Cretaceous to Jurassic rocks unit have lower concentrations of most constituents than samples from the overlying Frontier Formation and the underlying Tensleep Sandstone and Amsden Formation. Concentrations in water samples from the water-yielding units of the Lower Cretaceous to Jurassic rocks unit slightly exceed the MCL or SMCL. If substantial areal variability exists, this unit potentially may contain water with concentrations equal to or less than the associated MCL or SMCL for the constituents considered in this study.

The water samples available to evaluate the Tensleep Sandstone and Amsden Formation, Madison Limestone and Darby Formation, and Upper Ordovician to Middle Cambrian rocks came primarily from oil-field production wells and may not be representative of these units as a whole. On the basis of the limited water-quality analyses available, no firm comparisons can be made of concentrations of dissolved constituents in water from the Tensleep Sandstone and Amsden Formation, Madison Limestone and Darby Formation, and Upper Ordovician to Middle Cambrian rocks to the associated MCL or SMCL. The water quality of these units will not be known until more wells are drilled, and water is sampled over more varied geologic conditions.

In summary, chemical analyses of water samples from two water sources in the Owl Creek basin indicate concentrations consistently at or below the associated MCL or SMCL for sulfate, chloride, fluoride, dissolved solids, and nitrate (as nitrogen). Those two sources are surface water in the upper basin segment of Owl Creek and ground water from the Absaroka Volcanic Supergroup.

SELECTED REFERENCES

Berry, D.W., and Littleton, R.T., 1961, Geology and ground-water resources of the Owl Creek area, Hot Springs County, Wyoming: U.S. Geological Survey Water-Supply Paper 1519, 58 p.

Blackwelder, E., 1913, Origin of the Bighorn Dolomite of Wyoming: Geological Society of America Bulletin, v. 24, p. 607-624.

Blundell, J.S., 1988, Structural trends of Precambrian rocks, Sheep Ridge Anticline, western Owl Creek Mountains, Wyoming: Laramie, University of Wyoming unpublished Master's thesis, 81 p.

Condie, K.C., 1976, The Wyoming archean province of the western United States, in Windley, B.F. (ed.), 1976, The early history of the earth: New York, John Wiley, p. 499-510.

Cooley, M.E., 1986, Artesian pressures and water quality in Paleozoic aquifers in the Ten Sleep area of the Bighorn Basin, north-central Wyoming: U.S. Geological Survey Water-Supply Paper 2289, 54 p.

Cooley, M.E., and Head, W.J., 1982, Hydrogeologic features of the alluvial deposits in the Owl Creek valley, Bighorn Basin, Wyoming: U.S. Geological Survey Water-Resources Investigations Report 82-4007, 33 p.

Dalton, N.H., 1906, Geology of the Bighorn Mountains: U.S. Geological Survey Professional Paper 51, 129 p.

Fallat, Collin, Schoene, Lois, Lundberg, Billie, Sandene, Paulette, and Porter, Fred, 1987, Wyoming land inventory: Wyoming Department of Agriculture and the Geological Survey of Wyoming, Map Series 24, 1 sheet, scale 1:500,000.

Heasler, H.P., 1985, An analysis of the geothermal potential near Western Area Power Administration's facility in Thermopolis, Wyoming: Laramie, University of Wyoming, 42 p.

Helsel, D.R., and Cohn, T.A., 1988, Estimation of descriptive statistics for multiply censored water quality data: Water Resources Research, v. 24, no. 12, p. 1997-2004.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water: U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Larson, L.R., 1984, Ground-water quality in Wyoming: U.S. Geological Survey Water-Resources Investigations Report 84-4034, 71 p.

Love, J.D., 1939, Geology along the southern margin of the Absaroka Range, Wyoming: Geological Society of America Special Papers, no. 20, 134 p.

Love, J.D., Christiansen, A.C., Brown, T.M., Earle, J.L., compilers, 1979, Preliminary geologic map of the Thermopolis 1° x 2° quadrangle, central Wyoming: U.S. Geological Survey Open-File Report 79-962, scale 1:100,000.

Love, J.D., and Christiansen, A.C., 1985, Geologic map of Wyoming: U.S. Geological Survey, 3 sheets, scale 1:500,000.

Martner, B.E., 1986, Wyoming climate atlas: Lincoln, University of Nebraska Press, 432 p.

McGauhey, P.H., 1968, Engineering management of water quality: New York, McGraw-Hill, 295 p.

Miller, W.R., and Drever, J.I., 1977, Chemical weathering and related controls on surface water chemistry in the Absaroka Mountains, Wyoming: Geological Society of America Bulletin, v. 88, p. 286-290.

Peterson, D.A., 1988, Streamflow characteristics of the Missouri River basin, Wyoming, through 1984: U.S. Geological Survey Water-Resources Investigations Report 87-4018, 263 p.

Peterson, D.A., Mora, K.L., Lowry, M.E., Rankl, J.G., Wilson, J.F., Jr., Lowham, H.W., and Ringen, B.H., 1987, Hydrology of area 51, northern Great Plains and Rocky Mountain coal provinces, Wyoming and Montana: U.S. Geological Survey Water-Resources Investigations Open-File Report 84-734, 73 p.

Spencer, S.A., 1986, Groundwater movement in the Paleozoic rocks and impact of petroleum production on water levels in the southwestern Bighorn Basin, Wyoming: Laramie, University of Wyoming unpublished Master's thesis, 116 p.

Sundell, K.A., 1980, The Geology of the North Fork of Owl Creek area, Absaroka Range, Hot Springs County, Wyoming: Laramie, University of Wyoming unpublished Master's thesis, 150 p.

Sundell, K.A., Shive, P.N., Eaton, J.G., 1984, Measured sections, magnetic polarity and biostratigraphy of the Eocene Wiggins, Tepee Trail and Aycross Formations within the southeastern Absaroka Range, Wyoming: Wyoming Geological Association Earth Science Bulletin, v. 17, p. 1-6, 46-48.

Thomas, H.D., 1949, The geological history and geological structure of Wyoming: Wyoming Geological Survey Bulletin 42, 28 p.

U.S. Environmental Protection Agency, 1990, Drinking water regulations under the Safe Drinking Water Act: Criteria and Standards Division, Office of Drinking Water, U.S. Environmental Protection Agency, Safe Drinking Water Act Fact Sheet, May 1990, 43 p.

(page 59 follows)

SUPPLEMENTAL DATA

Table 10.--Discharge measurements and chemical analyses of water samples from the upper basin segment

[ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; --, no data; <, less than]

Site number (fig. 2)	Date of sample	Discharge, instantaneous (ft^3/s)	Specific conductance (µS/cm)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Bicarbonate, HCO_3 (mg/L)	Carbonate, CO_3 (mg/L)	Sulfate, dissolved (mg/L)	Chloride, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Dissolved solids, calculated, sum of constituents (mg/L)	Nitrate, dissolved as N (mg/L)
						South Fork Owl Creek and tributaries								
1-B	10-18-89	9.9	132	8.8	2.1	11	0.8	[1]47	--	7.0	0.5	0.1	77	<0.10
	9-21-87	--	103	9.2	2.7	9.9	.8	67	<2	<10	<1.0	< .1	90	--
	9-22-86	7.8	130	8.8	2.0	14	2	65	0	4.2	<1.0	< .2	98	< .20
	8-05-85	8.7	--	7.0	4.0	13	.9	64	0	4.0	5.0	.1	98	.06
	8-24-84	14	--	11	1.0	14	0	54	0	8.0	4.0	.1	92	.15
2-B	9-21-87	5.2	88	3.7	3.2	9.5	.9	55	<2	<10	<1.0	< .1	72	--
	9-22-86	2.6	110	5.2	1.6	8.3	3	50	0	2.8	<1.0	< .2	71	< .20
	8-24-84	5.6	--	7.0	0	16	0	49	0	6.0	6.0	.1	84	.20
3-B	9-21-87	.27	170	9.3	3.5	23	2	92	<2	12	<1.0	< .1	141	--
	9-22-86	.50	225	5.6	3.4	22	5	95	0	19	<1.0	< .2	152	< .20
	8-24-84	1.0	180	13	4.0	27	1	98	0	20	6.0	.2	169	.17
4-B	9-22-87	--	--	9.6	4.0	28	.9	95	<2	20	<1.0	< .2	156	--
	9-22-86	12	145	20	3.0	5.5	2	79	0	5.2	1.2	< .2	117	< .20
	8-05-85	11	120	11	5.0	10	.9	76	0	5.0	5.0	.1	113	.39
	8-25-82	22	120	12	1.9	9.6	.4	63	0	8.2	3.0	.1	100	1.2
	7-16-79	--	--	5.2	1.7	21	1	54	0	20	1.1	--	103	< .23
	6-21-79	--	--	4.6	1.8	110	1	44	0	200	11	--	374	--
	7-12-77	7.4	150	15	5.1	12	1	79	0	12	1.0	.1	99	.02
	6-30-77	14	120	19	5.0	16	1	64	--	9.2	1.7	.1	105	.10
	6-16-77	23	87	9.0	3.6	11	1	49	--	9.9	1.0	.1	78	.17
	6-06-77	50	58	7.9	2.8	6.0	.9	33	0	4.1	.7	.1	52	.19
	5-12-77	44	100	7.5	2.3	6.6	.9	35	0	8.1	1.6	.1	59	.25

Table 10.--Discharge measurements and chemical analyses of water samples from the upper basin segment--Continued

Site number (fig. 2)	Date of sample	Discharge, instantaneous (ft^3/s)	Specific conductance (µS/cm)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Bicarbonate, HCO_3 (mg/L)	Carbonate, CO_3 (mg/L)	Sulfate, dissolved (mg/L)	Chloride, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Dissolved solids, calculated, sum of constituents (mg/L)	Nitrate, dissolved as N (mg/L)
						North Fork Owl Creek and tributaries								
18-B	7-19-79	--	--	3.4	2.7	36	3	63	0	40	3.0	--	151	< .23
19-B	9-22-87	--	183	5.2	3.2	38	1	98	<2	29	<1.0	< .2	174	--
	9-22-86	1.0	200	13	2.3	20	2	79	0	17	<1.0	< .2	135	< .20
	9-06-83	2.4	150	1.2	1.6	30	2	86	0	17	2.1	.3	140	0
	8-25-82	3.4	150	10	1.9	28	2	73	2	20	4.0	.2	143	1.1
20-B	9-22-87	--	241	18	4.3	31	2	130	<2	25	<1.0	.2	211	--
	9-22-86	1.0	325	32	2.5	31	2	150	0	26	1.0	.2	244	< .20
	8-06-85	1.3	290	20	7.0	38	2	140	5	34	4.0	.3	248	.15
	8-25-82	1.9	265	26	2.5	39	2	130	7	33	4.0	.2	242	1.6
	7-12-79	--	--	16	4.7	23	2	110	0	15	2.3	--	173	--
22	7-17-88	--	267	--	--	--	--	--	--	--	--	--	--	--
23-B	10-02-89	2.7	203	15	3.9	24	2	[1]71	--	30	.8	.2	142	< .10
	9-22-87	--	255	26	6.3	23	2	130	<2	39	<1.0	.2	167	--
	9-22-86	2.6	300	24	2.1	29	2	140	0	20	1.0	.2	214	< .20
	8-25-82	1.9	250	24	3.1	29	2	110	10	14	5.0	.2	201	1.6
	7-12-79	--	--	150	27	170	5	200	0	650	6.8	--	1,190	< .23
24-M	11-04-76	--	348	--	--	--	--	--	--	--	--	--	--	--
	9-14-76	--	305	18	4.7	43	.1	120	15	31	1.4	.4	213	.05
	5-20-76	--	150	--	--	--	--	--	--	--	--	--	--	--

---

[1] Total alkalinity determined on site, in milligrams per liter as $CaCO_3$.

Table 11.--Discharge measurements and chemical analyses of water samples from the middle basin segment

[ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; --, no data; <, less than]

Site number (fig. 2)	Date of sample	Discharge, instantaneous (ft^3/s)	Specific conductance (µS/cm)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Bicarbonate, HCO_3 (mg/L)	Carbonate, CO_3 (mg/L)	Sulfate, dissolved (mg/L)	Chloride, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Dissolved solids, calculated, sum of constituents (mg/L)	Nitrate, dissolved as N (mg/L)
							South Fork Owl Creek							
10-B	9-22-87	--	246	27	7.0	14	1	92	<2	49	<1.0	<0.1	204	--
	9-23-86	3.0	790	88	16	23	3	130	0	220	1.2	< .2	575	<0.20
	8-05-85	5.6	270	32	8.0	14	1	93	0	61	4.0	.1	181	.16
11-M	9-14-76	--	302	--	--	--	--	--	--	--	--	--	--	--
	5-20-76	--	120	--	--	--	--	--	--	--	--	--	--	--
13-M	9-14-76	--	456	--	--	--	--	--	--	--	--	--	--	--
	5-20-76	--	210	--	--	--	--	--	--	--	--	--	--	--
15-M	7-17-88	--	255	--	--	--	--	--	--	--	--	--	--	--
	9-14-76	--	519	--	--	--	--	--	--	--	--	--	--	--
	5-20-76	--	330	--	--	--	--	--	--	--	--	--	--	--
16-B	9-22-87	--	398	32	19	55	2	130	<2	180	<1.0	< .2	411	--
	9-23-86	8.6	860	70	25	32	5	220	0	170	1.8	< .2	517	< .20
	8-05-85	2.1	680	83	29	48	3	190	19	210	8.0	.2	590	.19
	8-26-82	11	470	73	8.8	29	2	180	5	120	4.0	.1	423	1.7
17-M	9-14-76	--	547	61	19	27	2	180	0	140	2.3	.3	357	.09
							North Fork Owl Creek							
27-B	9-23-86	.50	900	70	28	45	2	240	0	190	2.4	< .2	579	< .20
	8-07-85	--	1,800	148	49	240	5	240	24	780	19	.4	1,505	.10
	6-21-79	--	--	50	24	108	4	220	0	250	13	--	673	--

Table 11.--Discharge measurements and chemical analyses of water samples from the middle basin segment--Continued

Site number (fig. 2)	Date of sample	Discharge, instantaneous (ft^3/s)	Specific conductance (µS/cm)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Bicarbonate, HCO_3 (mg/L)	Carbonate, CO_3 (mg/L)	Sulfate, dissolved (mg/L)	Chloride, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Dissolved solids, calculated, sum of constituents (mg/L)	Nitrate, dissolved as N (mg/L)
							Main stem Owl Creek							
28-M	7-17-88	--	720	--	--	--	--	--	--	--	--	--	--	--
	9-14-76	--	592	--	--	--	--	--	--	--	--	--	--	--
	5-20-76	--	340	--	--	--	--	--	--	--	--	--	--	--
30-B	10-02-89	6.2	560	60	19	33	3	[1]143	--	160	2.4	.1	383	< .1
	9-23-86	6.1	900	87	31	52	3	240	2	230	2.4	.2	643	< .20
	8-07-85	< .50	990	96	46	89	3	300	10	320	9.0	.3	876	.55

[1] Total alkalinity determined on site, in milligrams per liter as $CaCO_3$.

Table 12.--Discharge measurements and chemical analyses of water samples from the lower basin segment

[ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; --, no data; <, less than]

Site number (fig. 2)	Date of sample	Discharge, instantaneous (ft^3/s)	Specific conductance (µS/cm)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Bicarbonate, HCO_3 (mg/L)	Carbonate, CO_3 (mg/L)	Sulfate, dissolved (mg/L)	Chloride, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Dissolved solids, calculated, sum of constituents (mg/L)	Nitrate, dissolved as N (mg/L)
Mud Creek														
34-M	5-20-76	--	1,950	--	--	--	--	--	--	--	--	--	--	--
Main stem Owl Creek														
31-M	9-14-76	--	1,080	--	--	--	--	--	--	--	--	--	--	--
	5-20-76	--	650	--	--	--	--	--	--	--	--	--	--	--
32-M	9-14-76	--	1,780	--	--	--	--	--	--	--	--	--	--	--
	5-20-76	--	780	--	--	--	--	--	--	--	--	--	--	--
36-B	9-23-86	2.4	3,250	150	13	373	11	340	0	1,400	18	0.4	2,390	<0.20
	8-07-85	< .5	4,400	321	200	611	7	410	10	2,400	42	.4	4,000	.16
	9-07-83	4.9	4,200	304	240	567	8	460	0	2,500	40	.5	4,070	.09
37-M	11-04-76	--	2,190	170	91	250	4	320	0	1,100	14	.8	1,810	.09
39-M	11-04-76	--	2,240	--	--	--	--	--	--	--	--	--	--	--
40-M	11-04-76	--	2,250	--	--	--	--	--	--	--	--	--	--	--
41-M	11-04-76	--	2,290	--	--	--	--	--	--	--	--	--	--	--
	9-04-76	--	--	180	91	250	4	340	0	1,100	13	.8	1,820	.11
42-M	11-04-76	--	2,320	--	--	--	--	--	--	--	--	--	--	--

Table 12.--Discharge measurements and chemical analyses of water samples from the lower basin segment--Continued

Site number (fig. 2)	Date of sample	Discharge, instantaneous (ft^3/s)	Specific conductance (µS/cm)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Bicarbonate, HCO_3 (mg/L)	Carbonate, CO_3 (mg/L)	Sulfate, dissolved (mg/L)	Chloride, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Dissolved solids, calculated, sum of constituents (mg/L)	Nitrate, dissolved as N (mg/L)
							Main stem Owl Creek--Continued							
43-M	11-04-76	--	--	160	92	320	5	340	0	1,100	14	.8	1,880	.07
44-M	11-04-76	--	2,300	--	--	--	--	--	--	--	--	--	--	--
45-B	9-23-86	10.4	1,600	71	46	169	5	290	0	480	13	.4	1,040	< .20
	8-07-85	4.9	1,930	160	73	230	5	280	0	890	23	.5	1,680	22