GROUND-WATER CONTRIBUTION TO THE SALINITY OF THE UPPER COLORADO RIVER BASIN

By James W. Warner, Frederick J. Heimes, and Robert F. Middelburg

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METRIC CONVERSIONS

The inch-pound units used in this report may be converted to SI metric units by use of the following conversion factors:

Multiply inch-pound unit	By	To obtain metric unit
inch (in.)	25.40	millimeter
inch (in.)	2.540	centimeter
inch per year (in/yr)	2.540	centimeter per annum
foot (ft)	0.3048	meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
acre	4.047×10^{-3}	square kilometer
acre-foot (acre-ft)	1.233×10^{-3}	cubic hectometer
acre-foot per year (acre-ft/yr)	1.233×10^{-3}	cubic hectometer per annum
acre-foot per square mile (acre-ft/mi^2)	0.476	cubic hectometer per square kilometer
ton	0.9072	metric ton
ton per year (ton/yr)	0.9072	metric ton per annum

Water quality term used in this report is:
microsiemens per centimeter at 25° Celsius (μS/cm).

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. NGVD of 1929 is referred to as sea level in this report.

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ABSTRACT

A reconnaissance level study was conducted to estimate the ground-water contribution to the salinity of streamflow in the Upper Colorado River Basin. Salt-load estimates were derived from a mass balance using measurements of the quantity and quality of base flow. Ground-water inflow was considered to represent the bulk of the streamflow during the winter months of low flow.

A one-time sampling of the base flow of streams in the Upper Colorado River Basin was conducted in December 1977 and January 1978. Data on discharge and specific conductance and samples for chemical analysis were collected at 142 sites in the Upper Colorado River Basin upstream from the confluence of the Colorado and Green Rivers. Available data were used for other areas in the Upper Colorado River Basin. In some of these areas, data were obtained from local and regional studies. Elsewhere, data were obtained from records from streamflow-gaging stations operated by the U.S. Geological Survey.

The study area was divided into two major regions; the Green River basin (referred to here as the Green River region) and the Colorado River basin upstream from the confluence with the Green River (referred to here as the Colorado River region). These two regions were divided into nine subregions. The annual salt load contributed to streams by ground water in these subregions ranged from 30 to 93 percent. In general, the salt load contributed by ground water was larger in the Colorado River region than in the Green River region. The Colorado River region had an overall average ground-water salt-load contribution of 69 percent of the total compared with 38 percent for the Green River region.

The estimated total base-flow salt load of the Upper Colorado River Basin above the confluence of the Colorado and Green Rivers was 3.8 million tons per year. This is about 55 percent of the total annual salt load. Diffuse ground-water discharge to streams accounts for most of the base-flow salt load. However, significant increases in the salt load along fairly short reaches in certain locations result from the surface-water solution of salts in the Upper Cretaceous shales, mostly the Mancos Shale; ground-water discharge from highly saline formations, such as the Paradox Member of the Hermosa Formation of Pennsylvanian age; and from point sources, such as the highly saline mineral springs near Glenwood Springs, Colo., and Dotsero, Colo.

INTRODUCTION

The Upper Colorado River Basin upstream from the confluence of the Colorado and Green Rivers produces about 7 million tons of salt annually (Bentley and others, 1978). The salinity (as measured by dissolved-solids concentration) of the Colorado River and numerous tributary streams is a major concern to agricultural, industrial, and public water-supply users. The average annual salinity of the Colorado River has almost doubled during this century (Iorns and others, 1965). Although predictions are that salinity concentrations may again double by the year 2000, some recent studies have indicated a reduction in the increasing annual trend of the salinity concentrations (Kircher and others, 1984). The salinity of the Colorado River results in substantial economic damages to water users both in the United States and Mexico.

The BLM (U.S. Bureau of Land Management) is responsible for regulating all land and water use on Federal (public) lands under its jurisdiction and for controlling the salinity of streamflow in the Colorado River basin. Public lands administered by BLM comprise about 44 percent of the 62 million acres of land in the Upper Colorado River Basin within Colorado, Utah, and Wyoming. BLM is conducting a study on the feasibility of salinity control in the Upper Colorado River Basin. The objective of the BLM study is to identify ambient salinity levels, to identify salt transport mechanisms on public lands, and to formulate ways to control or reduce salt contribution. BLM needs to be able to delineate surface- and ground-water salt contributions from all sources.

BLM entered into a cooperative agreement with the U.S. Geological Survey to study the salt-load contribution from ground-water sources in the Upper Colorado River Basin in Colorado and adjacent parts of Wyoming and Utah upstream from the confluence of the Green and Colorado Rivers (fig. 1). The area of intensive study is that part of western Colorado drained by the Colorado, Gunnison, Dolores, White, Yampa, and Green Rivers. This study was limited to ground water and other sources that are defined as those not resulting from man's activities. Data for this study were collected only within Colorado. Salt-load contributions from ground water were determined from available data for the parts of the study area in Utah and Wyoming.

HYDROGEOLOGIC SYSTEM

Precipitation and Streamflow

The Upper Colorado River Basin consists of both low, arid watersheds that yield little streamflow and of high, mountainous watersheds that contribute large amounts of streamflow. Average annual precipitation ranges from less than 8 in. in some of the low, arid areas to more than 50 in. in the high, mountainous areas. Most of the streams in low, arid watersheds are ephemeral or intermittent. Runoff in these streams is generally derived from high intensity spring and summer thunderstorms. Because of the meager precipitation, little recharge reaches the water table in these areas and little or no base flow discharges to these ephermeral streams. The high,

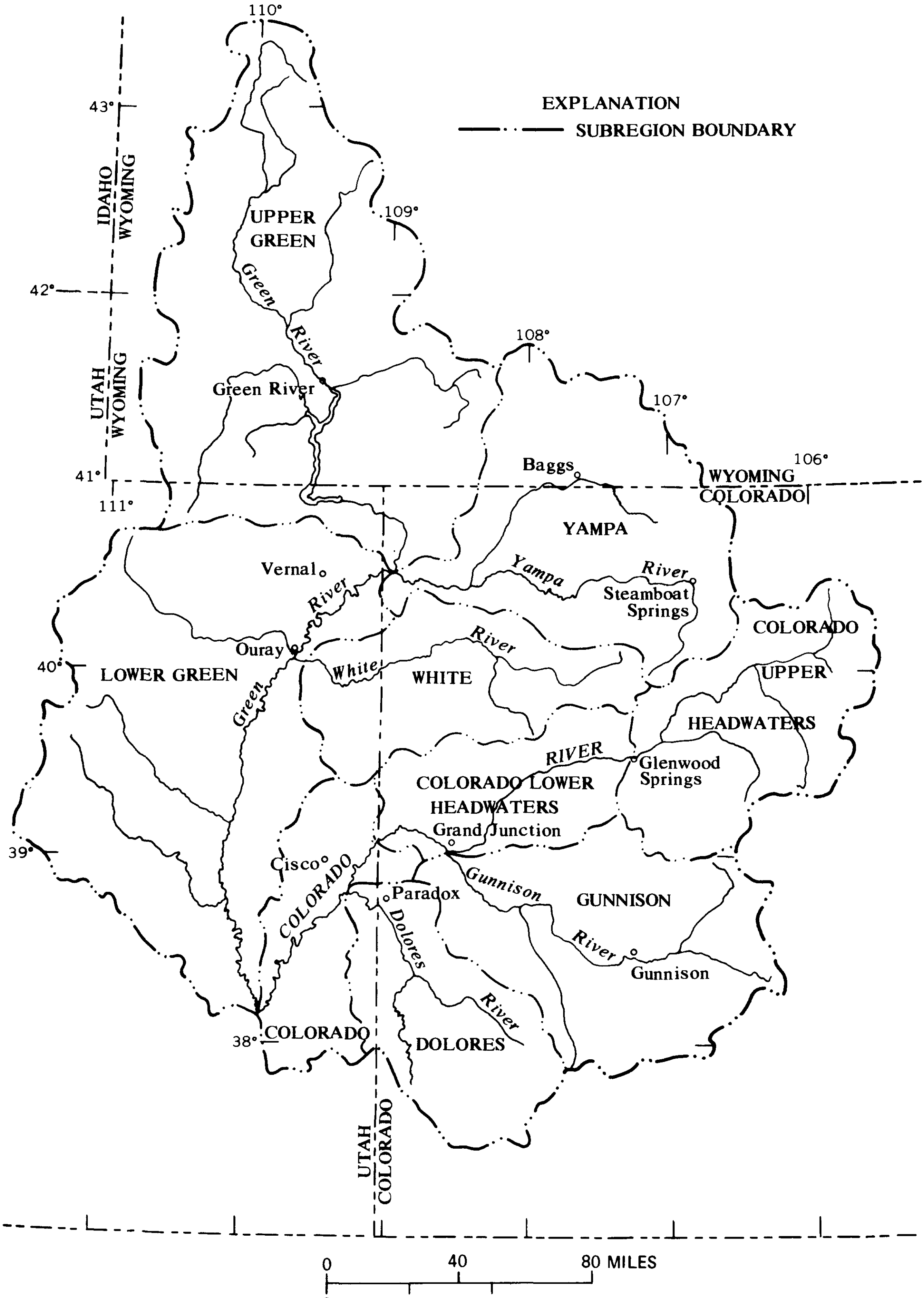


Figure 1.--Location of study area and major subregions.

mountainous watersheds produce the major perennial streams. Much runoff occurs in the spring and early summer and is caused primarily by melting of the mountain snowpack. The base-flow period is generally from late summer to early spring of the following year. During this time, streamflow is relatively uniform and consists primarily of ground-water discharge.

Geology and Ground Water

Hydrogeologic conditions in the Upper Colorado River Basin are complex. The geology of the area is the principal factor controlling the occurrence, movement, and the chemical quality of ground water. Rocks underlying the study area are mainly consolidated sedimentary deposits. Igneous and metamorphic rocks comprise most of the mountainous regions. Unconsolidated alluvial deposits border and underlie most of the major streams. Ground water occurs in all of the geologic formations in the study area. However, because of the diverse hydraulic properties and mineral composition of these formations, the quantity and chemical quality of the ground water varies considerably.

The source of almost all of the ground water in the study area is precipitation that falls within the study area. The principal areas of ground-water recharge are in the higher elevation areas. Normally, ground water moves only a short distance from the area of recharge to points of discharge. However, in some instances, ground water may move relatively long distances from the area of recharge to points of discharge. For instance, water in the Leadville Limestone of Mississippian age (table 1) moves many miles from the area of recharge to points of discharge. Most ground water is discharged to streams as diffuse nonpoint sources, discharged into the atmosphere by phreatophytes, or discharged from springs.

The rate and quantity of ground-water movement primarily depend on the hydraulic conductivity of the geologic formation and the hydraulic gradient. In general, alluvial deposits, other unconsolidated sedimentary deposits, and limestones have the largest hydraulic conductivities and are capable of transmitting water readily. Shales have the least hydraulic conductivity and are capable of transmitting water only slowly. Water movement in many consolidated sedimentary rocks and igneous and metamorphic rocks is primarily through fractures. The density and the degree of fracturing of the rocks determine the amount of water that can be stored and the rate at which it can be transmitted. Extensively fractured rocks are capable of transmitting water considerable distances.

The availability of recharge to the formation also determines the amount of water that can be transmitted. A permeable formation in an arid region where potential recharge is slight would transmit small quantities of water. Also, a relatively impermeable formation in an area of significant precipitation might still transmit only small quantities of water.

Chemical quality of ground water is dependent on the mineral composition and hydraulic properties of the aquifer, such as surface area of contact, porosity, and rate of water movement. Because water moves slowly through most

Table 1.--*Summary of the geologic formations and groups in the Upper Colorado River Basin and their physical, hydrologic, and chemical characteristics*

[mg/L, milligrams per liter]

Erathem	System	Series	Formation and group	Hydrogeologic unit[1]	Physical characteristics	Hydrologic characteristics	Chemical characteristics
CENOZOIC	QUATERNARY	Holocene and Pleistocene	Alluvial, landslide, eolian, and talus deposits	1	Primarily unconsolidated alluvial deposits. Some landslide, eolian, and talus deposits. Deposits are largely clay, sand, silt, and gravel derived from stream erosion of the bedrock formations. Generally only a few tens of feet thick.	Probably more wells tap the alluvial deposits than any other rocks. Yields as much as several hundred gallons per minute are common. Most of the alluvial deposits have close hydraulic connection with adjacent streams. The water level in the deposits is generally within a few feet of the elevation of the water in the stream. Recharge occurs primarily as seepage losses from streams or from ground-water discharge from the underlying bedrock aquifers. Discharge from the deposits is mostly to streams and from ground-water pumpage. Because most stream valleys in the basin are narrow, water withdrawn from wells offsets the flow in the stream within a few days.	The dissolved-solids concentration of water from the alluvial deposits varies over a wide range, depending on the source of the parent material, the salinity level of the stream, and the amount of irrigation. Most of the alluvial deposits yield water of only 200 to 300 mg/L dissolved-solids concentration. The alluvium is generally permeable and most of the highly soluble minerals have been leached. Where the river-channel deposits have been eroded from saline formations such as marine shales, the dissolved-solids concentration of the ground water from deposits may be as great as 1,000 mg/L.
	TERTIARY	Undifferentiated	Volcanic rocks	2	Dense, black, resistant basalt in lava flows having a thickness as much as 900 feet. Also includes ash-flow tuffs, breccias, and volcanic conglomerate.	No data available.	No data available.
		Miocene	Browns Park Formation	3	These formations consist primarily of sandstone and semiconsolidated conglomerate. The formations may be as much as 2,000 feet thick but normally overlie older formations in relatively thin beds 200 to 500 feet thick.	Favorably located wells which tap these formations might yield as much as 300 gallons per minute. Recharge is from direct infiltration of precipitation and snowmelt. Discharge is mainly to streams. In some areas, discharge is to underlying bedrock aquifers such as in the Yampa River basin where these formations overlie the upturned Mesaverde Group, but increasing amounts of ground-water pumpage in some areas also may be an important source of discharge.	The dissolved-solids concentration of water from the rocks is less than 1,000 mg/L and typically less than 500 mg/L.
			North Park Formation				
		Oligocene or Eocene	Duchesne River Formation				

Table 1.--*Summary of the geologic formations and groups in the Upper Colorado River Basin and their physical, hydrologic, and chemical characteristics*--Continued

Erathem	System	Series	Formation and group	Hydrogeologic unit[1]	Physical characteristics	Hydrologic characteristics	Chemical characteristics
CENOZOIC	TERTIARY	Eocene	Uinta Formation; Bridger Formation; Green River Formation	4	The Uinta and Bridger Formations consist primarily of claystone and some sandstone and minor amounts of shale. The Green River Formation consists primarily of marlstone, shale, oil shale, claystone, siltstone, and sandstone. These formations together generally are 500 to 2,000 feet thick.	The hydraulic conductivity of these formations is fairly small, and most wells yield less than 15 gallons per minute. Well yields as much as 200 gallons per minute have been reported. Recharge is from infiltration of precipitation and snowmelt. These formations are exposed for the most part in the low-lying arid regions of the basin where the potential for recharge is small.	The Green River Formation contains considerable amounts of very soluble minerals, the most extensive being nahcolite ($NaHCO_3$) and halite ($NaCl$). The normal range of dissolved-solids concentrations of ground water from the rocks is from 1,000 to 3,000 mg/L but locally may be much higher.
CENOZOIC	TERTIARY	Eocene; Paleocene	Wasatch Formation; Battle Springs Formation; Fort Union Formation	5	The Wasatch Formation underlies the Green River Formation and is normally about 1,000 to 4,000 feet thick. The Wasatch consists chiefly of sandy mudstone, calcareous mudstone, and carbonaceous shale. In the deeper parts of the basin the Wasatch Formation may be as much as 7,000 feet thick. The Fort Union Formation consists of approximately 1,500 feet of interbedded carbonaceous shale, sandstone, and coal beds.	The Wasatch Formation consists primarily of fluvial sediments and has generally a better water quality than the lacustrine Green River Formation. The Wasatch is a good source of water, and well yields of as much as 700 gallons per minute are reported. Recharge is from direct infiltration of precipitation and snowmelt. Recharge also may be from discharge from underlying bedrock aquifers. Recharge is small to this formation because of the meager precipitation that occurs in most areas where the formation is exposed. Discharge is small and is due primarily to evapotranspiration and discharge to streams. Because the Wasatch normally is very thick, there are tremendous quantities of ground water in storage in this formation.	The Green River and Wasatch sequence contributes significant salt loads to streamflow in the Upper Colorado River Basin. The dissolved-solids concentration of ground water normally is in the range of 500 to 1,500 mg/L but locally may be much greater.

Table 1.--*Summary of the geologic formations and groups in the Upper Colorado River Basin and their physical, hydrologic, and chemical characteristics*--Continued

Erathem	System	Series	Formation and group	Hydrogeologic unit[1]	Physical characteristics	Hydrologic characteristics	Chemical characteristics
MESOZOIC	CRETACEOUS	Upper Cretaceous	Mesaverde Group (Williams Fork and Iles Formation)	6	The Mesaverde Group in most places is about 1,500 to 5,000 feet thick and underlies the Wasatch Formation or Fort Union Formation and overlies the Mancos Shale. In some areas the Mesaverde is overlain by the Lance Formation and by the Lewis Shale, which may be as much as 2,000 feet thick. The Mesaverde Group consists of interbedded marine shale, sandstone, and coal.	The Mesaverde Group is one of the more productive aquifers in the basin. The fractured sandstone, and in some cases the coals, act as aquifers. Many wells tapping the Mesaverde yield 200 to 300 gallons per minute, and yields of 600 to 1,000 gallons per minute are possible for favorably-located wells. Recharge occurs for infiltration of precipitation and snowmelt in the outcrop areas. Discharge is to streams and also may occur upward to the Wasatch Formation.	The dissolved-solids concentration of the ground water ranges from about 300 to 2,500 mg/L but is normally less than 1,000 mg/L.

Table 1.--*Summary of the geologic formations and groups in the Upper Colorado River Basin and their physical, hydrologic, and chemical characteristics*--Continued

Erathem	System	Series	Formation and group	Hydrogeologic unit[1]	Physical characteristics	Hydrologic characteristics	Chemical characteristics
MESOZOIC	CRETACEOUS	Upper Cretaceous	Lance Formation Lewis Shale Mancos Shale Pierre Shale Niobrara Formation Benton Shale Baxter Shale Cody Shale Steele Shale Frontier Sandstone Mowry Shale Thermopolis Shale	7	The Mancos Shale consists primarily of an approximated 5,000-foot thick homogenous dark-grey marine shale. It also contains several discontinuous sandstone layers and limestone beds.	The porosity of shales is very great, and the Mancos Shale contains large quantities of ground water. These shales also have a very small permeability which effectively prevents the subsurface movement of water. Well yields are usually less than 5 gallons per minute. Small amounts of recharge occur in the outcrop areas for direct infiltration of precipitation and snowmelt. Because of the low permeability of the Mancos Shale, ground-water discharge to streams is small.	Generally the ground water is highly mineralized and has a dissolved-solids concentration of normally greater than 1,000 to 2,500 mg/L. Locally used for stock watering. The Upper Cretaceous marine shales probably have the greatest effect on salinity or streamflow in the basin than any other rocks. The Mancos Shale is highly erodable, and surface runoff from the Mancos Shale usually contains moderately saline levels of dissolved solids. In some areas stream-channel erosion along outcrops of the Mancos Shale can cause significant increases in the salinity of the stream. Where soils derived from the Mancos Shale are being extensively irrigated, such as the Grand Valley near Grand Junction, the irrigation-return flow to the stream can significantly add to the salt level.
		Lower Cretaceous	Dakota Sandstone Burro Canyon Formation or Cedar Mountain Formation Cloverly Formation	8	The Dakota Sandstone is a persistent sandstone unit that extends over much of the basin. Contains lenses of siltstone and shale and has a maximum thickness of 300 feet.	Well yields are less than 50 gallons per minute, but it is an important source of water for domestic and stock use.	The Dakota Sandstone contains large amounts of oil and gas. Oil-field waters from the Dakota have a dissolved-solids concentration of from 5,000 to 30,000 mg/L. In the outcrop areas, water from the Dakota generally has a dissolved-solids concentration of from 500 to 3,000 mg/L. Water from the deeper parts of the Dakota generally has a dissolved-solids concentration of more than 3,000 mg/L.

Table 1.--*Summary of the geologic formations and groups in the Upper Colorado River Basin and their physical, hydrologic, and chemical characteristics*--Continued

Era-them	System	Series	Formation and group	Hydro-geo-logic unit[1]	Physical characteristics	Hydrologic characteristics	Chemical characteristics
PALEOZOIC AND MESOZOIC	JURASSIC		Morrison Formation	9	Contained in these formations are several very good sandstone aquifers, the Entrada Sandstone and the Glen Canyon Group, which contain the Navajo and Wingate Sandstones. The Entrada Sandstone is from 50 to 500 feet thick and the Glen Canyon as thick as 750 feet in Colorado and up to 2,000 feet thick in Utah. The other Jurassic and Triassic formations typically consist of shale, siltstone, and interbedded lenses of sandstone.	The Entrada, Navajo, and Wingate Sandstones are excellent sources of ground water for domestic and stock use. Well yields of 100 gallons per minute are not uncommon, and well yields of 350 gallons per minute are reported. The Morrison and Summerville Formations are used locally for stock watering and have well yields of only a few gallons per minute.	The chemical quality of water in the Entrada Sandstone and Glen Canyon Group is generally good to excellent, and the dissolved-solids concentration is generally less than 500 mg/L. Below depths of 2,000 feet the dissolved-solids concentration increases to about 1,000 mg/L. Data are sketchy for other formations. Water from the Morrison and Summerville Formations has dissolved-solids concentrations of greater than 1,000 mg/L. The Moenkopi Formation contains local beds of gypsum. Data from one well indicate water from the Chinle and Moenkopi Formations is more highly mineralized than that from the Morrison and Summerville Formations.
			Summerville Formation				
			Curtis Formation				
			Entrada Sandstone				
	TRIASSIC		Glen Canyon Group				
			Navajo Sandstone				
			Wingate Sandstone				
			Chinle Formation				
			Dolores Formation				
			Moenkopi Formation				
	PERMIAN		State Bridge Formation				

Table 1.--*Summary of the geologic formations and groups in the Upper Colorado River Basin and their physical, hydrologic, and chemical characteristics*--Continued

Erathem	System	Series	Formation and group	Hydrogeologic unit[1]	Physical characteristics	Hydrologic characteristics	Chemical characteristics
	PERMIAN		Park City Formation	10	Most of the Permian and Pennsylvanian Formations consist chiefly of sandstone, conglomerate, shale, siltstone, and mudstone. An exception is the Paradox Member of the Hermosa Formation of Pennsylvanian age, which consists of salt, gypsum, anhydrite, black shale, sandstone, and limestone. The formation underlies large areas of western Colorado and eastern Utah and is known to be as much as 11,000 feet thick. The few surface exposures of the Paradox occur mostly in Paradox Valley in the Dolores River basin and in a few other scattered areas in southwest Colorado and southeast Utah. The Mississippian rocks consist of the Leadville and Madison Limestones. The Leadville crops out along the Colorado River near Glenwood Springs, in the upper reaches of the Eagle, Roaring Fork, and Gunnison River basins, and in Dinosaur National Monument. It consists largely of dense, impermeable limestone and dolomite. The pre-Mississippian rocks consist of dolomite, limestone, quartzite, sandstone, conglomerate, shale, and chert. The deposits are 2,500 feet thick in places.	Little is known about most of these formations. Some are fairly productive aquifers, such as the Weber Sandstone, Morgan Formation, and the Leadville and Madison Limestones. Water in the Leadville Limestone occurs primarily in fractures, caverns, and solution cavities. In several areas in the basin these caverns and solution cavities produce very large yields. The largest reported yields are from wells that tap the Leadville Limestone near McCoy, Colo. One well had a reported yield of 3,400 gallons per minute of water and a dissolved-solids concentration of about 3,000 mg/L.	Several formations have significant effects on salinity of streamflow in the basin. The Leadville Limestone is a possible source of the Glenwood and Dotsero mineral hot springs. These springs have a total discharge of about 17 cubic feet per second and a dissolved-solids concentration of about 30,000 mg/L. Ground water from the Paradox Member of the Hermosa Formation has a dissolved-solids concentration of more than 50,000 mg/L. Ground water from the Paradox is discharged chiefly along fault zones to shallow alluvial aquifers where it eventually is discharged into streams. The Eagle Valley Evaporite is suspected to be a major source of the salt in the Eagle River.
	PERMIAN / PENNSYLVANIAN		Cutler Formation				
	PENNSYLVANIAN		Rico Formation; Hermosa Formation; Maroon Formation; Weber Formation; Morgan Formation				
	PENNSYLVANIAN		Minturn Formation; Eagle Valley Evaporite				
	MISSISSIPPIAN		Leadville and Madison Limestones				
	PRE-MISSISSIPPIAN		Sedimentary rocks				

Table 1.--*Summary of the geologic formations and groups in the Upper Colorado River Basin and their physical, hydrologic, and chemical characteristics*--Continued

Erathem	System	Series	Formation and group	Hydrogeologic unit[1]	Physical characteristics	Hydrologic characteristics	Chemical characteristics
PRECAMBRIAN			Igneous and metamorphic rocks	11	The Precambrian rocks are igneous and metamorphic rocks which are mainly granite, schist, and gneiss. These rocks make up the high mountain ranges which form the headwaters of most of the major streams.	The rocks are nearly impermeable, except where fractured or weathered. Yields of 1 to 5 gallons per minute are common, but yields greater than 10 gallons per minute are rare. The potential recharge to these rocks are very large since they are exposed mostly in high, mountainous areas that receive great amounts of precipitation. Discharge is to streams.	The water generally has a very small dissolved-solids concentration, less than 100 mg/L. Discharge to streams from these rocks is large, and they contribute a large salt load.

[1]Numbers in this column correspond to the numbered areas on figure 2.

aquifers, the water has time to dissolve soluble mineral constituents. Most igneous and metamorphic rocks are composed primarily of silicate minerals, such as quartz, that are not readily soluble. Water from these rocks generally contains few dissolved solids. Some sedimentary rocks in the basin, primarily shales of marine or lacustrine origin, contain large amounts of readily soluble minerals. The abundance of soluble minerals, in conjunction with the small permeability of these shales, results in large concentrations of dissolved solids in the water. Coarse-textured sedimentary rocks, such as sandstones, contain fewer soluble minerals and have relatively large permeabilities. Therefore, water in these rocks generally contains fewer dissolved solids than water in shales.

A list of the major hydrogeologic units in the Upper Colorado River Basin is given in table 1. The potential that each geologic formation has for contributing saline waters is presented in table 1. The general locations of the major hydrogeologic units within the Upper Colorado River Basin is shown in figure 2.

Precambrian rocks underlie the headwaters of most of the major streams in the study area. The dissolved-solids concentration of this water is very small, generally less than 100 mg/L (milligrams per liter), but because the volume of water coming in contact with the Precambrian rocks is so great, they contribute most of the salt to streams in the study area. Some formations, such as the Paradox Member of the Hermosa Formation of Pennsylvanian age, discharge very small quantities of extremely saline ground water and produce large salt loads downstream. The sources of these mineralized waters are black shale containing interbedded anhydrite and dolomite and beds of potash salt and halite. The sedimentary formations that contribute most significantly to the salinity level (dissolved-solids concentration) of the Colorado River are Upper Cretaceous marine shales in hydrogeologic unit 7 (table 1). These shales normally discharge small quantities of moderately saline ground water. Soluble salts dissolved from the marine shales by overland runoff and by eroding streams that cross extensive outcrops of the shales cause the largest increase in salinity.

DATA COLLECTION AND METHOD OF ANALYSIS

Discharge and water-quality data were collected at 142 sites in the Upper Colorado River Basin upstream from the confluence of the Colorado and Green Rivers in December 1977 and January 1978. The data-collection sites were located so that the salt load from individual aquifer groups could be identified, thus allowing the results of this study to be more readily transferred to other areas. A one-time sampling program was conducted. The assumption was made that the ground-water discharge from aquifers remains nearly constant during the year and also from year to year. That is, the variation of the ground-water discharge to streams during the year is assumed to be minimal, but no calculation was made to verify this. The year-to-year variation of ground-water discharge to the streams was evaluated by comparing base-flow hydrographs from streamflow-gaging stations operated by the U.S.

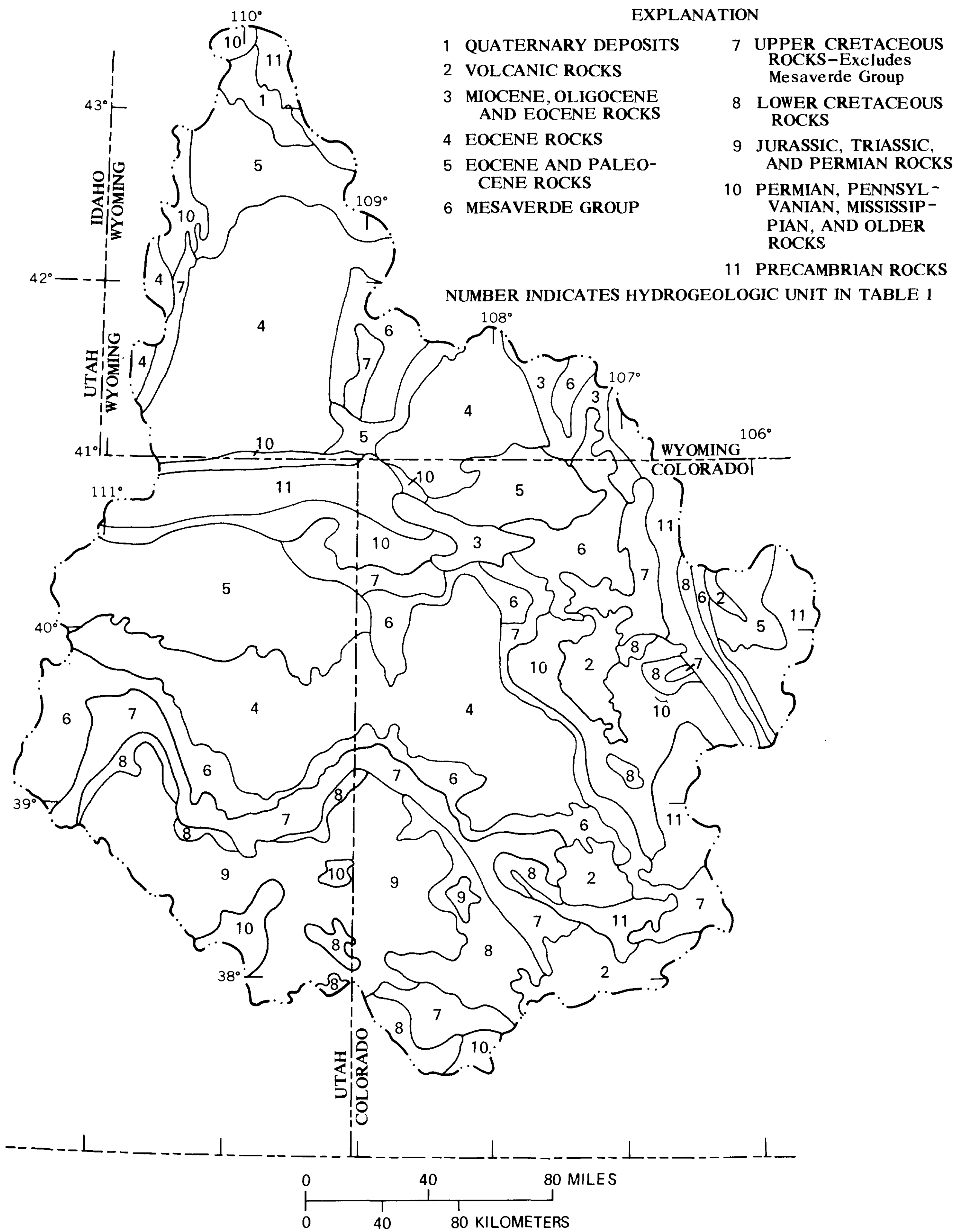


Figure 2.--Major hydrogeologic units in the Upper Colorado River Basin (structural features not shown).

Geological Survey with data collected during this study. In general, the variation was no more than 20 percent. The data were collected in this study following an abnormally dry year; thus, the calculated salinity contributed to the streamflow by ground water may be smaller than the long-term average.

Although the assumption is made that the ground-water discharge is from natural sources in several areas, such as the Grand Valley, lower Gunnison, and lower Green River reaches, there may be an unquantified amount of irrigation return flow adding to the base-flow salinity load.

Specific conductance and streamflow measurements were made at all sites, and samples were collected for chemical analyses at 78 of the sites. The chemical analyses are presented in table 11 (see Supplemental Information at back of report). A regression analysis of specific conductance versus laboratory-determined dissolved-solids concentration was performed for each basin in which chemical-analysis samples were taken. The results of this regression analysis were used to calculate the dissolved solids at sites where only specific conductance was measured.

Available data were used for all other parts of the study area. In some areas, data were available from local and regional studies of the Upper Colorado River Basin (Iorns and others, 1964, 1965; Price and Arnow, 1974). In the Yampa River basin, extensive measurements of the quantity and quality of streamflow were made as part of a 3-year river-basin assessment (Steele and others, 1979). Extensive streamflow and quality of water data also were available for the upper Green River (Lowham and others, 1976). Discharge and water-quality data obtained at streamflow-gaging stations operated by the U.S. Geological Survey also were used.

Calculation of the salt load transported in base flow was made using a mass-balance equation. The salt load was determined by:

$$S=ACQ \tag{1}$$

where: S = salt load, in tons per year;
A = conversion factor = 0.985;
C = dissolved-solids concentration of base flow of the stream, in milligrams per liter; and
Q = base-flow discharge of the stream, in cubic feet per second.

The computed base-flow salt loads are based on the assumption that point measurements at various sites are representative of the mean ground-water contribution to the total annual salt load. Adjustments for reservoir effects were made to computed base-flow salt loads in some of the subbasins.

The reservoir adjustments for both discharge and salt load were computed by setting the outflow discharge and salt load equal to the measured inflow and salt load.

The adjusted dissolved-solids concentration is calculated using equation 1 rewritten as:

$$C = \frac{S}{AQ} \qquad (2)$$

where: C = the equivalent dissolved-solids concentration, in mg/L;
S = the adjusted salt load, in tons per year;
Q = the adjusted discharge, in cubic feet per second; and
A = the conversion factor.

Calculations of the salt-load contributions to streams by major springs were made by directly measuring the spring discharges and indirectly by evaluating the chemical quality of the water. In June 1979, data were collected for 14 mineral springs (see table 12, Supplemental Information at back of report). In some places (Glenwood Springs, Colo., Dotsero, Colo., and Steamboat Springs, Colo.) the springs flow directly into the stream channel and direct measurement of the discharge is not possible. In these situations, measurements of the salinity of the river upstream and downstream from the springs, the salinity of the spring itself, and a measurement of the discharge of the river were used to compute the approximate spring discharge to the river. It was assumed that the river discharge was much greater than the spring discharge, and, therefore, the streamflow upstream and downstream from the spring discharge was assumed constant. Using this assumption, the spring discharge was approximated by the equation:

$$Qs = \frac{QrCrb - QrCra}{Cs} \qquad (3)$$

where: Qs = spring discharge, in cubic feet per second;
Qr = river discharge, in cubic feet per second;
Crb = salinity of river downstream from the spring discharge, in milligrams per liter;
Cra = salinity of river upstream from the spring discharge, in milligrams per liter; and
Cs = salinity of spring, in milligrams per liter.

GROUND-WATER SALINITY CONTRIBUTION

The study area was divided into two major regions: the region drained by the Colorado River and tributaries upstream from the confluence with the Green River and the region drained by the Green River and its tributaries. Each of these two major regions was divided into subregions (fig. 1). These subregions correspond closely with the subregions of the Upper Colorado River Basin shown on the hydrologic unit maps of Colorado (U.S. Geological Survey, 1976), Wyoming (U.S. Geological Survey, 1977), and Utah (U.S. Geological Survey, 1975).

Colorado River Region

Most of the flow of the Colorado River originates on the western slope of the Rocky Mountains in Colorado. Areas in Utah contribute only minor amounts of the flow. The drainage area of the Colorado River in western Colorado and eastern Utah is about 27,000 mi^2. The average flow of the Colorado River upstream from the confluence with the Green River is about 4.6 million acre-ft/yr (Bentley and others, 1978). The mean annual dissolved-solids concentration is about 610 mg/L, and the mean annual salt load is about 3.8 million tons.

The Colorado River region was divided into five subregions: the Colorado, Colorado lower headwaters, Colorado upper headwaters, Gunnison, and Dolores (fig. 1).

Colorado Upper Headwaters Subregion

The drainage area of the Colorado upper headwaters subregion is about 6,000 mi^2 (fig. 1). The average annual precipitation above 9,000 ft altitude ranges from about 25 to about 50 in. and is mostly snow. Below 9,000 ft, the average annual precipitation ranges from about 12 to about 25 in.

Measurements of specific conductance and stream discharge at 52 sites were made in the subregion (fig. 3). At 23 of the sites, samples were collected for chemical analysis. A linear regression (fig. 4) of specific conductance measured at 22 of the sites versus dissolved-solids concentration determined in the laboratory was used to calculate the dissolved-solids concentration at the 29 nonmeasured sites. One site (site 52, table 2) Colorado River below Glenwood Springs, Colo., was not included in the regression because localized impacts alter its ability to be representative of conditions farther up in the subregion. Values of discharge, specific conductance, dissolved-solids concentration, and salt loads for each site are presented in table 2. For purposes of discussion, the Colorado upper headwaters subregion was divided into four subbasins: Blue River, Eagle River, Roaring Fork River, and the main-stem Colorado River upper headwaters (fig. 3).

Blue River

The Blue River subbasin includes the drainage area of the Blue River and tributaries upstream from the confluence with the Colorado River. The Blue River has its headwaters in a steep mountainous area south of the main stem of the Colorado River. Igneous and metamorphic rocks are exposed at higher elevations in the subbasin. At lower elevations, Upper Cretaceous shales in hydrogeologic unit 7 (table 1) crop out principally along the eastern side of the Blue River, and the Dakota Sandstone of Early Cretaceous age crops out principally along the west side of the river. Downstream from Dillon Reservoir, alluvial deposits occur along the main channel of the Blue River.

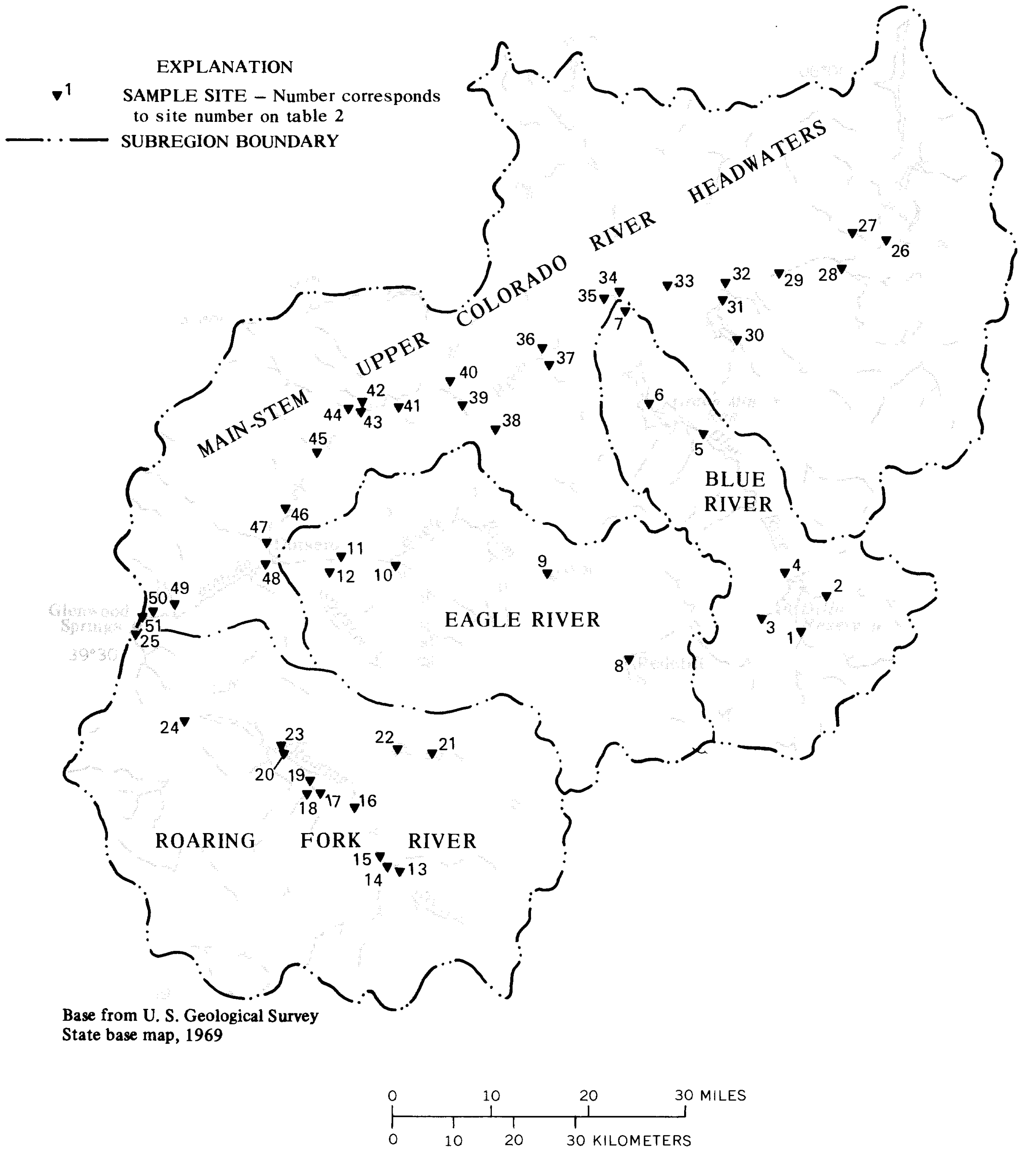


Figure 3.--Major subbasins and location of sampling sites: Colorado upper headwaters subregion.

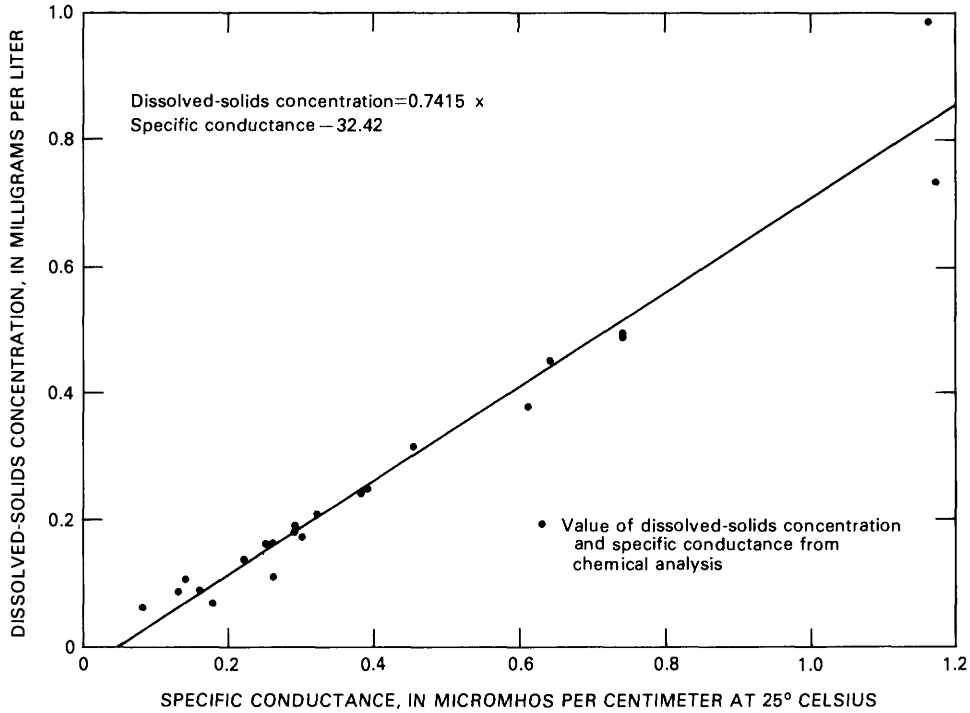


Figure 4.--Linear regression of specific conductance versus dissolved-solids concentration: Colorado upper headwaters subregion.

Flow in the Blue River is regulated by Dillon and Green Mountain Reservoirs. The capacity of Dillon Reservoir is about 254,000 acre-ft, which is approximately equal to the average annual flow of the Blue River. Dillon Reservoir stores water for transmountain diversions. Green Mountain Reservoir is 20 mi downstream from Dillon Reservoir and has a capacity of about 147,000 acre-ft. Green Mountain Reservoir stores replacement water for the Colorado-Big Thompson diversion project located near Grand Lake and for irrigation in the Colorado River basin. The mean annual dissolved-solids concentration of the Blue River is less than 100 mg/L.

Seven sampling sites were selected in this subbasin (figs. 3 and 5; table 2). The estimated dissolved-solids concentration at the sites upstream from Dillon Reservoir (sites 1-3) ranged from 42 to 90 mg/L, reflecting the predominance of igneous rocks in this area. Dissolved-solids concentrations at the sites downstream from Dillon Reservoir (sites 4-6) were affected by Dillon and Green Mountain Reservoirs, and estimated values ranged from 68 to about 120 mg/L. The dissolved-solids concentrations at sites 4 through 6 were adjusted to avoid the effects of storage in the reservoirs. The adjusted dissolved-solids concentration ranged from 63 to 65 mg/L. The relatively small concentrations of dissolved solids at all sites in the Blue River subbasin are a reflection of the relatively insoluble igneous rocks underlying

Table 2.--*Discharge, specific conductance, dissolved-solids concentration, and salt loads: Colorado upper headwaters subregion*

[ft^3/s, cubic feet per second; μS/cm, microsiemens per centimeter at 25° Celsius; mg/L, milligrams per liter; tons/yr, tons per year; dashes indicate not applicable]

Site	Site description	U.S. Geological Survey station number	Latitude	Longitude	Sample date	Discharge (ft^3/s) Measured	Discharge (ft^3/s) Adjusted	Specific conductance (μS/cm)	Dissolved solids (mg/L) Measured	Dissolved solids (mg/L) Calculated	Dissolved solids (mg/L) Adjusted	Salt load (tons/yr) Measured	Salt load (tons/yr) Adjusted
					BLUE RIVER SUBBASIN								
1	Blue River near Dillon, Colo.	09046600	39°32'55"	106°02'19"	12-6-77	17	---	100	---	42	---	700	---
2	Snake River near Montezuma, Colo.	09047500	39°36'20"	105°56'33"	12-6-77	12	---	140	---	71	---	840	---
3	Tenmile Creek below North Tenmile Creek, at Frisco, Colo.	09050100	39°34'37"	106°06'33"	12-6-77	10	---	165	---	90	---	890	---
4	Blue River below Dillon, Colo.	09050700	39°37'32"	106°03'57"	12-6-77	143	39	140	---	71	63	10,000	2,400
5	Blue River above Green Mountain Reservoir, Colo.	None	39°52'04"	106°16'24"	12-6-77	280	176	135	---	68	65	18,800	11,200
6	Blue River below Green Mountain Reservoir, Colo.	09057500	39°52'49"	106°20'00"	12-6-77	149	176	200	---	120	65	17,600	11,200
7	Blue River near mouth.	None	40°01'55"	106°23'08"	12-8-77	161	188	260	111	---	60	17,600	11,200
					EAGLE RIVER SUBBASIN								
8	Eagle River at Redcliff, Colo.	09063000	39°30'34"	106°22'00"	12-7-77	---	---	235	---	140	---	---	---
9	Eagle River near Avon, Colo.	None	39°37'55"	106°31'18"	12-7-77	83	---	290	190	---	---	15,600	---
10	Brush Creek near Eagle, Colo.	None	39°38'47"	106°50'12"	12-7-77	45	---	1,090	---	780	---	34,600	---
11	Eagle River above Gypsum, Colo.	None	39°38'58"	106°57'11"	12-7-77	164	---	1,170	731	---	---	118,000	---
12	Gypsum Creek near mouth near Gypsum, Colo.	None	39°38'42"	106°57'14"	12-7-77	34	---	740	494	---	---	16,800	---
					ROARING FORK RIVER SUBBASIN								
13	Roaring Fork River near Aspen, Colo.	09073400	39°10'48"	106°48'05"	12-6-77	23	---	80	62	---	---	1,400	---
14	Castle Creek near mouth.	None	39°11'34"	106°49'57"	12-6-77	30	---	510	---	350	---	10,300	---
15	Maroon Creek above Aspen Highlands.	None	39°12'02"	106°50'53"	12-6-77	35	---	540	---	370	---	12,800	---
16	Roaring Fork River near Woody Creek.	None	39°17'40"	106°55'07"	12-6-77	105	---	455	316	---	---	32,700	---
17	Snowmass Creek above Capitol Creek.	None	39°18'41"	106°58'45"	12-6-77	15	---	390	---	260	---	3,800	---
18	Capitol Creek near mouth.	None	39°18'40"	106°58'49"	12-6-77	10	---	760	---	530	---	5,200	---
19	Snowmass Creek near mouth.	None	39°19'44"	106°59'06"	12-6-77	26	---	640	---	440	---	11,300	---
20	Roaring Fork River near Basalt, Colo.	None	39°21'17"	107°01'18"	12-7-77	130	---	470	---	320	---	41,000	---

Table 2.--*Discharge, specific conductance, dissolved-solids concentration, and salt loads: Colorado upper headwaters subregion*--Continued

Site	Site description	U.S. Geological Survey station number	Latitude	Longitude	Sample date	Discharge (ft^3/s)		Specific conductance (µS/cm)	Dissolved solids (mg/L)			Salt load (tons/yr)	
						Measured	Adjusted		Measured	Calculated	Adjusted	Measured	Adjusted
	ROARING FORK RIVER SUBBASIN--Continued												
21	Fryingpan River at Meredith, Colo.	09080100	39°21'45"	106°43'55"	12-6-77	20	---	130	86	---	---	1,700	---
22	Fryingpan River near Ruedi, Colo.	09080400	39°21'56"	106°49'30"	12-6-77	50	20	380	242	---	86	11,900	1,700
23	Fryingpan River at Basalt, Colo.	None	39°22'10"	107°01'46"	12-7-77	66	36	400	---	260	190	16,900	6,700
24	Crystal River near Carbondale, Colo.	None	39°24'29"	107°13'44"	12-7-77	84	---	640	452	---	---	37,400	---
25	Roaring Fork River at Glenwood Springs, Colo.	09085000	39°32'37"	107°19'44"	---	400	370	740	490	---	500	193,000	183,000
	MAIN-STEM COLORADO RIVER UPPER HEADWATERS SUBBASIN												
26	Colorado River below Lake Granby, Colo.	09019000	40°03'39"	105°52'00"	12-7-77	19	---	160	---	86	---	1,600	---
27	Willow Creek below Willow Creek Reservoir, Colo.	09021000	40°08'45"	105°56'22"	12-7-77	6.4	---	160	---	86	---	540	---
28	Fraser River near mouth.	None	40°05'05"	105°57'12"	12-7-77	55	---	160	90	---	---	5,000	---
29	Colorado River at Hot Sulphur Springs, Colo.	09034500	40°05'00"	106°05'15"	12-7-77	77	---	220	137	---	---	10,400	---
30	Williams Fork near Parshall, Colo.	09037500	40°00'01"	106°10'45"	12-7-77	60	---	175	72	---	---	4,300	---
31	Williams Fork below Williams Fork Reservoir, Colo.	09038500	40°02'07"	106°12'17"	12-7-77	71	60	180	---	100	72	7,000	4,300
32	Corral Creek near mouth.	None	40°03'50"	106°11'28"	12-7-77	2.1	---	240	---	150	---	300	---
33	Troublesome Creek near mouth.	None	40°01'48"	106°16'30"	12-7-77	39	---	400	---	260	---	10,000	---
34	Muddy Creek near mouth at Kremmling, Colo.	None	40°03'37"	106°23'54"	12-9-77	---	---	1,160	984	---	---	---	---
35	Colorado River near Kremmling, Colo.	09058000	40°02'13"	106°26'22"	12-8-77	321	337	260	160	---	125	50,600	41,500
36	Blacktail Creek near Radium, Colo.	None	39°58'25"	106°32'58"	12-8-77	4.4	---	340	---	220	---	950	---
37	Sheephorn Creek near Radium, Colo.	None	39°57'15"	106°32'57"	12-8-77	4.7	---	1,030	---	730	---	3,400	---
38	Piney River near mouth.	None	39°51'26"	106°38'28"	12-8-77	48	---	320	209	---	---	9,900	---
39	Colorado River at Bond, Colo.	None	39°53'22"	106°42'25"	12-8-77	---	---	250	162	---	---	---	---
40	Rock Creek at McCoy, Colo.	None	39°55'58"	106°43'37"	12-8-77	17	---	290	183	---	---	3,100	---
41	Big Alkali Creek near mouth.	None	39°53'07"	106°49'50"	12-8-77	.25	---	1,930	---	1,400	---	340	---

Table 2.--*Discharge, specific conductance, dissolved-solids concentration, and salt loads: Colorado upper headwaters subregion*--Continued

Site	Site description	U.S. Geological Survey station number	Latitude	Longitude	Sample date	Discharge (ft^3/s)		Specific conductance (μS/cm)	Dissolved solids (mg/L)			Salt load (tons/yr)	
						Measured	Adjusted		Measured	Calculated	Adjusted	Measured	Adjusted
	MAIN-STEM COLORADO RIVER UPPER HEADWATERS SUBBASIN--Continued												
42	Sunnyside Creek near Burns, Colo.	None	39°52'35"	106°53'28"	12-8-77	4.7	---	870	---	610	---	2,800	---
43	Colorado River near Burns, Colo.	None	39°52'16"	106°54'04"	12-8-77	---	---	250	---	150	---	---	---
44	Derby Creek near mouth.	None	39°53'09"	106°54'12"	12-8-77	31	---	140	107	---	---	3,300	---
45	Red Dirt Creek near mouth.	None	39°48'07"	106°58'29"	12-8-77	4.9	---	170	---	94	---	450	---
46	Sweetwater Creek near mouth.	None	39°43'15"	107°02'11"	12-8-77	27	---	390	249	---	---	6,600	---
47	Deep Creek near mouth.	None	39°40'19"	107°04'38"	12-8-77	11	---	300	173	---	---	1,900	---
48	Colorado River near Dotsero, Colo.	09070500	39°38'40"	107°04'40"	12-7-77	706	722	610	379	---	359	264,000	255,000
49	Grizzly Creek near mouth.	None	39°34'02"	107°15'04"	12-7-77	2.0	---	240	---	150	---	300	---
50	No Name Creek near mouth.	None	39°33'39"	107°17'56"	12-7-77	7.0	---	280	---	180	---	1,200	---
51	Colorado River below No Name Creek.	None	39°33'41"	107°18'02"	12-7-77	---	---	930	---	660	---	---	---
52	Colorado River below Glenwood Springs, Colo.	09085100	39°33'18"	107°20'13"	12-6-77	1,240	1,226	1,350	813	---	807	993,000	974,000

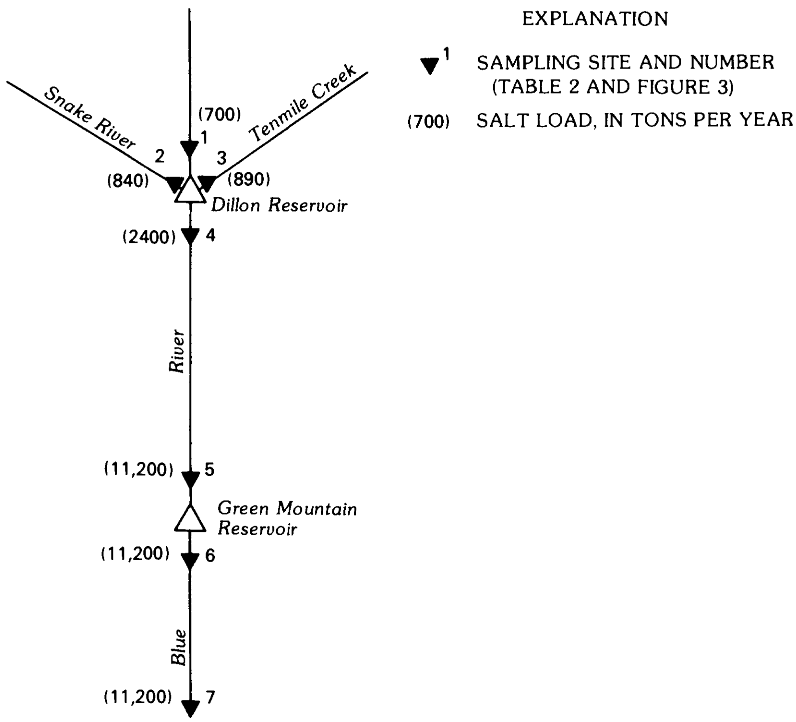


Figure 5.--Drainage system and salt load: Blue River subbasin.

most of the subbasin. No historical data were available for comparison with sample data.

The Blue River subbasin (site 7) discharged an adjusted estimated annual base flow of 188 ft^3/s and a salt load of 11,200 tons (fig. 5). The adjustment factors for Dillon Reservoir and Green Mountain Reservoir resulted in an increase of 27 ft^3/s above the measured base flow and a salt load of 6,400 ton/yr less than measured salt loads. This adjustment was applied to all affected downstream sites.

Eagle River

The Eagle River subbasin includes the drainage area of the Eagle River and tributaries upstream from the confluence with the Colorado River. Cambrian and Ordovician limestones and dolomites crop out in the headwaters region west of the Eagle River and upstream from Avon, Colo. Pennsylvanian and Permian sandstones, limestones, dolomites, and shale crop out in the headwaters east of the Eagle River upstream from Avon. Downstream from Avon, there are large areas of the Eagle Valley Evaporite, which contain thick salt beds. In addition, localized deposits of pre-Tertiary conglomerates, sandstones, and shales crop out in this reach.

The mean annual dissolved-solids concentration of the headwaters of the Eagle River is about 100 mg/L. At its mouth, the Eagle River has nearly triple that concentration, about 300 mg/L, and an average annual discharge of about 400,000 acre-ft (420 acre-ft/mi^2).

Five sampling sites were selected in this subbasin (figs. 3 and 6; table 2). Dissolved-solids concentrations in the Eagle River at the upstream sites were about 140 mg/L at Redcliff, Colo. (site 8), and 190 mg/L at Avon (site 9). These concentrations are small and indicate the relative insolubility of the metamorphic and carbonate rocks comprising much of the drainage area upstream from the sampling points. Dissolved-solids concentrations ranged from 494 to about 780 mg/L at the three sites downstream from Avon (sites 10-12), reflecting the contribution from extensive exposures of Eagle Valley Evaporite deposits in the drainage areas upstream from these three sites. Soil disturbance caused by extensive ongoing development around Avon also may be related to the larger salinity concentrations downstream.

A water-quality station is on the Eagle River upstream from Gypsum Creek (site 11). The average dissolved-solids concentration in the Eagle River at this site during December, January, and February of water years 1976-77 was 678 mg/L. The dissolved-solids concentration of the sample collected was 731 mg/L or about 8 percent larger. The discharge at this station is measured below Gypsum Creek. The 2-year base-flow average was 183 ft^3/s. The combined discharge for Eagle River upstream from Gypsum (site 11) and Gypsum Creek near the mouth (site 12) at the time the sample was collected was 198 ft^3/s or about 8 percent larger than the 2-year base-flow average. The Eagle River subbasin discharged an estimated average base flow of 198 ft^3/s and an annual salt load of 135,000 tons (fig. 6).

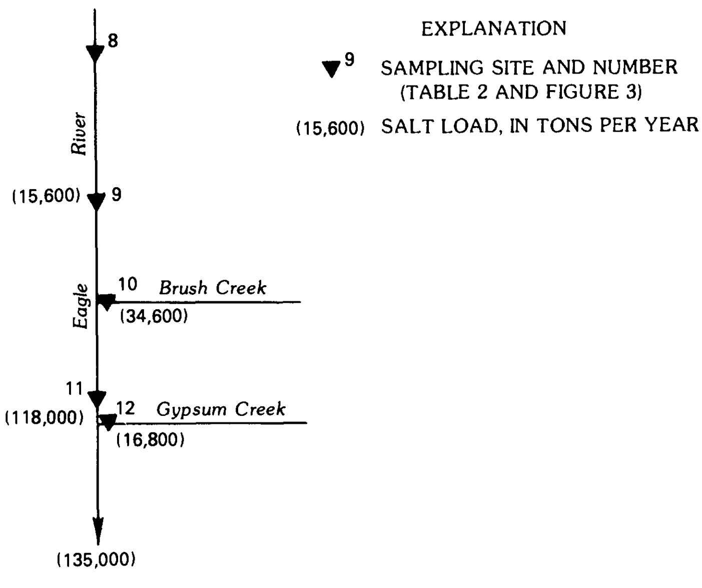


Figure 6.--Drainage system and salt load: Eagle River subbasin.

Roaring Fork River

The Roaring Fork River subbasin includes the drainage area of the Roaring Fork River and tributaries upstream from the confluence with the Colorado River. Igneous rocks underlie most of the headwaters of the main stem of the Roaring Fork River in the southern part of the subbasin. Pennsylvanian and Permian sandstones and localized areas of igneous rock and unconsolidated deposits crop out in the headwaters region of most of the major tributaries of the Roaring Fork River. At lower elevations the Upper Cretaceous Mancos Shale crops out along the southwestern side of the Roaring Fork River, and Lower Triassic, Pennsylvanian, and Permian sandstones, conglomerate, and marlstones together with a mixture of basalt and unconsolidated deposits occur along the northeastern side of the Roaring Fork River.

The Fryingpan River is a major tributary to the Roaring Fork River. Headwaters of the Roaring Fork and Fryingpan Rivers discharge water having a mean annual dissolved-solids concentration of generally less than 100 mg/L. At its mouth the Roaring Fork River has a mean annual dissolved-solids concentration of about 250 mg/L. The high mountains that form the headwaters region of the Roaring Fork River are the source of very large quantities of water. The mean annual discharge of the Roaring Fork River near its mouth is about 860,000 acre-ft (600 acre-ft/mi^2).

Thirteen sampling sites were selected in this subbasin (figs. 3 and 7; table 2). The dissolved-solids concentration in the Roaring Fork River upstream from Aspen, Colo. (site 13), of 62 mg/L is the result of the predominance of insoluble igneous rocks upstream from this site. The estimated base-flow salt load was 1,400 ton/yr and a discharge of 23 ft^3/s. The dissolved-solids concentration of Castle Creek (site 14) was about 350 mg/L and Maroon Creek (site 15) was about 370 mg/L. The Maroon Formation, which consists of Pennsylvanian and Permian sandstones, conglomerate, and siltstone, is drained by Maroon and Castle Creeks and may contribute to the higher salinity concentrations at these sites. The Maroon Formation of Pennsylvanian and Permian age intertongues with the underlying Eagle Valley Evaporite of Pennsylvanian and Permian age. The Aspen Mountain Ski Area near Aspen, Colo., which is drained by these streams, also may contribute to the higher salinity concentrations.

Dissolved-solids concentration in the Roaring Fork River downstream from Woody Creek (site 16) was 316 mg/L. At this site, the estimated base-flow salt load has increased to 32,700 ton/yr with a base-flow discharge of 105 ft^3/s. This is primarily a result of the effects of Castle and Maroon Creeks that contribute a combined base-flow salt load of about 23,100 ton/yr and a combined base-flow discharge of about 65 ft^3/s. The dissolved-solids concentration in Snowmass Creek (site 19) was about 440 mg/L. Outcrops of the Mancos Shale that underlie the area may be responsible for the larger salinity concentrations in Snowmass Creek. The base flow of the creek was 26 ft^3/s and carried a salt load of 11,300 ton/yr. The dissolved-solids concentration (about 320 mg/L) in the Roaring Fork River between Woody Creek and the confluence with the Fryingpan River (site 20) is almost the same as the concentration (316 mg/L) above Woody Creek (site 16).

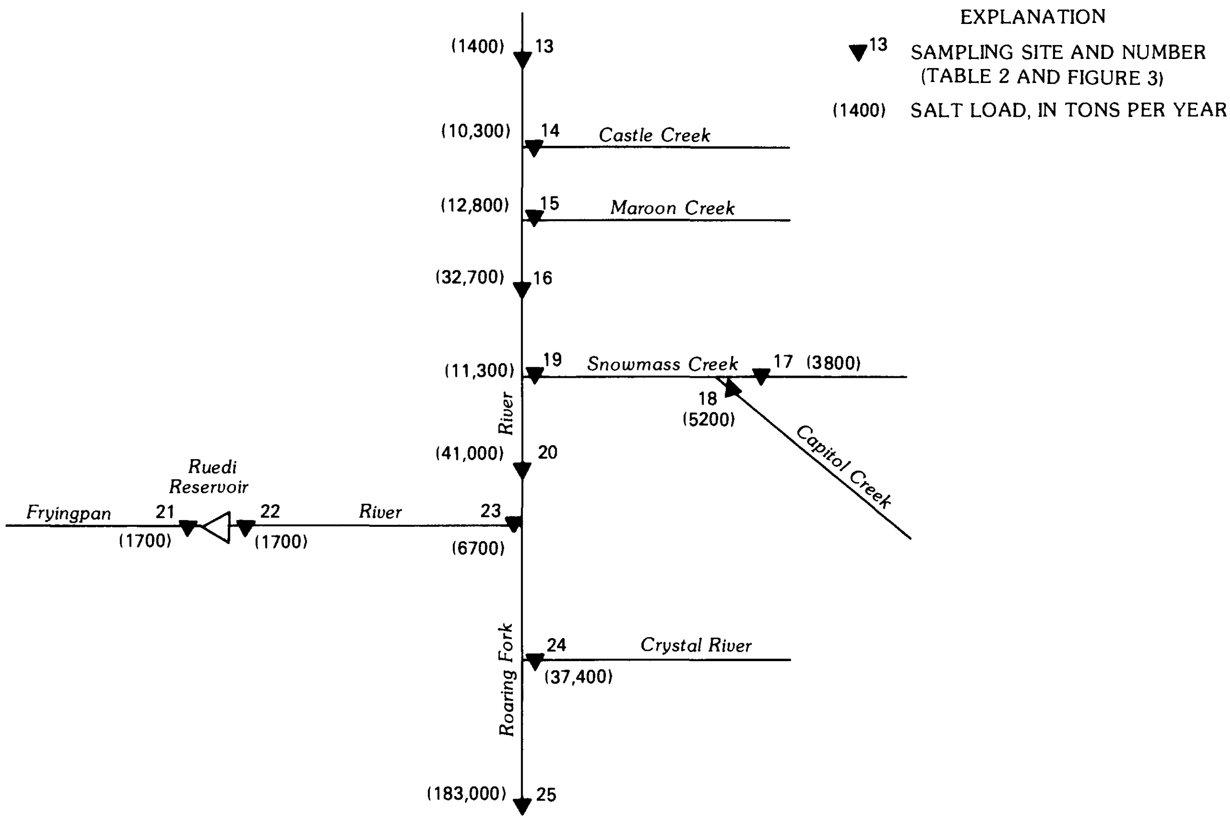


Figure 7.--Drainage system and salt load: Roaring Fork River subbasin.

Dissolved-solids concentration in the Fryingpan River upstream from the Ruedi Reservoir (site 21) was 86 mg/L, while below Ruedi Reservoir (site 22) dissolved-solids concentration was 242 mg/L. Flow in the Fryingpan River is controlled by Ruedi Reservoir. Normally, surface runoff impounded in a reservoir has a lower dissolved-solids concentration than the ground water; however, Ruedi Reservoir is in areas of evaporite deposits that may account for the larger dissolved-solids concentration in the river downstream from the reservoir. Dissolved-solids concentration adjusted for effects of reservoir storage was about 190 mg/L at Basalt (site 23).

Dissolved-solids concentration was 452 mg/L in the Crystal River (site 24). Seepage and runoff from marine shales and evaporite deposits are probably the principal sources of salinity in the Crystal River. A water-quality station is located on the Crystal River near the sampling site (site 24). Average dissolved-solids concentration was 441 mg/L, and flow was 60 ft^3/s at this station during December, January, and February of water year 1977. The measured dissolved-solids concentration of 452 mg/L was only about

2 percent greater than the average of 441 mg/L. However, the measured discharge of 84 ft^3/s was about 40 percent greater than the average discharge from the station of 60 ft^3/s.

The adjusted dissolved-solids concentration for the Roaring Fork River near Glenwood Springs (site 25) was about 500 mg/L. The adjusted base-flow salt load for the Roaring Fork River was 183,000 ton/yr, and the adjusted average discharge was about 370 ft^3/s (fig. 7). The Roaring Fork River downstream from the confluence with Woody Creek (site 16) increased discharge by about 265 ft^3/s and increased salt load by about 150,000 ton/yr. Measured tributary inflow along this reach accounts for 146 ft^3/s and 55,400 ton/yr, respectively. The remainder, 119 ft^3/s and 94,900 ton/yr, is estimated to be contributed by unmeasured tributary inflow, which is small, and by direct ground-water discharge into this reach of the Roaring Fork River.

Main-stem Colorado River upper headwaters

This subbasin includes the drainage area of the main-stem Colorado River and tributaries upstream from Glenwood Springs, exclusive of the Blue River, Eagle River, and Roaring Fork River drainages. Most of the rocks exposed in the headwaters region of the Colorado River, Fraser River and Williams Forks are igneous and metamorphic. Tertiary sandstones and semi-consolidated conglomerate in hydrogeologic unit 3 (table 1) and local areas of extrusive igneous rocks underlie the north side of the subbasin between Granby, Colo., and Kremmling, Colo. Upper Cretaceous shales in hydrogeologic unit 7, rocks in hydrogeologic unit 3 (table 1), and local areas of extrusive igneous rocks crop out in the Muddy Creek drainage north of Kremmling. Some igneous and metamorphic rocks, some Permian rocks, and the rocks in hydrogeologic units 7 and 3 crop out in the Piney River and Sheephorn Creek drainages south of the Colorado River. Principally igneous and metamorphic rocks underlie the drainages north of the Colorado River between Kremmling and State Bridge, Colo. The remainder of the subbasin north of the Colorado River between State Bridge and Glenwood Springs is underlain mostly by undifferentiated Cambrian, Ordovician, Devonian, and Mississippian rocks; the Maroon Formation; the Eagle Valley Evaporite of Pennsylvanian and Permian age, and other related Pennsylvanian and Permian formations; the Dakota Sandstone; the Mancos Shale; and landslide deposits of Quaternary age.

The headwaters of the main stem of the Colorado River are located above Lake Granby. The high mountainous terrain that forms the headwaters region of the Colorado River produces large quantities of good quality water. The discharge of the Colorado River at Hot Sulphur Springs, Colo. (site 29), averages about 130,000 acre-ft/yr, and the mean annual dissolved-solids concentration is 80 mg/L. This discharge is about 200 acre-ft/mi^2. Most of the tributaries entering the Colorado River from the north between Kremmling and Glenwood Springs, Colo., originate in the White River Plateau. They have a mean annual dissolved-solids concentration of about 200 mg/L. The Colorado River just below Glenwood Springs has an average annual discharge of close to 2.6 million acre-ft and a mean annual dissolved-solids concentration of about 400 mg/L.

Twenty-six sampling sites were selected in this subbasin (figs. 3 and 8; table 2). The dissolved-solids concentration of the Colorado River below Lake Granby (site 26), Willow Creek (site 27), Fraser River (site 28), Colorado River at Hot Sulphur Springs (site 29), Williams Fork (sites 30 and 31), and Corral Creek (site 32) in Colorado ranged from 72 to about 150 mg/L. These relatively low concentrations are indicative of the insoluble igneous and metamorphic rocks exposed in these areas.

The estimated base-flow salt load computed for the Colorado River at Hot Sulphur Springs (site 29) was 10,400 ton/yr with a measured discharge of 77 ft^3/s. Comparisons with historical data for December, January, and February of water years 1976-77 from a water-quality station at this site indicate that the measured discharge was 26 percent greater than the average of 61 ft^3/s, and the measured dissolved-solids concentration was 54 percent greater than the average of 89 mg/L.

Flow in the Williams Fork is regulated by the Williams Fork Reservoir. Adjustments for the effects of Williams Fork Reservoir resulted in a decrease of 11 ft^3/s discharge of the Williams Fork at its mouth (site 31) and a corresponding decrease of 2,700 ton/yr in the estimated base-flow salt load. This adjustment was applied to all affected downstream sites. The Williams Fork contributed an adjusted base-flow salt load of 4,300 ton/yr and an adjusted base-flow discharge of 60 ft^3/s.

Troublesome Creek (site 33), which has a dissolved-solids concentration of about 260 mg/L, reflects the slightly higher salinity of hydrogeologic unit 3 (table 1) that it drains. The estimated base-flow salt load for Troublesome Creek was 10,000 ton/yr. The large dissolved-solids concentration of 984 mg/L in Muddy Creek (site 34) probably results from the large area of Upper Cretaceous marine shales in hydrogeologic unit 7 (table 1) found in its drainage.

Dissolved-solids concentrations of about 220 and 183 mg/L in Blacktail (site 36) and Rock Creeks (site 40), respectively, are indicative of the insolubility of igneous rocks underlying most of these drainages. Sheephorn Creek (site 37) had a dissolved-solids concentration of about 730 mg/L. This area is underlain by marine shales of hydrogeologic unit 7 (table 1), which probably contribute to the relatively large dissolved-solids concentration. The dissolved-solids concentration of the Piney River (site 38) was 209 mg/L. The Piney River drains predominantly hydrogeologic unit 3 basalt (table 1) and, in the upper reaches, Permian through Cretaceous rocks. Most of the base flow in the Piney River is probably from the basalt and accounts for the fairly low salinity concentrations.

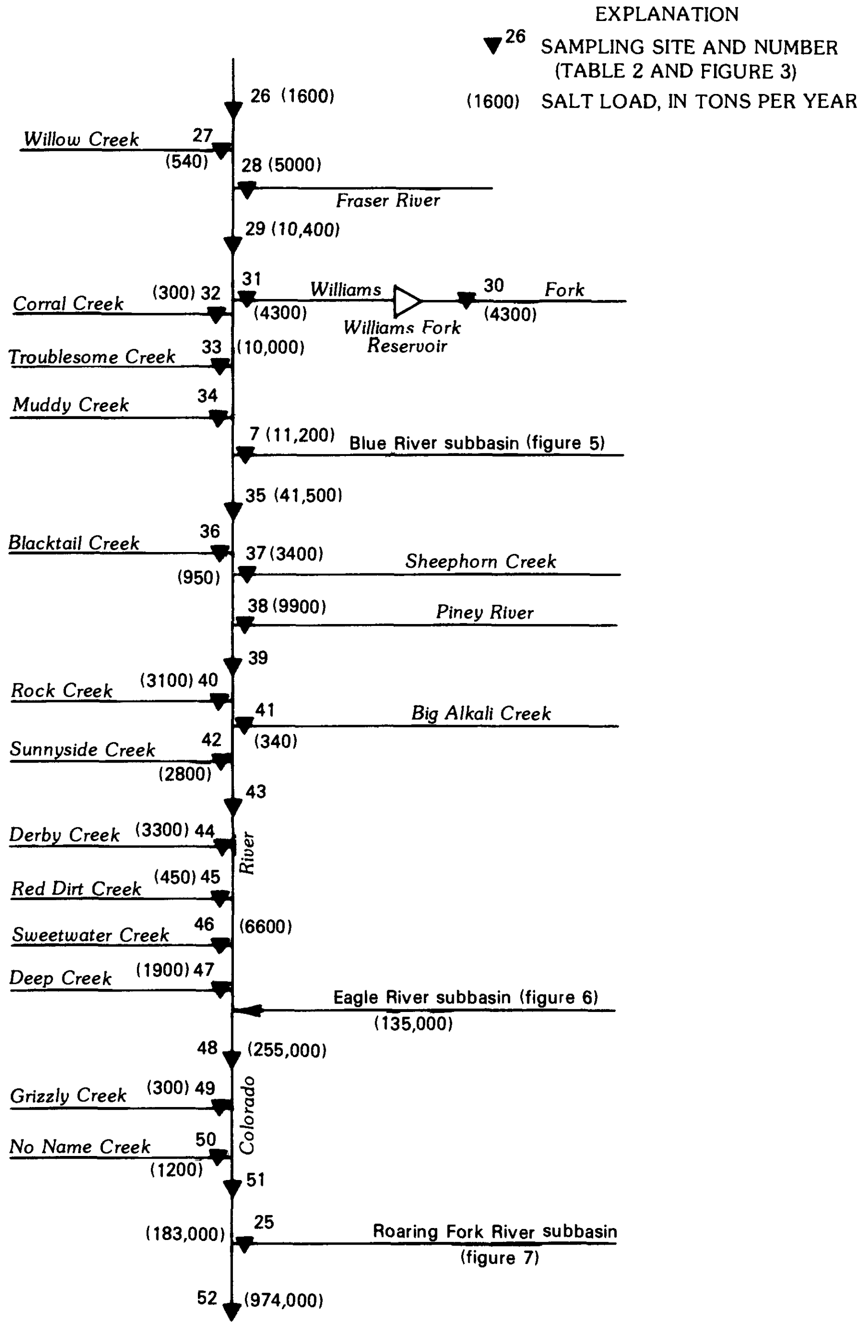


Figure 8.--Drainage system and salt load: main-stem Colorado River upper headwaters subbasin.

The dissolved-solids concentration was about 1,400 mg/L in Big Alkali Creek (site 41), but the flow was only 0.25 ft^3/s. Big Alkali Creek drains predominantly the Dakota Sandstone and Upper Cretaceous shales in hydrogeologic unit 7. Sunnyside Creek (site 42) had a dissolved-solids concentration of about 610 mg/L. Areas of Mancos Shale are in the upper reaches of the drainage, and the Dakota Sandstone is predominant in the middle and lower reaches.

Dissolved-solids concentrations ranged from about 94 mg/L to 249 mg/L in Derby Creek (site 44), Red Dirt Creek (site 45), Sweetwater Creek (site 46), Deep Creek (site 47), Grizzly Creek (site 49), and No Name Creek (site 50). The relatively small salinity concentrations are indicative of the small-solubility basalts of the White River Plateau that probably contribute most of the base flow to these creeks.

The data for the main-stem Colorado River sites were adjusted for effects of reservoirs on the Blue River and the Williams Fork. The adjusted dissolved-solids concentration was 125 mg/L at Kremmling (site 35). This relatively small salinity is indicative of the small-solubility rocks that underlie most of the drainage area upstream from this site. The adjusted base-flow salt load was 41,500 ton/yr at Kremmling, and the base-flow discharge was 337 ft^3/s.

The adjusted dissolved-solids concentration of the Colorado River near Dotsero (site 48) was 359 mg/L. The increase in dissolved-solids concentration at this site primarily is the result of salinity contributions from the Eagle River. The adjusted base-flow salt load was 255,000 ton/yr, and the base-flow discharge was 722 ft^3/s. Comparison with historical data for December, January, and February of water years 1976-77 from a water-quality station at this site indicated that measured discharge was 44 percent lower than the average of 1,293 ft^3/s, and the measured dissolved-solids concentration was 40 percent higher than the average of 256 mg/L. The deviation of the measured flow and dissolved-solids concentration from the average values at the Dotsero site may be, in part, a function of reservoir control on flow in the Blue River.

The calculated dissolved-solids concentration in the Colorado River below No Name Creek (site 51) was about 660 mg/L. The relatively large dissolved-solids concentration at this site is probably caused by the flow into the Colorado River of highly saline water from hot and warm springs between Dotsero and Glenwood Springs. Tributaries to the Colorado River along this reach (sites 49, 50) contained measured dissolved-solids concentrations of less than 200 mg/L and only contributed an estimated flow of 9 ft^3/s and 1,500 ton/yr of base-flow salt load to the Colorado River.

The adjusted dissolved-solids concentration in the Colorado River below Glenwood Springs (site 52) was 807 mg/L. The estimated base-flow salt load in the Colorado River below Glenwood Springs was 974,000 ton/yr (fig. 8), and the base-flow discharge was 1,226 ft^3/s. This estimate included adjustments for Williams Fork, Dillon, Green Mountain, and Ruedi Reservoirs. The total calculated contributions from the Colorado River upper headwaters subbasin was 645,000 ton/yr, and the adjusted discharge addition was 470 ft^3/s. In the reach between Dotsero and Glenwood Springs, the salt load of the Colorado River increased by 719,000 ton/yr. The Roaring Fork River added 183,000 ton/yr, and other measured tributary inflow to the Colorado River in this reach added 1,500 ton/yr. The remaining 534,000 ton/yr in this reach probably originates from many hot and warm springs. If these springs are the primary source of the additional salt, they contribute about one-half of the annual base-flow salt load for the Upper Colorado River Basin above Glenwood Springs. Under this assumption the combined discharge of the Dotsero-Glenwood Springs hot springs group was estimated using equation 3 outlined in the "Data Collection and Method of Analysis" section of this report. An estimated discharge of 18 ft^3/s was computed for this group of springs.

Salt-load distribution

The areal distribution of the sources of flow and estimated salt load in the Colorado upper headwaters subregion indicates that the Blue River produces an estimated 1 percent of the base-flow salt load and 15 percent of the base-flow discharge; the Eagle River produces an estimated 14 percent of the base-flow salt load and about 16 percent of the base-flow discharge; the Roaring Fork River produces an estimated 19 percent of the base-flow salt load and about 30 percent of the base-flow discharge; and the Dotsero-Glenwood Springs hot springs produce about 55 percent of the estimated base-flow salt load and an insignificant volume of flow. Combined, these sources represent 89 percent of the estimated base-flow salt load and 61 percent of the base-flow discharge of the Colorado upper headwaters subregion.

The graph of salt load, dissolved-solids concentration, and discharge for the main stem of the Colorado River (fig. 9) depicts the impact of these various sources on salinity levels of the Colorado River. A slight increase in salt load and dissolved-solids concentration in the main stem of the Colorado River is apparent until its confluence with the Eagle River. The most apparent impact is the large increase in salt load and dissolved-solids concentration of the Colorado River downstream from the Eagle River near Glenwood Springs due to the discharge of highly saline mineral springs along this reach.

The base-flow salt loads measured at selected sites in the Colorado upper headwaters subregion were compared with the total annual salt load reported by BLM (Bentley and others, 1978). The estimated base-flow salt load of

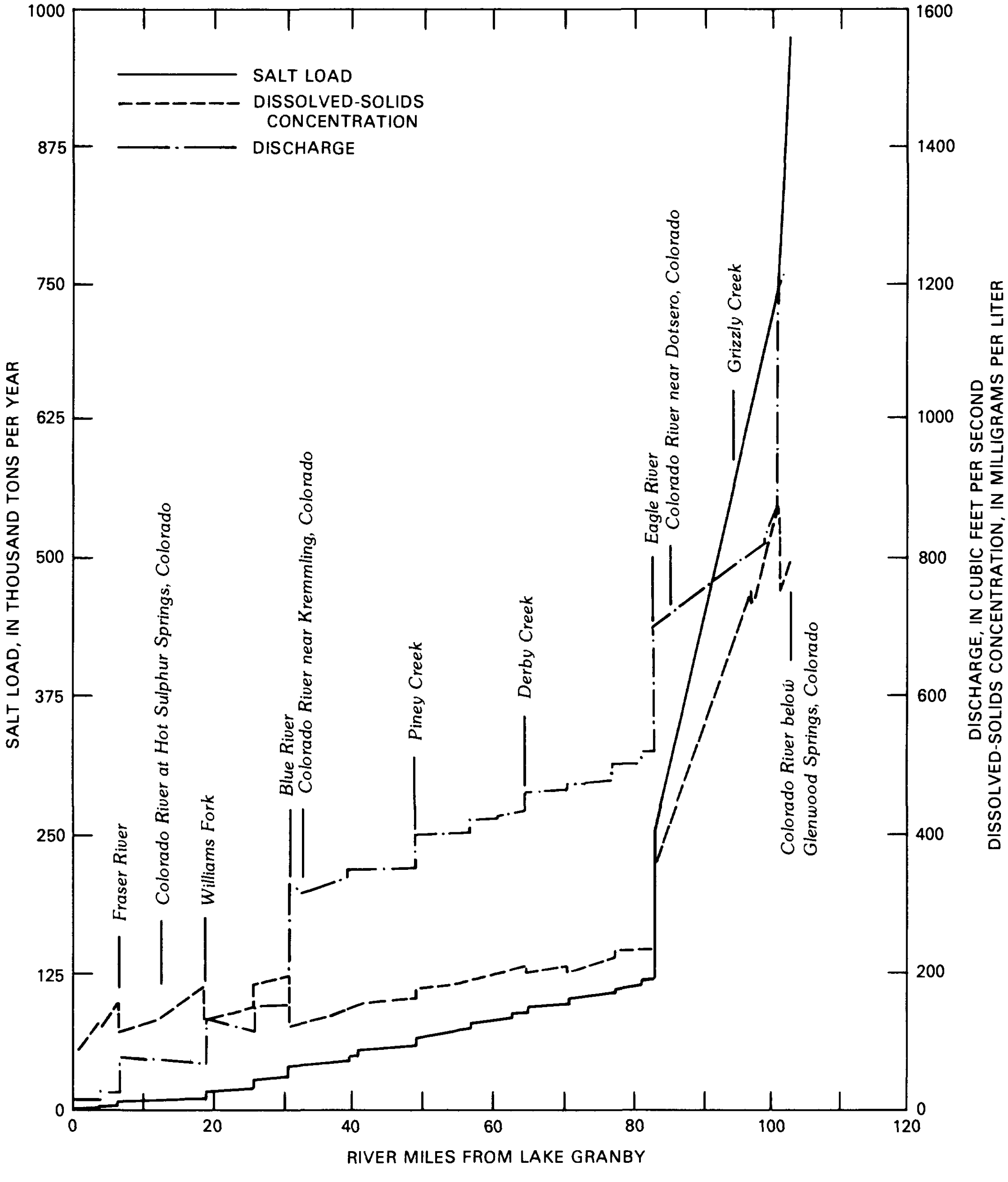


Figure 9.--Salt load, dissolved-solids concentration, and discharge: main-stem Colorado River upper headwaters.

10,400 ton/yr in the Colorado River at Hot Sulphur Springs was 53 percent of the estimated total annual salt load of 19,500 ton/yr. The estimated base-flow salt load of 135,000 ton/yr for the Eagle River was 89 percent of the estimated total annual salt load of 151,200 ton/yr. The estimated base-flow salt load of 183,000 ton/yr for the Roaring Fork River was 59 percent of the estimated total annual salt load of 308,100 ton/yr. The estimated base-flow salt load of 255,000 ton/yr for the Colorado River at Dotsero was 59 percent of the estimated total annual salt load of 431,300 ton/yr. The estimate of total annual salt load reported by BLM for the Colorado River below Glenwood Springs did not include the effect of the hot springs discharge of the Dotsero-Glenwood Springs group. If the effect of the hot springs is added to the estimate reported by BLM, then the estimated total annual salt load for the Colorado River below Glenwood Springs is 1,117,300 ton/yr. The estimated base-flow salt load of 974,000 ton/yr accounts for 87 percent of the estimated total annual salt load (the hot spring's effect plus the BLM estimate) for the Colorado River below Glenwood Springs.

Gunnison Subregion

The drainage area of the Gunnison River basin is about 8,000 mi^2 (fig. 1). Annual precipitation, mostly snow, ranges from about 20 to 50 in. in the areas above 9,000 ft. Annual precipitation ranges from about 8 to 20 in. in the remainder of the basin below 9,000 ft.

The Gunnison River is the largest tributary to the Colorado River in Colorado. The headwaters of the Gunnison River are near Gunnison in high mountainous terrain. The headwaters are generally less than 100 mg/L in dissolved-solids concentration. By the time the Gunnison River has neared Delta, the mean annual dissolved-solids concentration in the river has increased to about 400 mg/L. The Uncompahgre River enters the Gunnison River at Delta. At its mouth the mean annual dissolved-solids concentration of the Uncompahgre River is about 1,200 mg/L. This is caused by both natural sources and man's activities. During most of the irrigation season, all flows in the Uncompahgre River are diverted for irrigation and only irrigation-return flows enter the Gunnison River. At its mouth the Gunnison River has a mean annual dissolved-solids concentration of about 600 mg/L. The average discharge of the Gunnison River at its mouth is about 1.7 million acre-ft/yr. This discharge is about 200 acre-ft/mi^2.

Flow in the Gunnison River is regulated by Blue Mesa and Morrow Point Reservoirs. Blue Mesa Reservoir has a capacity of 830,000 acre-ft, and Morrow Point Reservoir has a capacity of 121,000 acre-ft. The combined storage capacity of the two reservoirs is equal to about 1.7 times the mean annual discharge of the Gunnison River near Gunnison, Colo. Both reservoirs generate power and provide downstream requirements under the Colorado River Compact.

Measurements of specific conductance and stream discharge at 38 sites were made in the Gunnison subregion (fig. 10). At 25 of the sites, samples were collected for chemical analysis. Two linear regression analyses of specific conductance measured at the sites versus dissolved-solids concentrations determined in the laboratory were made on these data and then used to

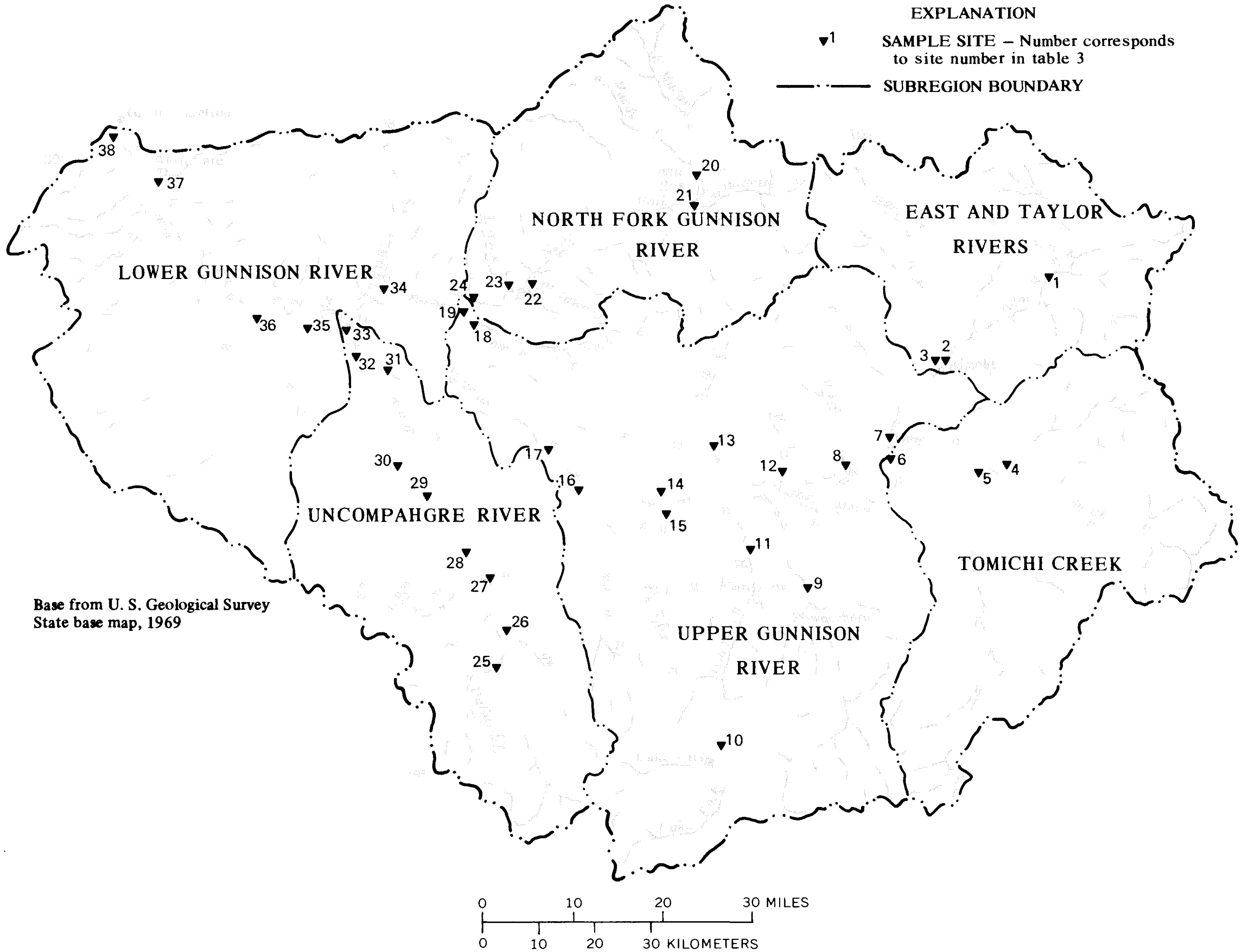


Figure 10.--Major subbasins and location of sampling sites: Gunnison subregion.

calculate dissolved-solids concentrations at the remaining 13 sites. Data from the upper part of the Gunnison River basin (sites 1-6, 8, 11, 14, 16, 19-21) were used for one regression analysis (fig. 11) to compute dissolved-solids concentrations when the specific conductance values were 600 μS/cm (microsiemens per centimeter at 25° Celsius) or less. Data from the lower part (sites 18, 23, 24, 27, 32-38) were used for a second regression analysis (fig. 12) when specific conductance values were greater than 600 μS/cm. Values of discharge, specific conductance, dissolved-solids concentration, and salt load for each site are presented in table 3. The Gunnison subregion was divided into six subbasins: East and Taylor Rivers, Tomichi Creek, Upper Gunnison River, North Fork Gunnison River, Uncompahgre River, and Lower Gunnison River (fig. 10).

East and Taylor Rivers

This subbasin includes the drainage area upstream from the confluence of the East and Taylor Rivers (fig. 10). Igneous and metamorphic rocks underlie most of the Taylor River drainage, but the Leadville Limestone underlies the drainage locally. The East River drainage contains large areas of Mancos Shale as well as smaller areas of the Maroon Formation and other related Pennsylvanian and Permian rocks and the Mesaverde Group of Late Cretaceous age.

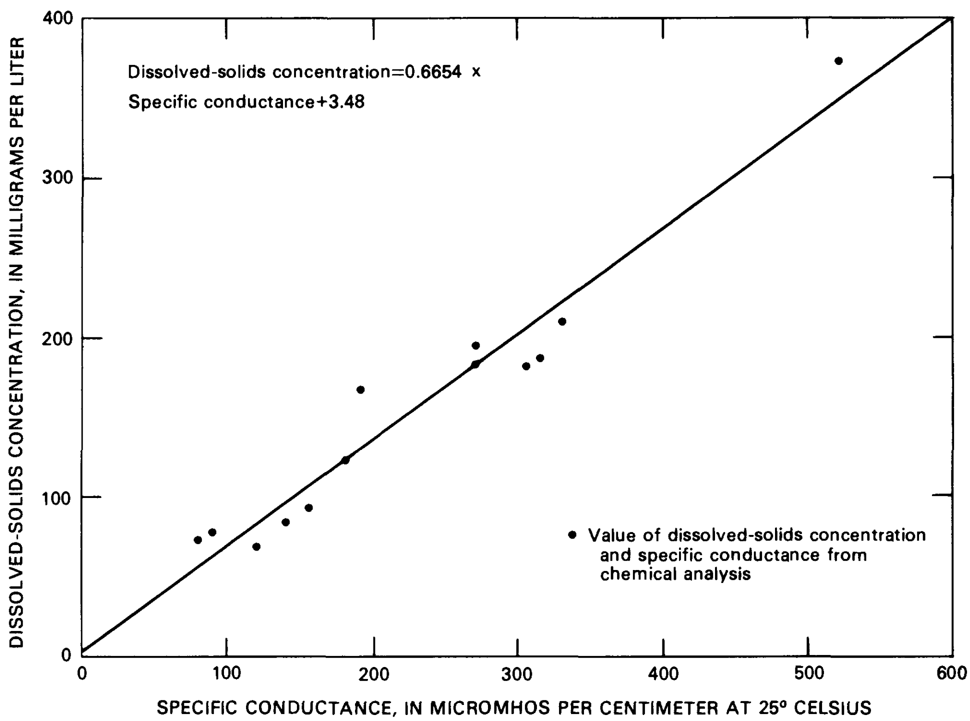


Figure 11.--Specific conductance versus dissolved-solids concentration, Gunnison subregion, for specific conductance values of 600 microsiemens per centimeter at 25° Celsius, or less.

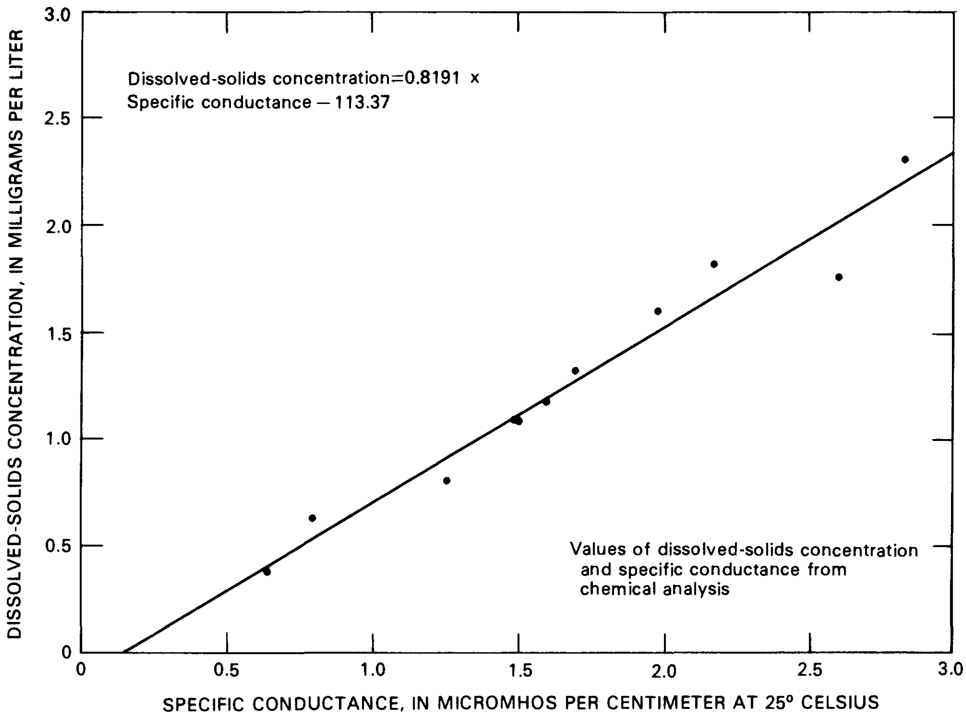


Figure 12.--Specific conductance versus dissolved-solids concentration, Gunnison subregion, for specific conductance values greater than 600 microsiemens per centimeter at 25° Celsius.

Three sampling sites were selected for this subbasin (figs. 10 and 13; table 3). Dissolved-solids concentrations were 69 mg/L in the Taylor River below Taylor Park Reservoir (site 1) and were 84 mg/L in the Taylor River and at Almont (site 2). These relatively small dissolved-solids concentrations are indicative of the relatively insoluble igneous and metamorphic rocks underlying this drainage. No adjustment was made for the effects of Taylor Park Reservoir. Dissolved-solids concentration in the East River at Almont (site 3) was 210 mg/L. This slightly larger concentration probably reflects the occurrence of the Mancos Shale in the East River drainage. There are no water-quality stations in the East and Taylor Rivers subbasin for comparison of historical data with sample data.

Taylor River contributed 10,300 ton/yr base-flow salt load (fig. 13) at a 124 ft^3/s discharge, and East River also contributed 10,300 ton/yr (fig. 13) but at a discharge of only 50 ft^3/s. The estimated total base-flow salt load for the East and Taylor Rivers subbasin was 20,600 ton/yr at a combined measured discharge of 174 ft^3/s.

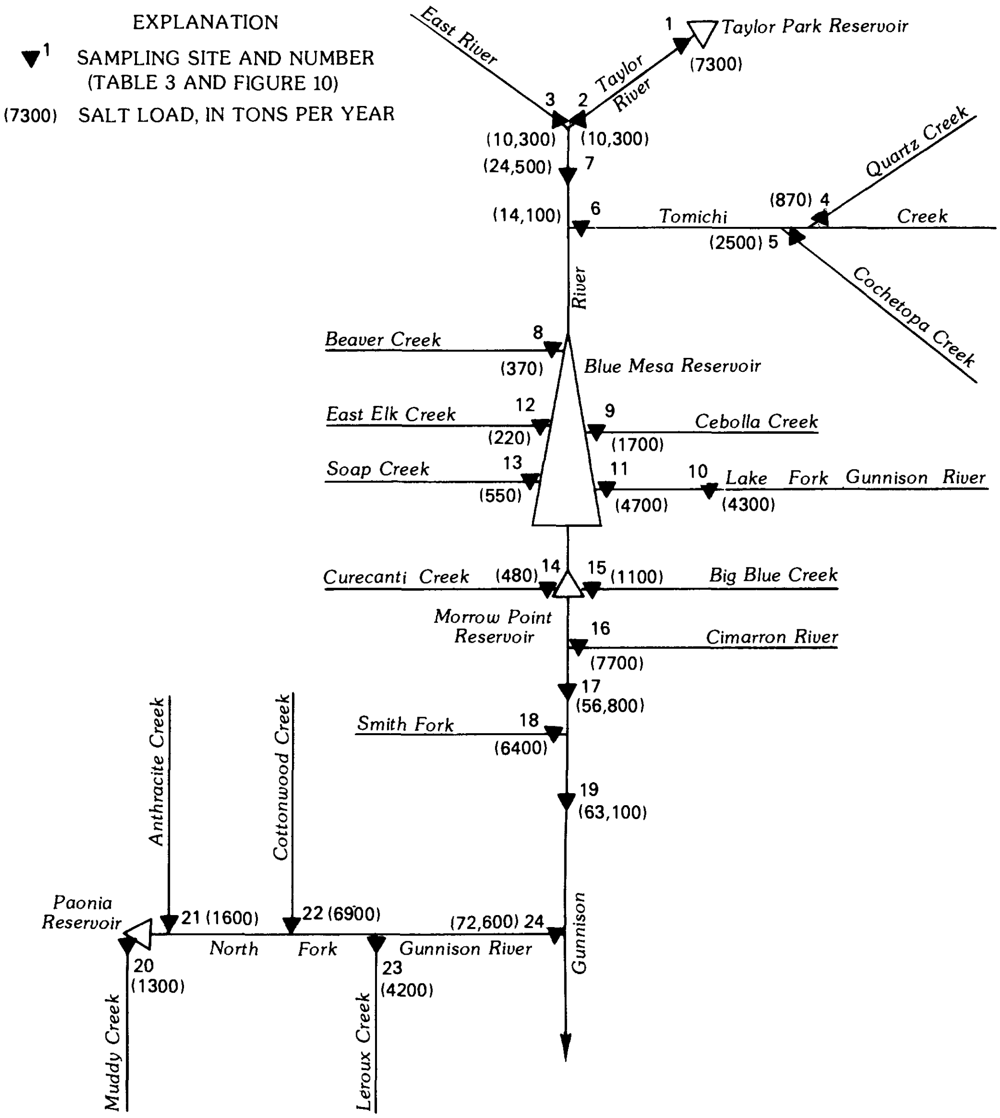


Figure 13.--Drainage system and salt load: Gunnison subregion above Tongue Creek.

Table 3.--*Discharge, specific conductance, dissolved-solids concentration, and salt loads: Gunnison subregion*

[ft^3/s, cubic feet per second; μS/cm, microsiemens per centimeter at 25° Celsius; mg/L, milligrams per liter; tons/yr, tons per year; dashes indicate not applicable]

Site	Site description	U.S. Geological Survey station number	Latitude	Longitude	Sample date	Discharge (ft^3/s)		Specific conductance (μS/cm)	Dissolved solids (mg/L)			Salt load (tons/yr)	
						Measured	Adjusted		Measured	Calculated	Adjusted	Measured	Adjusted
	EAST AND TAYLOR RIVERS SUBBASIN												
1	Taylor River below Taylor Park Reservoir, Colo.	09109000	38°49'06"	106°36'31"	12-6-77	107	---	120	69	---	---	7,300	---
2	Taylor River at Almont, Colo.	09110000	38°39'52"	106°50'41"	12-6-77	124	---	140	84	---	---	10,300	---
3	East River at Almont, Colo.	09112500	38°39'52"	106°50'51"	12-6-77	50	---	330	210	---	---	10,300	---
	TOMICHI CREEK SUBBASIN												
4	Quartz Creek at Parlin, Colo.	None	38°30'05"	106°43'23"	12-9-77	5.3	---	190	167	---	---	870	---
5	Cochetopa Creek near Parlin, Colo.	None	38°31'01"	106°47'11"	12-9-77	13	---	270	195	---	---	2,500	---
6	Tomichi Creek at Gunnison, Colo.	09119000	38°31'18"	106°56'25"	12-8-77	78	---	270	183	---	---	14,100	---
	UPPER GUNNISON RIVER SUBBASIN												
7	Gunnison River near Gunnison, Colo.	09114500	38°32'31"	106°56'57"	12-8-77	207	---	180	---	120	---	24,500	---
8	Beaver Creek near mouth.	None	38°29'42"	107°01'59"	12-8-77	5.2	---	80	73	---	---	370	---
9	Cebolla Creek near Powderhorn, Colo.	None	38°17'27"	107°06'49"	12-7-77	21	---	118	---	82	---	1,700	---
10	Lake Fork Gunnison River near Lake City, Colo.	None	38°04'29"	107°17'50"	12-7-77	36	---	180	---	120	---	4,300	---
11	Lake Fork Gunnison River near Gateview, Colo.	None	38°24'11"	107°14'54"	12-7-77	39	---	180	123	---	---	4,700	---
12	East Elk Creek near mouth.	None	38°29'03"	107°10'13"	12-8-77	3.9	---	80	---	57	---	220	---
13	Soap Creek near mouth.	None	38°32'47"	107°18'53"	12-6-77	5.8	---	140	---	97	---	550	---
14	Curecanti Creek near mouth.	None	38°29'15"	107°24'55"	12-7-77	6.2	---	90	78	---	---	480	---
15	Big Blue Creek near mouth.	None	38°24'18"	107°24'26"	12-7-77	18	---	85	---	60	---	1,100	---
16	Cimarron River near mouth.	None	38°26'49"	107°33'16"	12-8-77	21	---	520	374	---	---	7,700	---
17	Gunnison River below Gunnison Tunnel, Colo.	09128000	38°31'45"	107°38'54"	12-8-77	316	420	260	---	180	137	56,000	56,800
18	Smith Fork near Lazear, Colo.	09129600	38°42'27"	107°42'55"	12-7-77	2.8	---	2,830	2,310	---	---	6,400	---
19	Gunnison River above North Fork Gunnison River.	None	38°46'56"	107°50'09"	12-7-77	338	442	315	187	---	145	62,300	63,100

Table 3.--*Discharge, specific conductance, dissolved-solids concentration, and salt loads: Gunnison subregion*--Continued

Site	Site description	U.S. Geological Survey station number	Latitude	Longitude	Sample date	Discharge (ft^3/s) Measured	Discharge (ft^3/s) Adjusted	Specific conductance (μS/cm)	Dissolved solids (mg/L) Measured	Dissolved solids (mg/L) Calculated	Dissolved solids (mg/L) Adjusted	Salt load (tons/yr) Measured	Salt load (tons/yr) Adjusted
	NORTH FORK GUNNISON RIVER SUBBASIN												
20	Muddy Creek above Paonia Reservoir, Colo.	None	38°59'18"	107°20'52"	12-6-77	7.2	---	305	182	---	---	1,300	---
21	Anthracite Creek near mouth.	None	38°56'20"	107°21'31"	12-6-77	18	---	155	93	---	---	1,600	---
22	Cottonwood Creek near Hotchkiss, Colo.	09134200	38°48'22"	107°43'53"	12-6-77	1.5	---	5,500	4,640	---	---	6,900	---
23	Leroux Creek at Hotchkiss, Colo.	09135900	38°47'53"	107°43'53"	12-6-77	3.9	---	1,490	1,090	---	---	4,200	---
24	North Fork Gunnison River near mouth.	None	38°47'00"	107°50'06"	12-6-77	63	---	1,600	1,170	---	---	72,600	---
	UNCOMPAHGRE RIVER SUBBASIN												
25	Dallas Creek near mouth.	None	38°10'20"	107°45'31"	12-6-77	13	---	1,010	---	710	---	9,100	---
26	Cow Creek near mouth.	None	38°14'51"	107°45'29"	12-6-77	12	---	680	---	440	---	5,200	---
27	Uncompahgre River at Colona, Colo.	09147500	38°19'53"	107°46'44"	12-7-77	90	---	800	632	---	---	56,000	---
28	Horsefly Creek near Uncompahgre, Colo.	None	38°22'27"	107°49'23"	12-7-77	3.5	---	975	---	690	---	2,400	---
29	Happy Canyon Creek near Montrose, Colo.	None	38°28'28"	107°54'15"	12-7-77	3.7	---	1,900	---	1,400	---	5,100	---
30	Spring Creek near mouth.	None	38°32'01"	107°57'52"	12-7-77	18	---	1,450	---	1,100	---	19,500	---
31	Loutsenhizer Arroyo near Olathe, Colo.	None	38°29'26"	107°59'30"	12-7-77	10	---	3,000	---	2,300	---	22,700	---
32	Dry Creek near Delta, Colo.	None	38°42'02"	108°03'20"	12-7-77	68	---	1,700	1,320	---	---	88,400	---
33	Uncompahgre River at Delta, Colo.	09149500	38°44'31"	108°04'49"	12-7-77	180	---	2,170	1,820	---	---	323,000	---
	LOWER GUNNISON RIVER SUBBASIN												
34	Tongue Creek at Cory, Colo.	09144200	38°47'16"	107°59'41"	12-7-77	6.8	---	2,600	1,760	---	---	11,800	---
35	Roubideau Creek at mouth near Delta, Colo.	09150500	38°44'06"	108°09'40"	12-7-77	37	---	1,980	1,600	---	---	58,300	---
36	Escalante Creek near Delta, Colo.	09151500	38°45'24"	108°15'34"	12-7-77	6.6	---	640	382	---	---	2,500	---
37	East Creek near Whitewater Colo.	None	38°58'08"	108°28'00"	12-8-77	.5	---	1,260	808	---	---	400	---
38	Gunnison River near Grand Junction, Colo.	09152500	38°59'00"	108°27'00"	12-8-77	680	784	1,510	1,080	---	938	723,000	724,000

Tomichi Creek

The Tomichi Creek subbasin includes the area drained by Tomichi Creek and tributaries (fig. 10). Igneous and metamorphic rocks underlie most of the subbasin, but the Mancos Shale and Dakota Sandstone are present in a few areas.

Three sampling sites were selected in this subbasin (figs. 10 and 13; table 3). Dissolved-solids concentration measured at the three sites (4-6) ranged from 167 to 195 mg/L. These values are slightly higher than would be expected in a subbasin predominantly underlain by igneous and metamorphic rocks. There are no water-quality stations in the Tomichi Creek subbasin for comparison of historical data with sample data. The estimated base-flow salt load from the Tomichi Creek subbasin was about 14,100 ton/yr at a measured discharge of 78 ft^3/s.

Upper Gunnison River

This subbasin includes the drainage area of the Gunnison River upstream from the confluence with the North Fork Gunnison River but excluding the areas contained in the East and Taylor Rivers and Tomichi Creek subbasins (fig. 10). Igneous and metamorphic rocks are adjacent to the main stem of the Gunnison River. The upper reaches of most of the tributary streams drain mostly volcanic rocks. Large areas of Mancos Shale and Dakota Sandstone underlie the west end of the subbasin.

Streamflow was sampled at 13 sites in this subbasin (figs. 10 and 13; table 3). Dissolved-solids concentration in the Gunnison River near Gunnison (site 7) was about 120 mg/L at a measured base-flow discharge of 207 ft^3/s. Most of the flow at this site comes from the East and Taylor River drainages. Downstream from this site, the Gunnison River is controlled by Blue Mesa and Morrow Point Reservoirs. Eleven tributary streams discharge directly into Blue Mesa or Morrow Point Reservoirs. Seven of these were sampled: Beaver Creek (site 8), Cebolla Creek (site 9), Lake Fork Gunnison River (sites 10 and 11), East Elk Creek (site 12), Soap Creek (site 13), Curecanti Creek (site 14), and Big Blue Creek (site 15). The dissolved-solids concentration at these sites ranged from about 60 to 123 mg/L. The discharge of these seven tributaries ranged from 3.9 to 39 ft^3/s. The total combined discharge was 99 ft^3/s, and the combined base-flow salt load was 9,100 ton/yr. These tributaries drain primarily igneous and metamorphic rocks in the lower reaches and volcanic rocks in the upper reaches. Most of the flow in these streams is probably from the volcanic rocks.

The Lake Fork of the Gunnison River was sampled near its mouth and also in the headwaters region near Lake City, Colo. Most of the flow of the Lake Fork of the Gunnison River was produced in the headwaters region, which contains predominantly volcanic rocks. Combined discharge of the four streams not sampled that discharge directly into the reservoirs was estimated at 15 ft^3/s adding 1,400 ton/yr base-flow salt load based on the results measured at the other seven sites.

The dissolved-solids concentration in the Cimarron River (site 16) was 374 mg/L. This relatively large value is most likely due to the Mancos Shale that underlies the lower reaches of the river. The dissolved-solids concentration, adjusted for the effects of Blue Mesa and Morrow Point Reservoirs, in the Gunnison River below Gunnison Tunnel (site 17), was 137 mg/L at an adjusted flow of 420 ft^3/s.

The dissolved-solids concentration in the Smith Fork (site 18) was 2,310 mg/L. This large value is probably a result of the large area of Mancos Shale that underlies the drainage. The base flow in the Smith Fork was only 2.8 ft^3/s. The adjusted dissolved-solids concentration in the Gunnison River above the North Fork (site 19) was 145 mg/L. This is only slightly greater than the value below the Gunnison Tunnel and reflects the small discharge from the Smith Fork and other tributaries. Igneous and metamorphic rocks underlie this stretch of the main stem of the Gunnison River, but the Dakota Sandstone and Mancos Shale underlie most of the tributaries.

No water-quality gaging stations are in this subbasin and, therefore, no comparison of sample data with historical data was possible. The upper Gunnison River subbasin contributed an estimated 28,400 ton/yr of base-flow salt load adjusted for reservoir effects. The estimate is relatively low considering the combined measured base-flow discharge of 190 ft^3/s contributed by the subbasin drainage. The low value is due to the predominance of igneous rocks beneath the drainages north and south of Blue Mesa and Morrow Point Reservoirs. The Cimarron and Smith Fork Rivers, which are underlain by areas of Mancos Shale, contributed an estimated 7,700 and 6,400 ton/yr of salt, respectively. These two rivers contributed about 50 percent of the estimated annual base-flow salt load produced by the subbasin but only about 13 percent of the measured base-flow discharge from the subbasin.

North Fork Gunnison River

This subbasin includes the drainage area of the North Fork Gunnison River (fig. 10). The Wasatch Formation of Paleocene and Eocene age is at higher altitudes, the Mesaverde Group at middle altitudes, and the Mancos Shale at lower altitudes. Intrusive igneous rocks are locally present along the southern and eastern parts of the subbasin.

Five sampling sites were selected in this subbasin (figs. 10 and 13; table 3). Dissolved-solids concentration were 182 mg/L in Muddy Creek (site 20) and 93 mg/L in Anthracite Creek (site 21). These creeks drain predominantly the Wasatch Formation. The dissolved-solids concentration in Cottonwood Creek (site 22) was 4,640 mg/L, in Leroux Creek (site 23) 1,090 mg/L, and in the North Fork Gunnison River near the mouth (site 24) 1,170 mg/L. These large values are due to salt from the Mancos Shale that underlies the lower part of the subbasin. No adjustment was made for the effects of Paonia Reservoir.

No water-quality gaging stations are located within the subbasin; and, therefore, no comparison of sample data with historical data was possible. The North Fork Gunnison River subbasin contributed an estimated 72,600 ton/yr of base-flow salt load at a measured discharge of 63 ft^3/s. This fairly large salt load is produced primarily in the lower reaches of the subbasin by the Mancos Shale. This subbasin alone contributed a larger estimated base-flow salt load per year than the combined estimated base-flow salt load from East and Taylor Rivers, Tomichi Creek, and upper Gunnison River subbasins. The subbasin had a measured base-flow discharge of only 14 percent of the combined base-flow discharge from those three subbasins.

Uncompahgre River

This subbasin includes the drainage area of the Uncompahgre River (fig. 10). The headwaters areas of the subbasin are underlain primarily by volcanic rocks. The remainder of the subbasin is underlain primarily by sedimentary rocks. Upland areas along the western part of the subbasin are generally Dakota Sandstone. In the eastern part of the subbasin, upland areas are underlain principally by glacial till and other unconsolidated rocks of Quaternary age. The subbasin at lower altitudes is underlain primarily by large areas of the Mancos Shale.

Nine sampling sites were selected in the Uncompahgre River subbasin (figs. 10 and 14; table 3). Dallas Creek (site 25), Cow Creek (site 26), the Uncompahgre River at Colona (site 27), and Horsefly Creek (site 28) had dissolved-solids concentrations ranging from about 440 to about 710 mg/L. The drainage basins of all of these streams are underlain by the Mancos Shale, which is probably responsible for the relatively large dissolved-solids concentrations. Dissolved-solids concentrations at the five remaining sites (29-33) in the subbasin ranged from about 1,100 to about 2,300 mg/L. All these drainages are underlain by extensive deposits of Mancos Shale and also may be influenced by the residual effects of extensive irrigation within the basin.

A water-quality station is located on the Uncompahgre River at Delta, Colo., (site 33). Average dissolved-solids concentration at this station for December, January, and February of water year 1977 was 1,760 mg/L, which is only a 3-percent difference from the measured value of 1,820 mg/L at this site. The Uncompahgre River subbasin contributed an estimated base-flow salt load of 323,000 ton/yr and had a base-flow discharge of 180 ft^3/s. The drainage area upstream from Colona, Colo., (site 27) produced an estimated base-flow salt load of 56,000 ton/yr, which represents about one-sixth of the total estimated base-flow salt load from the subbasin. The drainage area between Colona and the mouth of the Uncompahgre River produced an estimated base-flow salt load of about 267,000 ton/yr and a discharge of 90 ft^3/s. Estimates using measured tributary inflow accounted for only 138,200 ton/yr of the estimated base-flow salt load but accounted for all of the additional discharge. This indicates that direct channel erosion of the Mancos Shale by the Uncompahgre River may have produced an estimated 129,000 ton/yr of base-flow salt load. The Uncompahgre River subbasin contributed an estimated 2.4 times more base-flow salt load than the combined estimated base-flow salt load of the four other previously discussed subbasins.

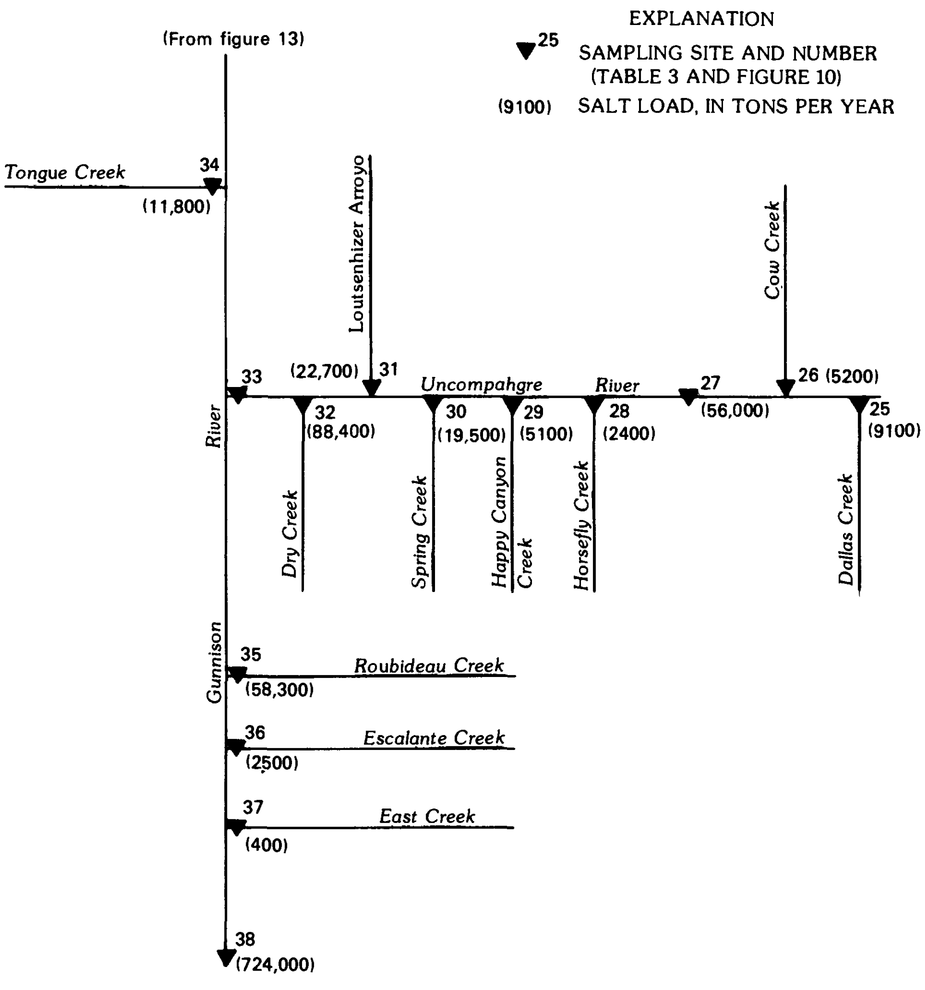


Figure 14.--Drainage system and salt load: Gunnison subregion downstream from Tongue Creek.

Lower Gunnison River

The lower Gunnison River subbasin encompasses the drainage area of the lower Gunnison River upstream from the confluence with the Colorado River excluding the five other subbasins discussed previously (fig. 10). In the southwestern part of the subbasin, Jurassic sandstones and shales of the Morrison Formation underlie the headwaters areas of most of the tributary streams. At lower altitudes, the Morrison Formation is exposed only adjacent to the stream channel, and the Dakota Sandstone is found elsewhere. In the northern and eastern parts of the subbasin, the Mesaverde Group is in upland areas and the Mancos Shale at lower altitudes. In some areas the Dakota Sandstone is locally present.

Five sampling sites were selected in the lower Gunnison River subbasin (figs. 10 and 14; table 3). The dissolved-solids concentrations in Tongue Creek (site 34) were 1,760 mg/L and in Roubideau Creek (site 35) were 1,600 mg/L. These relatively large values are probably a result of the erosion of outcrops of Mancos Shale in the drainages of these creeks. Escalante Creek (site 36) had dissolved-solids concentrations of 382 mg/L, and East Creek (site 37) had dissolved-solids concentrations of 808 mg/L. These creeks drain areas underlain primarily by the Dakota Sandstone and the Morrison Formation.

The dissolved-solids concentration in the Gunnison River near Grand Junction, Colo., (site 38), adjusted for the effects of Blue Mesa and Morrow Point Reservoirs, was 938 mg/L at an adjusted discharge of 784 ft^3/s. At site 38, comparison of the measured dissolved-solids concentration, 1,080 mg/L, with the historical mean for December, January, and February for water years 1976 and 1977 from a water-quality station at this site, shows the measured value to be about 80 percent greater than the mean value of 600 mg/L. Measured flow, 680 ft^3/s, was about 29 percent of the historical base-flow average of 2,357 ft^3/s. The large difference between measured data and mean average data at this site is most likely a result of regulation of flow by Blue Mesa and Morrow Point Reservoirs.

The lower Gunnison River subbasin contributed an estimated base-flow salt load of 265,000 ton/yr at a discharge of about 99 ft^3/s. Measured tributary inflow accounted for an estimated 73,000 ton/yr of the base-flow salt load and for 51 ft^3/s of the estimated base-flow discharge. The remaining estimated base-flow salt load of 92,000 ton/yr is probably produced by unmeasured tributary inflow, residual irrigation return flow, and channel erosion of the Mancos Shale by the Gunnison River.

Salt-load distribution

The adjusted estimated base-flow salt load of the Gunnison subregion was 724,000 ton/yr, using an adjusted base-flow discharge of 784 ft^3/s (fig. 14). These figures were adjusted to account for the effects of Blue Mesa and Morrow Point Reservoirs. The areal distribution of the sources of base-flow salt load and discharge for the Gunnison River basin is as follows: The East and Taylor Rivers, Tomichi Creek, and upper Gunnison River subbasins produce about 9 percent of the estimated base-flow salt load and about 56 percent of the estimated base-flow discharge; the North Fork Gunnison River subbasin produces about 10 percent of the estimated base-flow salt load and about 8 percent of the estimated base-flow discharge; the Uncompahgre River subbasin produces about 45 percent of the estimated base-flow salt load and about 23 percent of the estimated base-flow discharge; and the lower Gunnison River subbasin produces about 37 percent of the estimated base-flow salt load and about 13 percent of the estimated base-flow discharge.

A plot of salt load, dissolved-solids concentration, and discharge for the main stem of the Gunnison River (fig. 15) graphically depicts the impact of these sources on the salinity levels of the Gunnison River. Little change in salt load or dissolved-solids concentration is apparent until the confluence with the North Fork Gunnison River. Downstream from there the trend toward a sharp increase in dissolved-solids concentration and salt load is apparent. The most apparent impact is the large increase in salinity levels of the Gunnison River by the addition of the Uncompahgre River.

A comparison of the estimated base-flow salt load of 724,000 ton/yr with the total annual salt load of 1,364,600 ton/yr reported by BLM (Bentley and others, 1978) indicates that about 53 percent of the total estimated annual salt load for the Gunnison River basin is contributed by ground-water sources.

Colorado Lower Headwaters Subregion

The Colorado lower headwaters subregion consists of the drainage area of the Colorado River between approximately the Colorado-Utah State line and Glenwood Springs but excluding the Gunnison River basin. The subregion has a drainage area of about 3,800 mi^2 (fig. 1). Average annual precipitation ranges from less than 8 to more than 40 in.

West of Glenwood Springs, the Colorado River flows through a relatively low-lying arid region. Most of the smaller tributaries in this reach are ephemeral. Between Glenwood Springs and Grand Junction, the largest tributary to the Colorado River is Plateau Creek, which has a mean annual discharge of about 130,000 acre-ft or about 100 acre-ft/mi^2. The mean annual dissolved-solids concentration of Plateau Creek is approximately 340 mg/L. At Grand Junction, the Gunnison River joins with the Colorado River. The Colorado River at the Colorado-Utah State line has a mean annual discharge of about 4.3 million acre-ft and a mean annual dissolved-solids concentration of about 600 mg/L.

The Colorado lower headwaters subregion is underlain principally by Tertiary sandstone, mudstone, claystone, and shale of the Wasatch and Green River Formations. Oil shale is present in the Green River Formation. Cambrian, Ordovician, Devonian, and Mississippian rocks, and exposures of the Dakota Sandstone, Mancos Shale, Mesaverde Group, and related formations are found in the Grand Hogback. The Grand Valley near Grand Junction consists mainly of Mancos Shale.

Measurements of specific conductance and stream discharge at 19 sites were made in the Colorado lower headwaters subregion (fig. 16). Samples were collected for chemical analyses at five sites. Dissolved-solids concentrations for the remaining 14 sites were calculated using a linear regression analysis (fig. 17) of specific conductance measured at these five sites versus dissolved-solids concentration determined in the laboratory. Values of discharge, specific conductance, dissolved-solids concentration, and salt load for each site are presented in table 4. The subregion was not divided into any subbasins. The data for sites in the Colorado lower headwaters subregion are shown in figures 16 and 18 and in table 4.

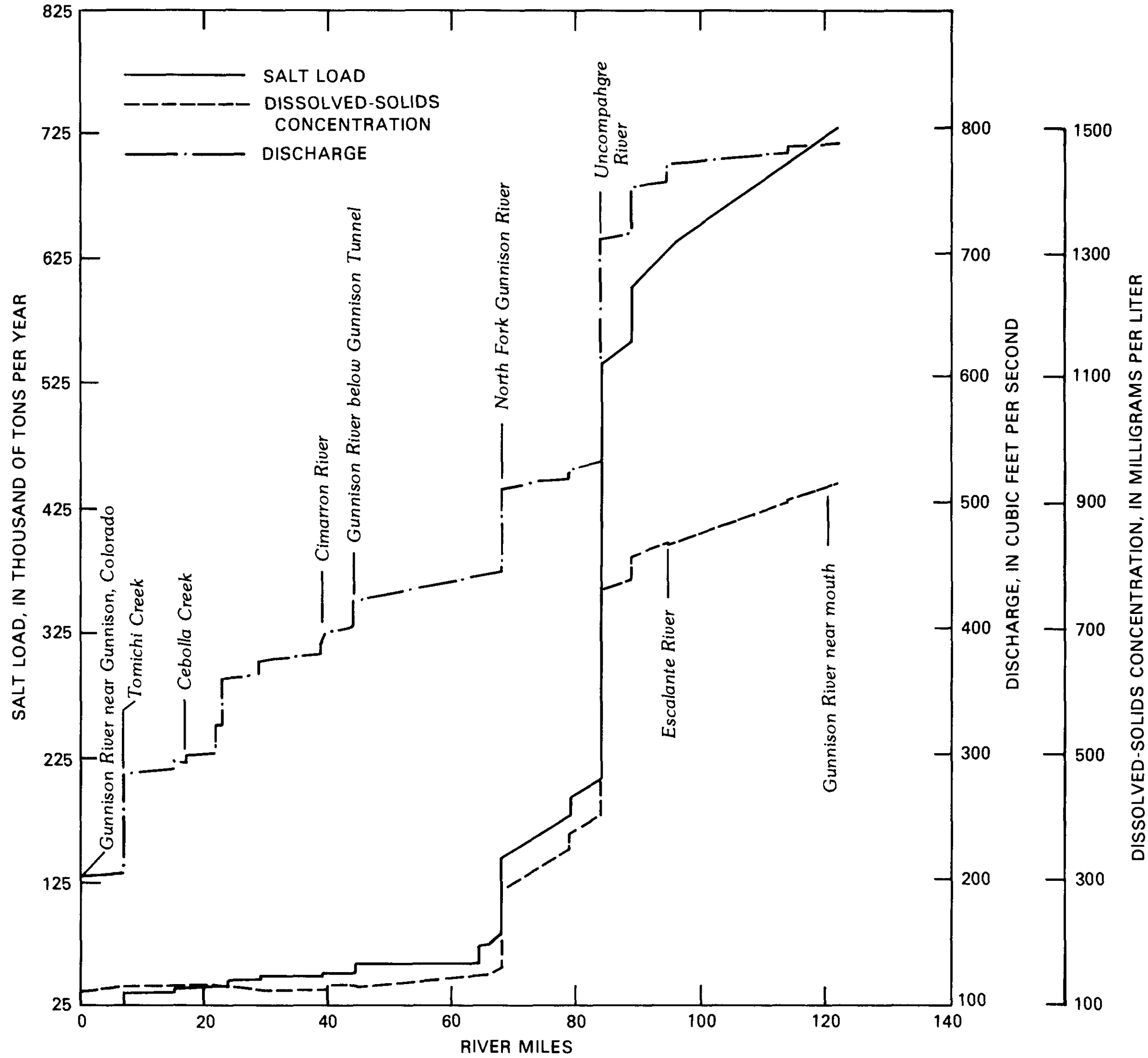
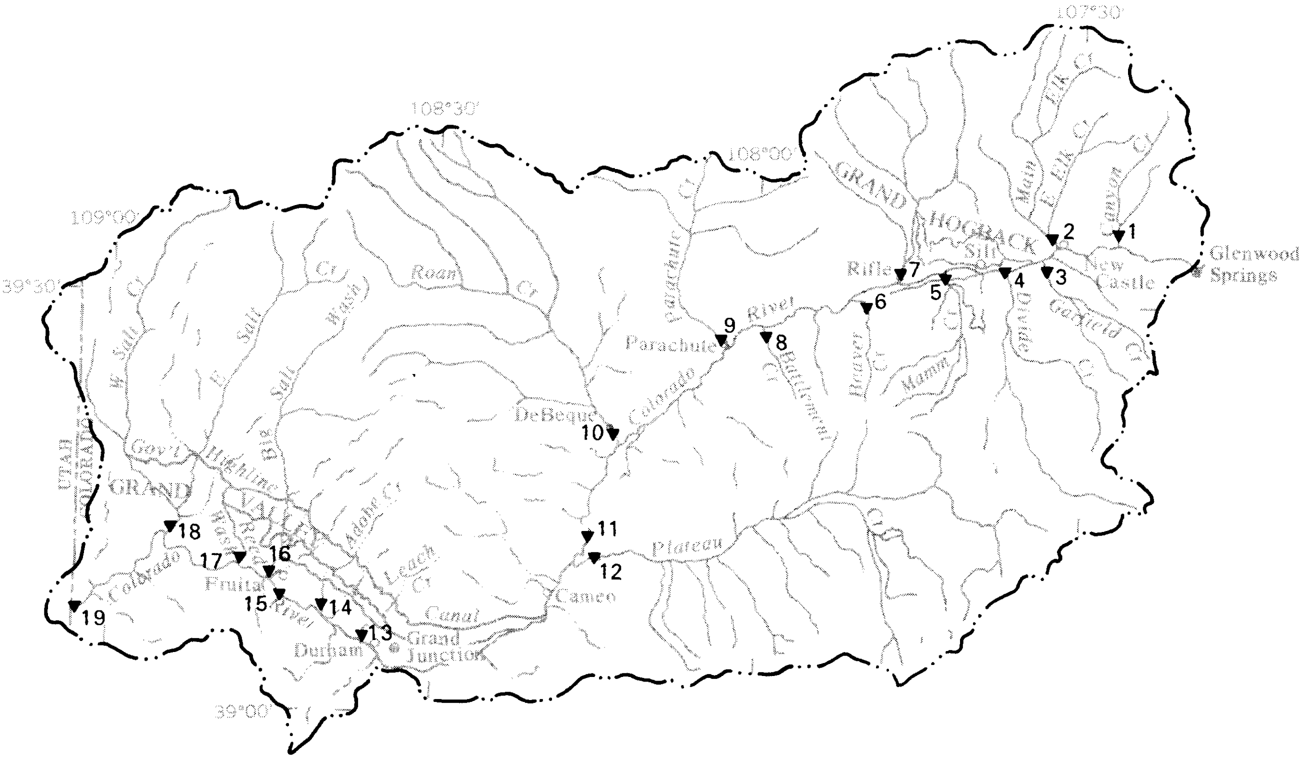


Figure 15.--Salt load, dissolved-solids concentration, and discharge: main-stem Gunnison River.

EXPLANATION

▼1 SAMPLE SITE – Number corresponds to site number in table 4

—·· — SUBREGION BOUNDARY



Base from U.S. Geological Survey 1:500 000, Colorado State base map, 1969, and Utah State base map, 1958

0 10 20 30 MILES

0 10 20 30 KILOMETERS

Figure 16.--Location of sample sites: Colorado lower headwaters subregion.

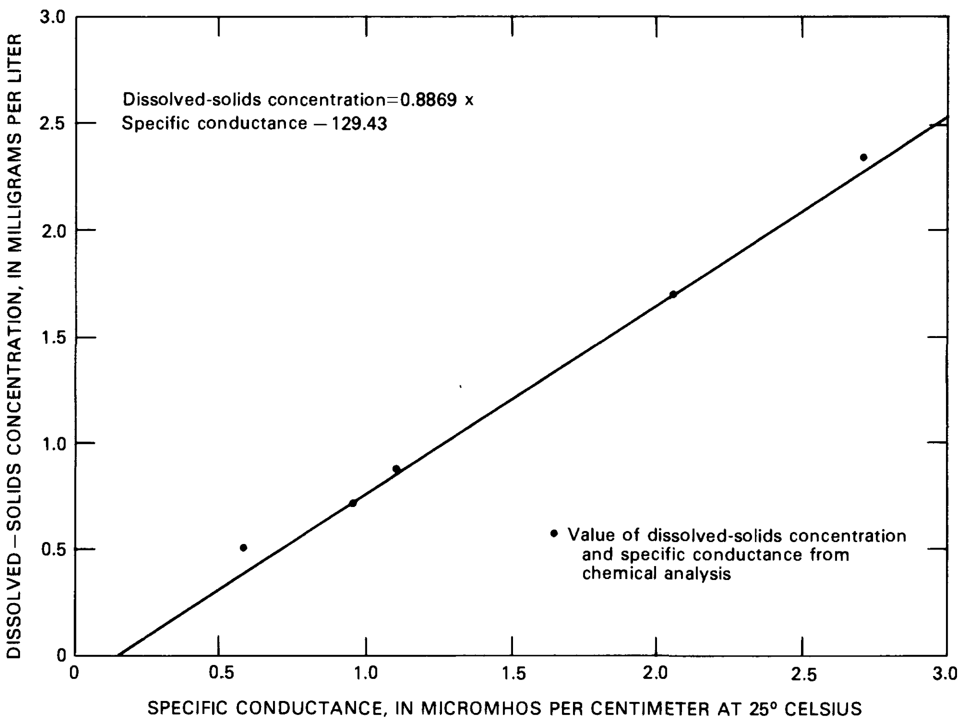


Figure 17.--Specific conductance versus dissolved-solids concentration: Colorado lower headwaters subregion.

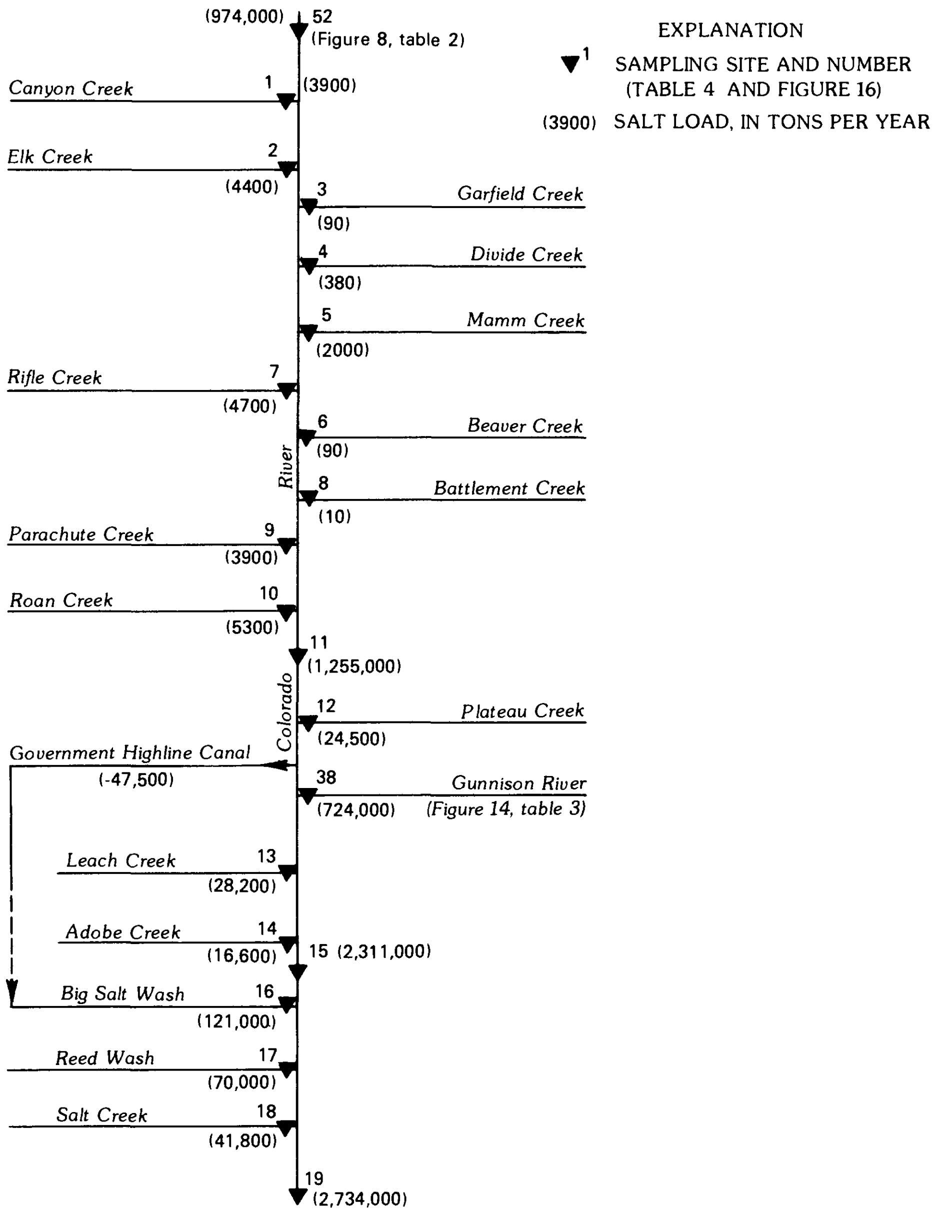


Figure 18.--Drainage system and salt load: Colorado lower headwaters subregion.

Table 4.--*Discharge, specific conductance, dissolved-solids concentration, and salt loads: Colorado lower headwaters subregion*

[ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25° Celsius; mg/L, milligrams per liter; tons/yr, tons per year; dashes indicate not applicable]

Site	Site description	U.S. Geological Survey station number	Latitude	Longitude	Sample date	Discharge (ft^3/s)		Specific conductance (µS/cm)	Dissolved solids (mg/L)			Salt load (tons/yr)	
						Measured	Adjusted		Measured	Calculated	Adjusted	Measured	Adjusted
1	Canyon Creek near mouth.	None	39°34'29"	107°26'49"	12-6-77	17	---	400	---	230	---	3,900	---
2	Elk Creek near mouth near New Castle, Colo.	None	39°34'47"	107°32'19"	12-6-77	14	---	950	721	---	---	9,900	---
3	Garfield Creek near mouth.	None	39°33'09"	107°33'29"	12-6-77	.16	---	800	---	580	---	90	---
4	Divide Creek near mouth.	None	39°32'27"	107°37'22"	12-6-77	.44	---	1,100	881	---	---	380	---
5	Mamm Creek near mouth near Silt, Colo.	None	39°31'50"	107°42'47"	12-6-77	1.0	---	2,400	---	2,000	---	2,000	---
6	Beaver Creek near Rifle, Colo.	09092500	39°28'19"	107°49'55"	12-6-77	.58	---	320	---	150	---	90	---
7	Rifle Creek near mouth near Rifle, Colo.	None	39°31'54"	107°47'12"	12-7-77	2.8	---	2,050	1,700	---	---	4,700	---
8	Battlement Creek near mouth.	None	39°28'14"	108°00'06"	12-7-77	.03	---	480	---	300	---	10	---
9	Parachute Creek near Parachute, Colo.	09093000	39°34'02"	108°06'37"	12-7-77	5.2	---	1,000	---	760	---	3,900	---
10	Roan Creek near mouth at De Beque, Colo.	None	39°19'53"	108°12'50"	12-7-77	2.3	---	2,700	2,340	---	---	5,300	---
11	Colorado River near Cameo, Colo.	09095500	39°14'20"	108°16'00"	12-7-77	1,320	1,306	1,250	---	980	976	1,274,000	1,255,000
12	Plateau Creek near Cameo, Colo.	09105000	39°11'01"	108°16'06"	12-7-77	48	---	580	511	---	---	24,500	---
13	Leach Creek at Durham, Colo.	09152650	39°05'27"	108°36'25"	12-7-77	15	---	2,300	---	1,910	---	28,200	---
14	Adobe Creek near Fruita, Colo.	09152900	39°08'13"	108°41'48"	12-7-77	4.0	---	4,900	---	4,220	---	16,600	---
15	Colorado River at Fruita Bridge, Colo.	None	39°08'30"	108°44'15"	12-8-77	1,970	2,060	1,500	---	1,200	1,139	2,329,000	2,311,000
16	Big Salt Wash at Fruita, Colo.	09153270	39°09'49"	108°45'01"	12-7-77	115	---	1,350	---	1,070	---	121,000	---
17	Reed Wash near Loma, Colo.	09153300	39°11'01"	108°47'12"	12-7-77	18	---	4,600	---	3,950	---	70,000	---
18	Salt Creek near Mack, Colo.	09163490	39°13'18"	108°53'32"	12-7-77	11	---	4,500	---	3,860	---	41,800	---
19	Colorado River near Colorado-Utah State Line.	09163500	39°10'00"	108°57'26"	12-9-77	2,200	2,290	1,580	---	1,270	1,212	2,752,000	[1]2,734,000

[1]Base-flow salt load may include an unquantified amount of salt load from residual irrigation return flow.

The dissolved-solids concentration of Canyon Creek (site 1) was about 230 mg/L, of Elk Creek (site 2) was 721 mg/L, and of Rifle Creek (site 7) was about 1,700 mg/L. Drainage areas of Canyon and Elk Creeks contain diverse geologic formations that are predominantly Cambrian, Ordovician, Devonian, and Mississippian rocks and other formations found in the Grand Hogback. The rocks underlying Rifle Creek are similar in the upper and middle reaches to those underlying Elk and Canyon Creeks. In the lower reaches, Rifle Creek is underlain predominantly by the Wasatch Formation. These three streams draining from the north into the Colorado River contributed a combined discharge of 33.8 ft^3/s and 18,500 ton/yr of base-flow salt load.

The dissolved-solids concentration of Garfield Creek (site 3) was 580 mg/L, of Divide Creek (site 4) 881 mg/L, and of Mamm Creek (site 5) about 2,000 mg/L. The drainages of these creeks are underlain predominantly by the Wasatch Formation, and small deposits of gravel are adjacent to the streams. The dissolved-solids concentration in Beaver Creek (site 6) was about 150 mg/L and in Battlement Creek (site 8) about 300 mg/L. These creeks are underlain primarily by the Wasatch Formation in the lower reaches and the Green River Formation in the upper reaches. The combined discharge of these five tributary streams draining from the south into the Colorado River was only 2.2 ft^3/s, and the base-flow salt-load contribution was only 2,570 ton/yr.

The dissolved-solids concentrations of Parachute Creek (site 9) was about 760 mg/L, and the dissolved-solids concentration of Roan Creek (site 10) was 2,340 mg/L. Parachute and Roan Creeks, in the lower reaches, drain the Wasatch Formation; in the upper reaches they drain the oil-shale deposits in the Green River Formation north of the Colorado River. The combined discharge of these two creeks was 7.5 ft^3/s, and the base-flow salt-load contribution was 9,200 ton/yr.

The salt load entering the subregion at the site on the Colorado River below Glenwood Springs (site 52, table 2) was measured to be 993,000 ton/yr. The measured salt load of the Colorado River at Cameo, Colo., (site 11) was 1,274,000 ton/yr. Between these two sites, there was an increase in estimated base-flow salt load of 281,000 ton/yr. Measured salt loads of tributaries accounted for an estimated 30,300 ton/yr. The remaining estimated 249,700 ton/yr was produced by other sources, possibly direct ground-water discharge to the river. Adjusting the discharge and salt load of the Colorado River at Cameo (site 11) for reservoir effects upstream changes the values to 1,306 ft^3/s and 1,255,000 ton/yr.

The largest tributary discharging into the Colorado lower headwaters subregion is Plateau Creek. Plateau Creek (site 12) had a dissolved-solids concentration of 511 mg/L at a measured discharge of 48 ft^3/s. The main stem of Plateau Creek is underlain predominantly by the Mesaverde Group in the lower reaches and the Wasatch Formation in the middle and upper reaches. Most of the tributaries to Plateau Creek have their headwaters in areas consisting mostly of the Green River Formation.

Leach Creek (site 13), Adobe Creek (site 14), Reed Wash (site 17), and Salt Creek (site 18) had dissolved-solids concentrations ranging from about 1,910 to about 4,220 mg/L at measured discharges ranging from 4.0 to 18 ft^3/s. These tributaries enter the Colorado River from the north through the Grand

Valley, which consists mainly of Mancos Shale. These creeks drain the Wasatch Formation and Mesaverde Group in the middle reaches and the Green River Formation in the headwaters region.

An estimated 50 ft^3/s of water was diverted from the Colorado River below Cameo by the Government Highline Canal. Some of this water probably filtered down the water table and returned to the Colorado River by seepage. The remaining water from the canal discharged into Big Salt Wash. This would account for the relatively high discharge of 115 ft^3/s and relatively low dissolved-solids concentration of 1,070 mg/L in Big Salt Wash (site 16) when compared with other tributary streams draining the Grand Valley.

Adjustments for effects of reservoirs in the upper Colorado River and Gunnison River subregions were applied to sites on the lower Colorado River. The adjusted dissolved-solids concentration for the Colorado River near Cameo (site 11) was 976 mg/L, for the Colorado River near the new Fruita, Colo., bridge (site 15) 1,139 mg/L, and for the Colorado River near the Colorado-Utah State line (site 19) 1,212 mg/L.

The plot of salt load, dissolved-solids concentration, and discharge of the main stem of the Colorado River as it flows through this subregion is shown in figure 19. A downstream progressive increase in salinity is apparent. Note that diversion of water from the Colorado River by the Government Highline Canal resulted in a drop in salt load and discharge but did not affect the salinity. The addition of the Gunnison River near Grand Junction caused a drop of about 100 mg/L in the dissolved-solids concentration of the Colorado River below their confluence.

Between the sites on the Colorado River near Cameo (site 11) and at the Colorado-Utah State line (site 19), the adjusted base-flow salt load increased by 1,479,000 ton/yr. The Gunnison River contributed 724,000 ton/yr, Plateau Creek contributed an estimated 24,500 ton/yr, and measured tributaries in the Grand Valley contributed 230,100 ton/yr of base-flow salt load. The remainder, an estimated 501,400 ton/yr, was probably produced by direct erosion of the Mancos Shale by the Colorado River in the Grand Valley and by the residual effects of extensive irrigation in the Grand Valley.

Measured base-flow discharges and dissolved-solids concentrations were compared with historical data from water-quality stations for the months of December, January, and February, water years 1975-77, for sites on the Colorado River near Cameo and at the Colorado-Utah State line. The measured discharge at the Cameo site was 1,320 ft^3/s or about 74 percent of the average of 1,773 ft^3/s, and the calculated dissolved-solids concentration of 980 mg/L was about 34 percent greater than the average of 732 mg/L. The measured discharge of 2,200 ft^3/s near the Colorado-Utah State line was only about 59 percent of the average of 3,742 ft^3/s, and the calculated dissolved-solids concentration of 1,270 mg/L was about 80 percent greater than the average of 705 mg/L.

At the Colorado-Utah State line, the Colorado River has an estimated adjusted base-flow salt load of 2,734,000 ton/yr (fig. 18). Approximately 1,037,000 ton/yr of this was produced within the Colorado lower headwaters

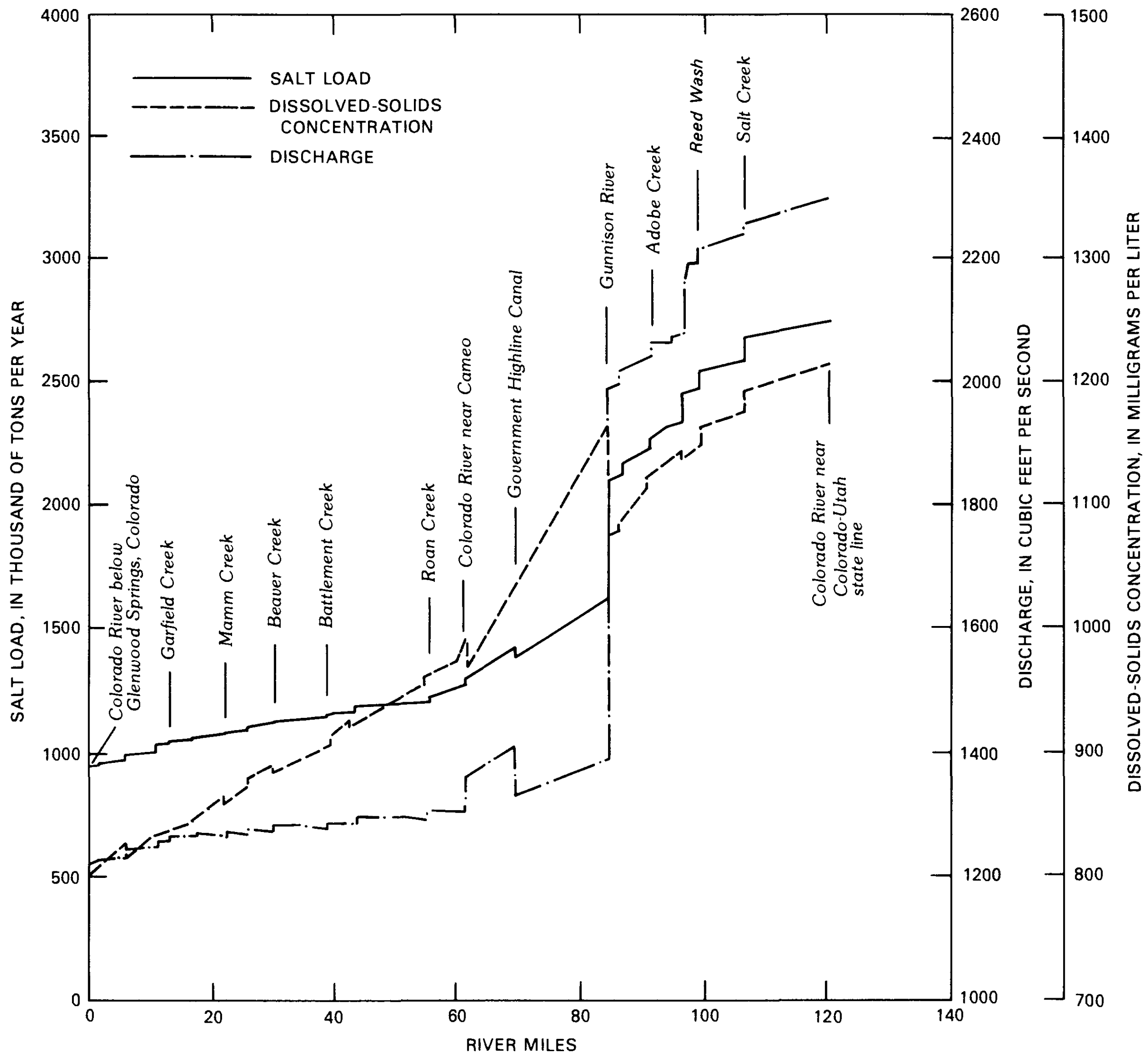


Figure 19.--Salt load, dissolved-solids concentration, and discharge: main-stem of the Colorado River in the Colorado lower headwaters subregion.

subregion. The estimated base-flow salt load of 2,734,000 ton/yr compared with the estimated total annual salt load of 3,595,000 ton/yr reported by BLM (Bentley and others, 1978) for the Colorado River at the Colorado-Utah State line indicates that about 76 percent of the total annual salt load at this site was produced by ground-water sources.

Dolores Subregion

The drainage area of the Dolores River basin is about 4,700 mi^2 (figs. 1 and 20). Annual precipitation in the basin ranges from about 12 in. to more than 50 in. Most of the precipitation is snow at altitudes above 9,000 ft.

The headwaters of the Dolores River and its only major tributary, the San Miguel River, are in the San Juan Mountains. The headwaters produce most of the water in the river. The mean annual dissolved-solids concentration of the headwaters is about 200 mg/L. Downstream from the headwaters, most tributaries are located in low-lying arid regions, and their inflow to the Dolores River is small. The mean annual discharge of the Dolores River at its mouth is about 570,000 acre-ft, and the mean annual dissolved-solids concentration is about 630 mg/L.

Measurements of specific conductance and stream discharge were made at 33 sites in the Dolores River subregion (fig. 20). Samples were collected for chemical analysis at 25 of the sites. A linear regression (fig. 21) of specific conductance measured at these 25 sites versus dissolved-solids determined in the laboratory was used to calculate dissolved-solids concentrations at the remaining eight sites. Values of discharge, specific conductance, dissolved-solids concentration, and salt load at each site are presented in table 5. For the purposes of discussion, the Dolores subregion was divided into three subbasins: upper Dolores River, San Miguel River, and lower Dolores River (fig. 20).

Upper Dolores River

This subbasin includes the drainage area of the Dolores River upstream from the confluence with the San Miguel River (fig. 20). The headwaters areas of the Dolores and West Dolores Rivers at higher altitudes consist predominantly of Pennsylvanian and Permian sandstone, siltstone, limestone, and conglomerate of the Rico and Cutler Formations. At middle altitudes the Dakota Sandstone underlies the stream channels, and Triassic and Jurassic sandstones and shales of the Morrison Formation and related formations are adjacent to the stream channels. Localized areas of Mancos Shale also occur in the northern part of the headwaters area. The geology below the confluence of the Dolores and West Dolores Rivers downstream to Disappointment Creek consists primarily of Dakota Sandstone near the main stem of the Dolores River. The area north of the Dolores River and most of the Disappointment Creek drainage is predominantly Mancos Shale. The remainder of the subbasin consists primarily of Dakota Sandstone and the Morrison Formation and some older Jurassic rocks adjacent to stream channels. The surface geology of the Paradox Valley is primarily alluvium but also contains exposures of the Paradox Member of the Hermosa Formation. The Paradox Member consists of salt, gypsum, anhydrite, black shale, sandstone, and limestone and is known to be highly saline.

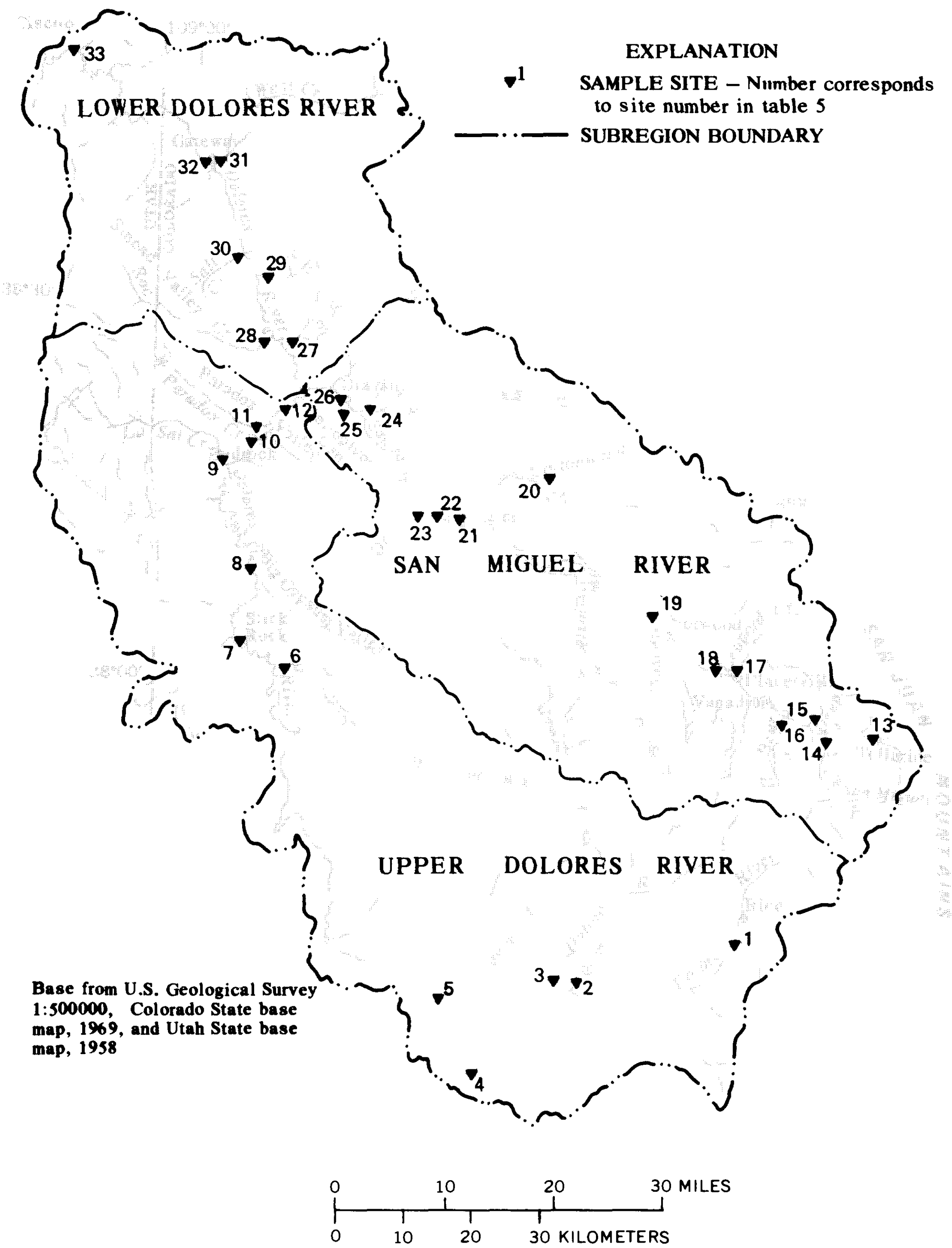


Figure 20.--Major subbasins and location of sampling sites: Dolores subregion.

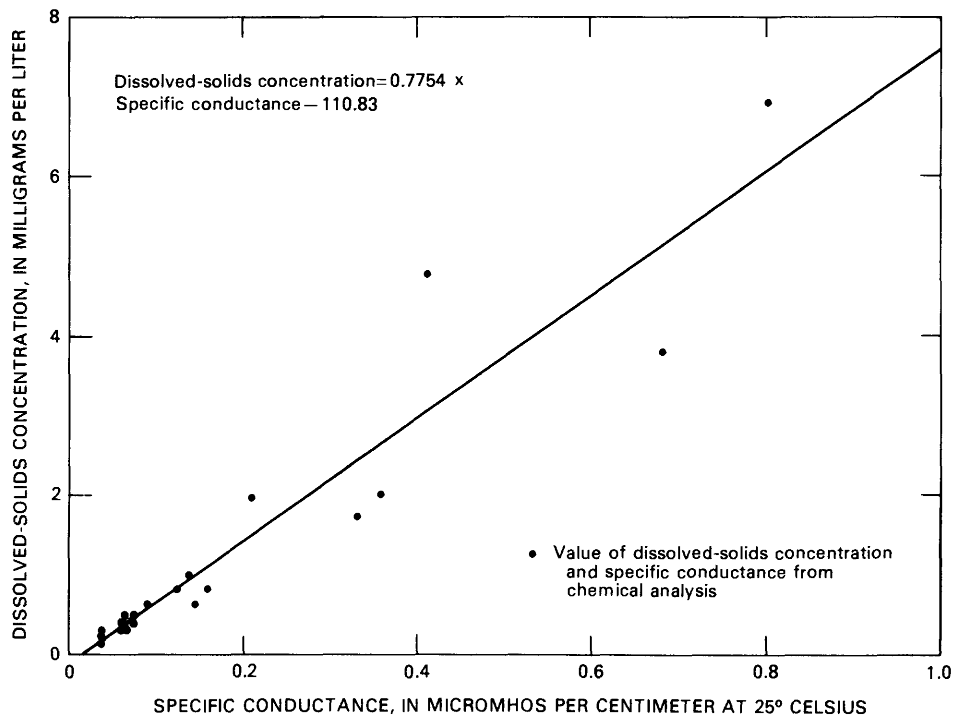


Figure 21.--Specific conductance versus dissolved-solids concentration: Dolores subregion.

Table 5.--*Discharge, specific conductance, dissolved-solids concentration, and salt loads: Dolores subregion*

[ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25° Celsius; mg/L, milligrams per liter; tons/yr, tons per year; dashes indicate not applicable]

Site	Site description	U.S. Geological Survey station number	Latitude	Longitude	Sample date	Discharge (ft^3/s)		Specific conductance (µS/cm)	Dissolved solids (mg/L)			Salt load (tons/yr)	
						Measured	Adjusted		Measured	Calculated	Adjusted	Measured	Adjusted
	UPPER DOLORES RIVER SUBBASIN												
1	Dolores River below Rico, Colo.	09165000	37°38'20"	108°03'35"	1-4-78	25	---	600	399	---	---	9,800	---
2	Stoner Creek near mouth.	None	37°35'23"	108°19'16"	1-4-78	1.1	---	360	166	---	---	180	---
3	West Dolores River near mouth.	None	37°35'22"	108°21'23"	1-4-78	13	---	750	413	---	---	5,300	---
4	Dolores River at Dolores, Colo.	09166500	37°28'16"	108°30'15"	1-4-78	33	---	650	313	---	---	10,200	---
5	Beaver Creek near mouth.	None	37°34'32"	108°33'31"	1-4-78	.17	---	640	491	---	---	80	---
6	Disappointment Creek near Slick Rock, Colo.	None	38°00'50"	108°49'50"	1-3-78	.10	---	8,000	6,940	---	---	680	---
7	Dolores River at Slick Rock, Colo.	None	38°01'50"	108°53'03"	1-3-78	38	---	800	493	---	---	18,700	---
8	Dolores River below Big Gypsum Valley near Slick Rock, Colo.	None	38°07'28"	108°52'12"	1-5-78	31	---	1,100	---	740	---	22,600	---
9	La Sal Creek near mouth.	None	38°16'44"	108°55'52"	1-5-78	7.9	---	345	---	160	---	1,200	---
10	Dolores River at Bedrock, Colo.	09169500	38°18'37"	108°53'05"	1-4-78	45	---	1,450	635	---	---	28,100	---
11	West Paradox Creek near mouth.	None	38°19'49"	108°52'27"	1-4-78	3.8	---	1,365	1,000	---	---	3,700	---
12	Dolores River near Bedrock, Colo.	09171100	38°21'29"	108°49'54"	1-4-78	48	---	6,500	3,800	---	---	180,000	---
	SAN MIGUEL RIVER SUBBASIN												
13	San Miguel River near Telluride, Colo.	None	37°56'39"	107°53'56"	1-4-78	16	---	360	228	---	---	3,600	---
14	South fork, San Miguel River near mouth.	None	37°56'13"	107°53'50"	1-4-78	62	---	340	---	150	---	9,200	---
15	Deep Creek near mouth.	None	37°57'12"	107°55'52"	1-4-78	1.0	---	450	---	240	---	240	---
16	Big Bear Creek near mouth at Vanadium, Colo.	None	37°57'58"	107°58'13"	1-4-78	.5	---	380	227	---	---	110	---
17	Leopard Creek near mouth.	None	38°01'13"	108°03'37"	1-4-78	2.4	---	440	---	230	---	540	---
18	San Miguel River near Placerville, Colo.	09172500	38°02'05"	108°07'15"	1-4-78	50	---	375	288	---	---	14,200	---
19	Beaver Creek near mouth near Norwood, Colo.	None	38°06'22"	108°11'17"	1-4-78	1.8	---	400	249	---	---	440	---
20	Cottonwood Creek near mouth.	None	38°16'07"	108°24'00"	1-4-78	.1	---	900	---	590	---	60	---

Table 5.--*Discharge, specific conductance, dissolved-solids concentration, and salt loads: Dolores subregion*--Continued

Site	Site description	U.S. Geological Survey station number	Latitude	Longitude	Sample date	Discharge (ft^3/s)		Specific conductance (μS/cm)	Dissolved solids (mg/L)			Salt load (tons/yr)	
						Measured	Adjusted		Measured	Calculated	Adjusted	Measured	Adjusted
	SAN MIGUEL RIVER SUBBASIN--Continued												
21	Naturita Creek near mouth at Naturita, Colo.	None	38°13'04"	108°32'42"	1-3-78	0.75	---	2,100	1,970	---	---	1,500	---
22	San Miguel River at Naturita, Colo.	09175500	38°13'04"	108°13'04"	1-3-78	69	---	740	528	---	---	35,900	---
23	Dry Creek near mouth near Naturita, Colo.	None	38°13'53"	108°36'00"	1-3-78	.3	---	4,100	4,770	---	---	1,400	---
24	Tabeguache Creek near Uravan, Colo.	None	38°21'28"	108°42'38"	1-4-78	.05	---	1,020	---	680	---	30	---
25	Hieroglyphic Canyon near mouth.	None	38°21'53"	108°44'08"	1-4-78	.05	---	7,700	---	5,900	---	290	---
26	San Miguel River at Uravan, Colo.	09177000	38°21'26"	108°42'44"	1-4-78	72	---	900	637	---	---	45,200	---
	LOWER DOLORES RIVER SUBBASIN												
27	Mesa Creek near mouth near Uravan, Colo.	None	38°36'19"	108°50'12"	1-4-78	.37	---	1,240	823	---	---	300	---
28	Roc Creek near mouth.	None	38°37'14"	108°51'46"	1-3-78	4.3	---	1,590	824	---	---	3,500	---
29	Blue Creek near mouth near near Gateway, Colo.	None	38°31'58"	108°53'33"	1-3-78	.91	---	580	300	---	---	270	---
30	Salt Creek near mouth near Gateway, Colo.	None	38°33'42"	108°55'10"	1-3-78	.1	---	50,000	43,000	---	---	4,200	---
31	West Creek near mouth.	None	38°40'52"	108°58'21"	1-3-78	4.7	---	420	231	---	---	1,100	---
32	Dolores River at Gateway, Colo.	None	38°40'53"	108°58'47"	1-3-78	96	---	3,300	1,740	---	---	165,000	---
33	Dolores River near Cisco, Utah.	09180000	38°47'50"	109°11'40"	1-5-78	142	---	3,575	2,020	---	---	283,000	---

Twelve sampling sites were selected in this subbasin (figs. 20 and 22; table 5). The dissolved-solids concentrations at the four sites in the headwaters area (sites 1-4) ranged from 166 to 413 mg/L. Beaver Creek (site 5) had a very small discharge of 0.17 ft^3/s and a dissolved-solids concentration of 491 mg/L. Disappointment Creek (site 6) had a very small discharge of 0.10 ft^3/s and a dissolved-solids concentration of 6,940 mg/L. Disappointment Creek is underlain by the Mancos Shale, which probably accounts for the high salinity concentration of this stream.

The dissolved-solids concentrations on the main stem of the Dolores River show a progressive increase downstream. The dissolved-solids concentration of the Dolores River at Slick Rock (site 7) was 493 mg/L and below Big Gypsum Valley near Slick Rock (site 8) was about 740 mg/L. La Sal Creek (site 9) had a dissolved-solids concentration of about 160 mg/L at a measured discharge of 7.9 ft^3/s. The headwaters of La Sal Creek are mostly underlain by Quaternary alluvium, the Morrison Formation, and hydrogeologic unit 8 (table 1). Most of the base flow of La Sal Creek probably originates from the fairly extensive alluvial deposits, resulting in the relatively low dissolved-solids concentration and relatively large base-flow discharge. The effect of La Sal Creek was to lower the dissolved-solids concentration of the Dolores River to 635 mg/L at Bedrock, Colo., (site 10).

Downstream from Bedrock, the Dolores River flows through the Paradox Valley. The dissolved-solids concentration of the Dolores River increased from 635 mg/L upstream from the valley to 3,800 mg/L downstream from the valley (site 12). The only flowing tributary along this section of the Dolores River was West Paradox Creek (site 11), which had a dissolved-solids concentration of 1,000 mg/L at a measured discharge of 3.8 ft^3/s. The very large increase in dissolved-solids concentration of the Dolores River is attributed to seepage from the Paradox Member of the Hermosa Formation. The ground water is discharged chiefly along fault zones into the shallow alluvium that covers most of the valley.

No water-quality stations are in this subbasin and, therefore, no comparison of measured and historical data was possible. The estimated base-flow salt load from the upper Dolores River subbasin was 180,000 ton/yr at a measured discharge of 48 ft^3/s. The estimated base-flow salt load for the Dolores River at Bedrock, upstream from the Paradox Valley, was 28,100 ton/yr. The difference, about 152,000 ton/yr, was contributed as the Dolores River flowed through Paradox Valley. West Paradox Creek, the only flowing tributary along this reach, had an estimated base-flow salt load of 3,700 ton/yr. Most of the remaining estimated salt load, about 148,000 ton/yr, was contributed by ground-water discharge in Paradox Valley.

San Miguel River

This subbasin includes the drainage area of the San Miguel River (fig. 23). The headwaters of the San Miguel River above Placerville are mostly underlain by volcanic rocks at the highest altitudes. Mancos Shale also underlies the headwaters, and alluvium fills the valleys. The Pennsylvanian to Jurassic rocks and Dakota Sandstone are exposed immediately

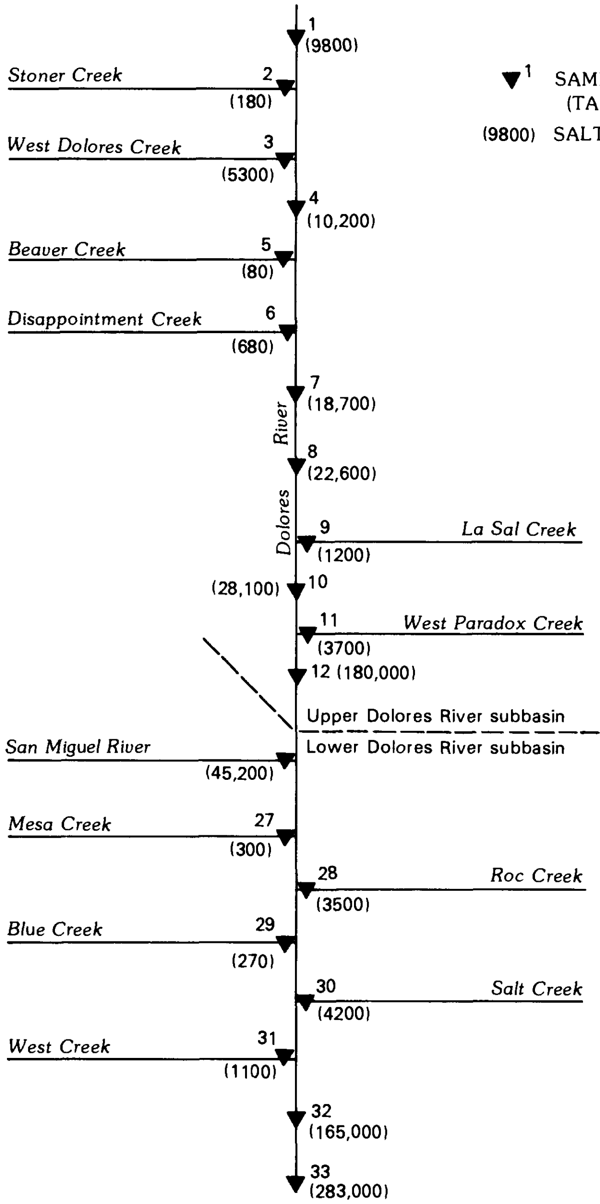


Figure 22.--Drainage system and salt load: upper and lower Dolores River subbasins.

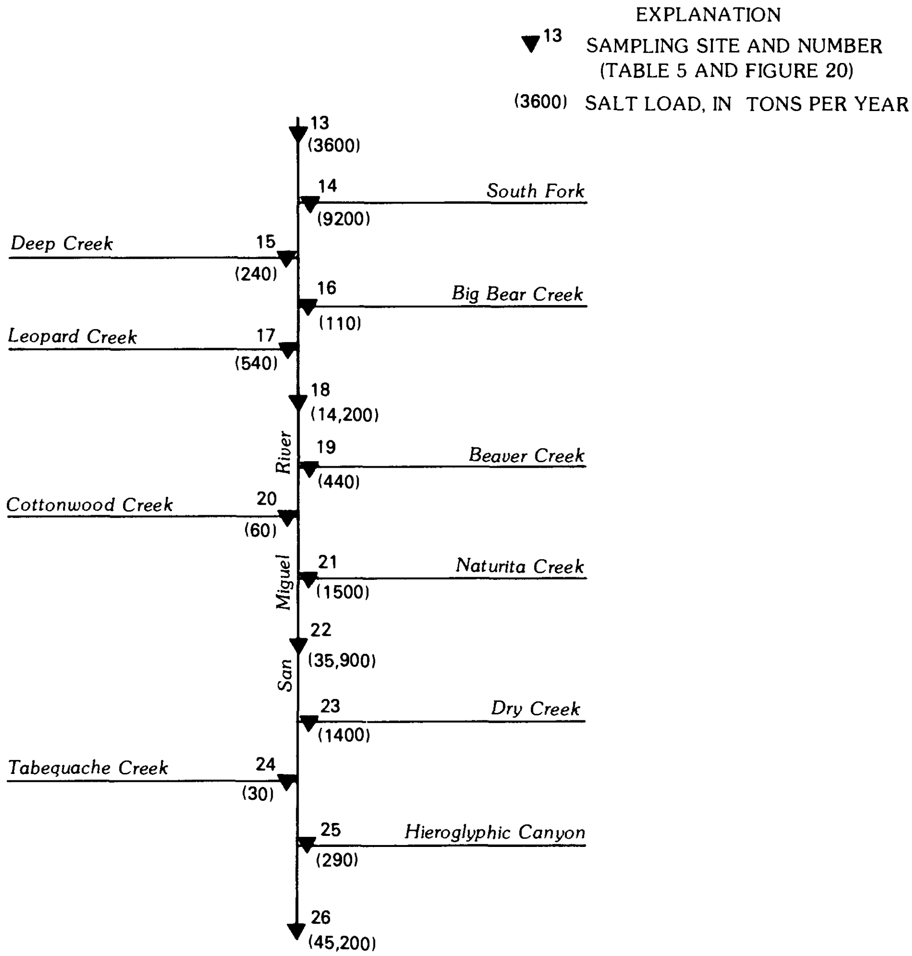


Figure 23.--Drainage system and salt load: San Miguel River subbasin.

adjacent to the stream channels. The geology of the remainder of the subbasin consists mostly of the Morrison Formation and the Dakota Sandstone principally adjacent to stream channels. Most of the southern tributaries to the San Miguel River have their headwaters in areas consisting of the Mancos Shale.

Fourteen sites were selected in this subbasin for sampling (figs. 20 and 23; table 5). Deep, Big Bear, Leopard, and Beaver Creeks (sites 15, 16, 17, and 19) had dissolved-solids concentrations ranging from 227 to 249 mg/L and a combined discharge of only 5.7 ft^3/s. Dissolved-solids concentrations in Cottonwood, Naturita, Dry, and Tabeguache Creeks and Hieroglyphic Canyon (sites 20, 21, 23, 24, and 25) ranged from about 590 to about 5,900 mg/L and had a combined discharge of only 1.25 ft^3/s.

The main stem of the San Miguel River was sampled at five sites. Most of the flow in the San Miguel River is produced in the headwaters areas. The combined measured discharge of the San Miguel River near Telluride, Colo., (site 13) and the south fork of the San Miguel River (site 14) was 78 ft^3/s, compared with a measured discharge of 72 ft^3/s in the San Miguel River near its mouth (site 26). The dissolved-solids concentration of the San Miguel River near Telluride, Colo., (site 13) was 228 mg/L; near Placerville, Colo., (site 18) 288 mg/L; at Naturita, Colo., (site 22) 528 mg/L; and at Uravan, Colo., (site 26) 637 mg/L. No geologic source could be identified as the possible cause of this downstream increase in dissolved-solids concentration. Tributary discharge into the San Miguel River is small and should not cause this increase. Residual effects of extensive irrigation in the subbasin may be a possible source.

No water-quality stations are in this subbasin; therefore, no comparison between sample and historical data was possible. The estimated base-flow salt load from the San Miguel River subbasin was 45,200 ton/yr at a measured discharge of 72 ft^3/s.

Lower Dolores River

This subbasin includes the drainage area of the Dolores River between the confluence with the Colorado River and the confluence with the San Miguel River. The subbasin is underlain by a complex of Pennsylvanian to Jurassic sandstone and shale formations, the Morrison Formation, the Dakota Sandstone, and Precambrian rocks and alluvium along the streams. The Paradox Member of the Hermosa Formation also underlies the Sinbad Valley area that is drained by Salt Creek.

Seven sampling sites were selected in this subbasin (figs. 20 and 22; table 5). The dissolved-solids concentrations measured in tributaries in the subbasin (sites 27, 28, 29, 30, and 31), with the exception of Salt Creek, ranged from 231 to 824 mg/L. The combined measured discharge of these tributaries was 10.4 ft^3/s. The dissolved-solids concentration in Salt Creek (site 30) was 43,000 mg/L. This extremely large value can be related to the Paradox Member of the Hermosa Formation, which underlies Sinbad Valley.

The Dolores River near its mouth (site 33) had a dissolved-solids concentration of 2,020 mg/L, which is about a 53-percent decrease from that of the Dolores River below Paradox Valley (site 12). This reduction in dissolved-solids concentration is probably due to the addition of less saline water from the San Miguel River. The base-flow salt load from the lower Dolores River subbasin was 57,800 ton/yr.

Comparison of measurements on the Dolores River near Cisco, Utah, (site 33) with historic data for December, January, and February for water years 1975-77 showed the measured discharge of 142 ft^3/s was about 5 percent above the average discharge of 136 ft^3/s. The measured dissolved-solids concentration of 2,020 mg/L was 52 percent of the average dissolved-solids concentration of 3,867 mg/L. Records indicate that discharge and dissolved-solids concentration at this site may vary considerably. During December, January, and February of water years 1976-77, discharge varied from 69 ft^3/s to 232 ft^3/s. Dissolved-solids concentrations varied from 1,869 mg/L to 5,380 mg/L.

Salt-load distribution

The base-flow salt load produced in the Dolores subregion was 283,000 ton/yr with a measured discharge of 142 ft^3/s. The upper Dolores River, San Miguel River, and lower Dolores River subbasins contributed 64, 16, and 20 percent respectively of the total estimated base-flow salt load and 34, 51, and 15 percent respectively of the total measured discharge. The Paradox Member of the Hermosa Formation in Paradox Valley contributed about 52 percent of the total estimated base-flow salt load.

A comparison of the estimated base-flow salt load of 283,000 ton/yr with the estimated total annual salt load of 489,800 ton/yr reported by BLM (Bentley and others, 1978) indicates that about 58 percent of the total annual salt load for Dolores subregion is contributed by ground-water sources.

The plot of salt load, dissolved-solids concentration, and discharge (fig. 24) graphically depicts the impact on the salinity level of the main-stem Dolores River from various sources. The most apparent impacts are the sharp increase in dissolved-solids concentration of the Dolores River as it flows through Paradox Valley and the sharp decrease in the dissolved-solids concentration of the Dolores River downstream from the confluence with the San Miguel River.

Colorado Subregion

The Colorado subregion includes the drainage area of the Colorado River from the Colorado-Utah State line to the confluence with the Green River, excluding the Dolores subregion (fig. 1). This subregion is underlain by Triassic and Jurassic rocks.

No data were collected in this subregion as part of the study. The U.S. Geological Survey operates a streamflow water-quality station on the Colorado River near Cisco, Utah. From a sample collected on December 13, 1977, as part of the routine operation of this site, the dissolved-solids concentration was 1,240 mg/L, discharge was 2,160 ft^3/s, and base-flow salt load was 2,638,000 ton/yr. This value compares favorably with the 2,633,000 tons as computed from all the subregions upstream from this site.

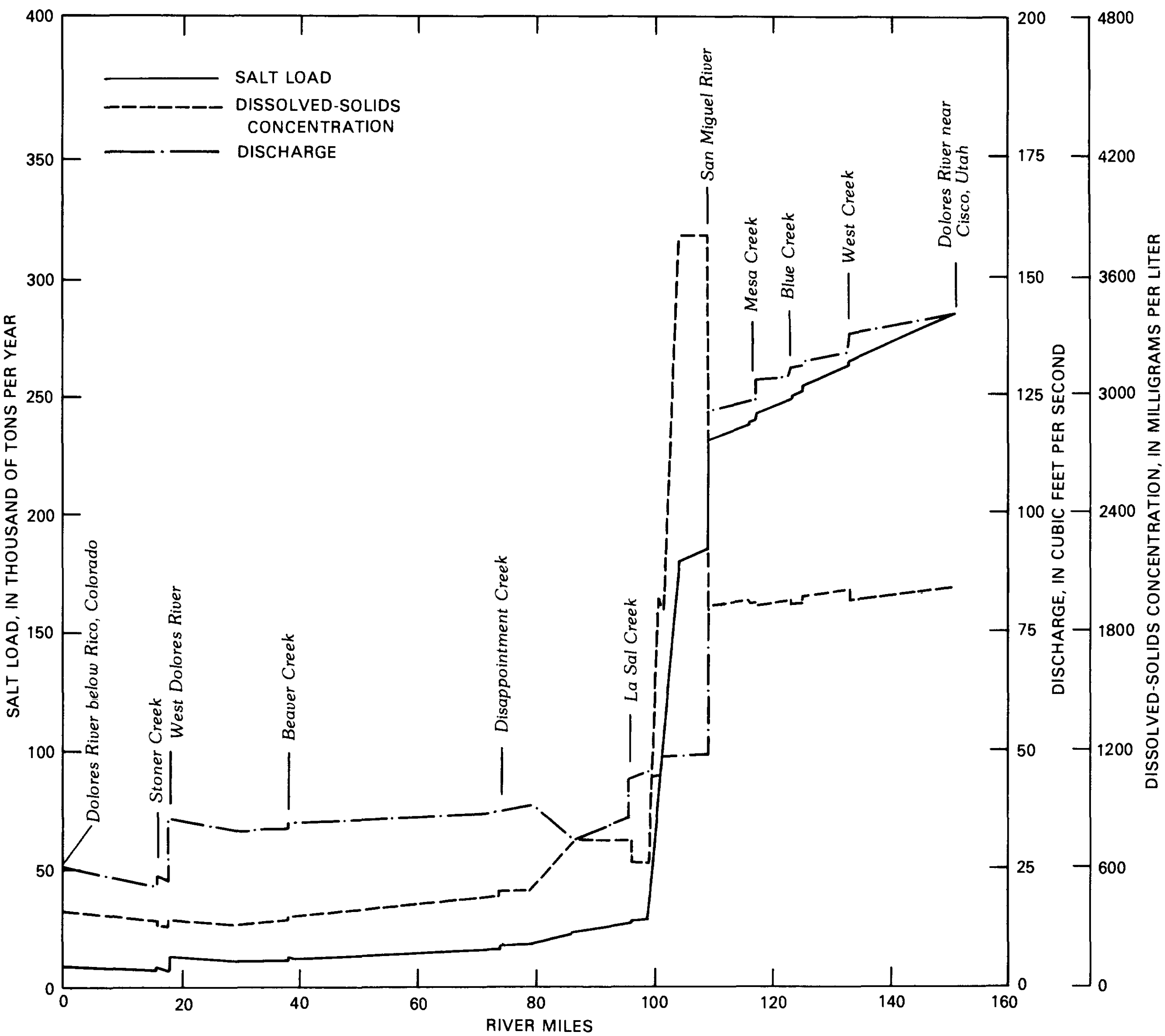


Figure 24.--Salt load, dissolved-solids concentration, and discharge: main-stem Dolores River.

Comparison of records for the past 10 years for stations on the Colorado River near Cisco, Utah, the Colorado River near the Colorado-Utah State line, and the Dolores River near Cisco, Utah, which represent virtually all of the surface-water flow in this subregion, indicates that an average of 271,700 acre-ft/yr is lost to ground water. A similar mass balance on the estimated base-flow data indicates a reduction in base-flow salt load of 385,000 ton/yr with a base-flow discharge reduction of 277 ft^3/s in the Colorado River between the streamflow-gaging station near the Colorado-Utah State line and the streamflow-gaging station near Cisco, Utah.

A comparison of the estimated base-flow salt load of 2,633,000 ton/yr with the estimated total annual salt load of 3,816,000 ton/yr reported by BLM (Bentley and others, 1978) indicates that about 69 percent of the total annual salt load for the Colorado River region is contributed by ground-water sources.

Green River Region

The drainage area of the Green River region is about 50,000 mi^2 and occupies parts of Colorado, Wyoming, and Utah (fig. 1). The average flow of the Green River above the confluence with the Colorado River is about 4.5 million acre-ft/yr. The mean annual dissolved-solids concentration is about 500 mg/L. The mean annual salt load is about 3.0 million tons.

For the purposes of discussion, the Green River region was divided into four major subregions: upper Green, Yampa, White, and lower Green.

Upper Green Subregion

The upper Green subregion includes a drainage area of about 17,000 mi^2 (figs. 1 and 25). Headwaters of the Green River are located in south-central Wyoming, in the Wind River Range. Most of the upper Green subregion is arid, receiving less than 12 in. of precipitation per year. However, precipitation may be as much as 35 in. in the higher altitudes of the Wind River Range. Two large reservoirs are located on the Green River. The Fontenelle Reservoir near La Barge, Wyo., has a capacity of about 345,000 acre-ft. This represents about 27 percent of the mean annual flow of 1.2 million acre-ft of the Green River near La Barge. Flaming Gorge Reservoir is located south of Green River, Wyo., and has a capacity of about 3.8 million acre-ft. This represents about 3 times the mean annual flow of 1.2 million acre-ft of the Green River near Green River, Wyo.

The upper Green subregion includes the Green River structural basin and is bordered on all sides by major uplifts. The Wyoming overthrust belt borders on the west, the Wind River and Sweetwater uplifts on the north, Rawlins and Sierra Madre uplifts on the east, and the Uinta uplift on the south. The Rock Springs uplift occurs in the southeastern part of the basin. Most of these features are products of the Laramide orogeny, which extended from Late Cretaceous to the Eocene. Post-Laramide deformation, mainly in the late Cenozoic, was largely responsible for the Uinta and Sweetwater uplifts. The geology of these uplifts varies considerably. The Wind River, Sweetwater, and Sierra Madre uplifts are comprised mainly of Precambrian

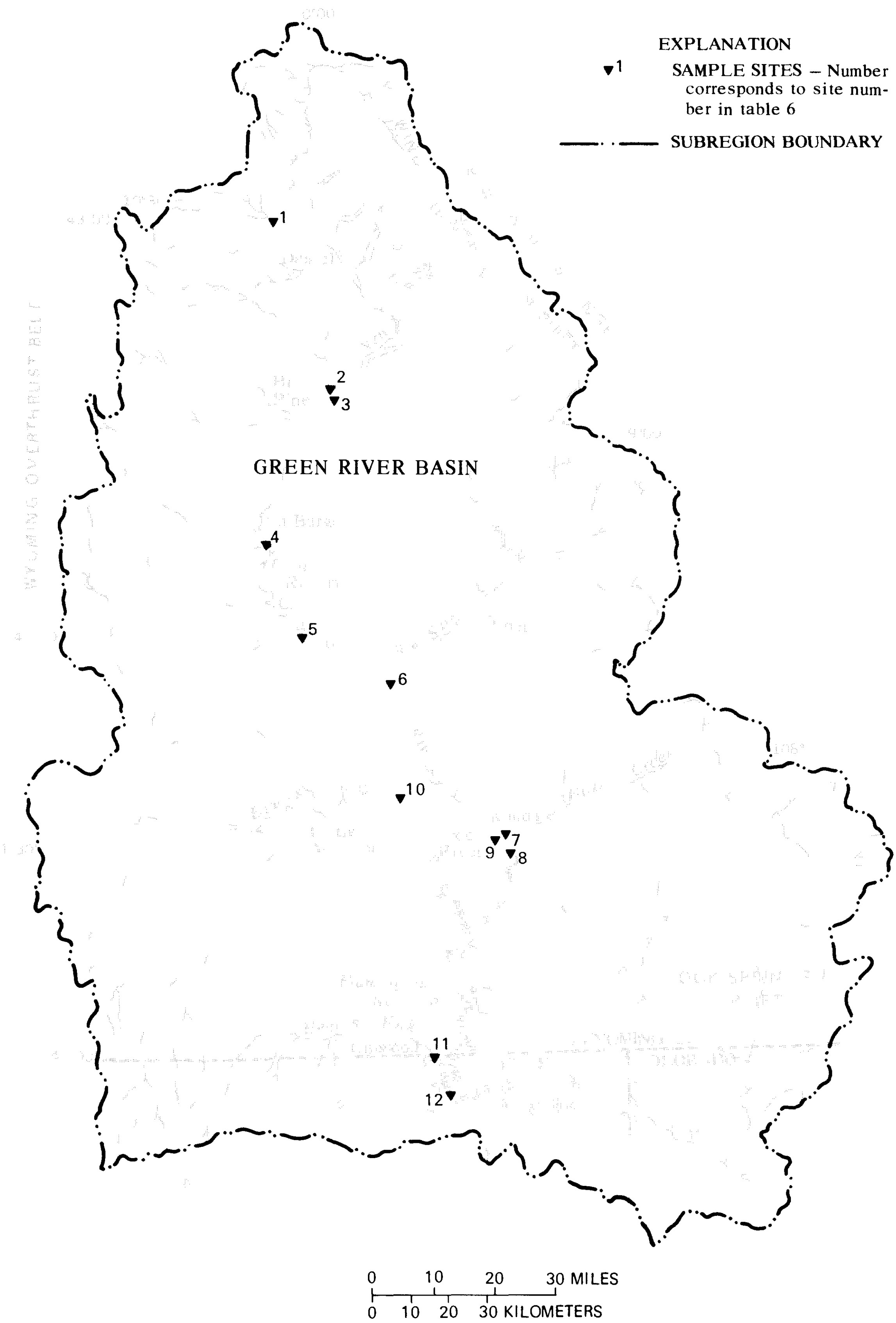


Figure 25.--Location of sites: upper Green subregion.

igneous and metamorphic rocks. The Rawlins and Rock Springs uplifts are comprised mostly of undifferentiated Triassic and Jurassic formations and the Mancos Shale, Mesaverde Group, and other related Upper Cretaceous shales. The Uinta uplift consists mostly of Precambrian, Mississippian, and Pennsylvanian sedimentary rocks. Very thick sedimentary deposits, as much as 25,000 ft, underlie most of the interior of the basin. At the surface, mostly Tertiary age formations crop out. The Wasatch Formation is found in the northern reaches of the basin along the main stem of the Green River and again in part of the basin east of the Rock Springs uplift. Rocks of the Green River Formation are found throughout most of the remainder of the interior of the basin.

No data were collected in the upper Green subregion as part of this study. However, the U.S. Geological Survey has been conducting a 5-year intensive river basin-assessment study of the Green River basin in Wyoming. As a part of that study, an extensive river water-quality sampling program was conducted. Data from 12 sites used in the river basin assessment were selected for use in this study (fig. 25). Discharge, specific conductance, dissolved-solids concentration, and salt-load values for each of the 12 sites are presented in table 6. For sites at which only specific-conductance data were available, a separate linear regression of specific conductance versus dissolved-solids concentrations was made using historical data and was used to calculate the dissolved-solids concentrations.

Discharge and chemical quality of streams in this subregion vary considerably. The dissolved-solids concentration of flows originating in the headwaters of the Green River (site 1) (table 6) was about 340 mg/L with a discharge of 94 ft^3/s. The geology in this area is undifferentiated Cretaceous through Cambrian rocks. The area is underlain by rocks ranging in age from Precambrian to Permian, by the Wasatch Formation of Paleocene and Eocene age, and by deposits of Quaternary age. The dissolved-solids concentration of the Green River near Big Piney, Wyo., (site 2) had increased to 503 mg/L with a discharge of 182 ft^3/s. This increase in discharge is due to runoff from the overthrust belt to the west. The overthrust belt in this area consists mostly of Triassic and Jurassic formations and Upper Cretaceous shales. The Wasatch Formation also is exposed extensively in the upper reaches of the Green River and probably contributes to the increase in dissolved-solids concentration.

The New Fork River (site 3) which enters the Green River from the east near Big Piney, Wyo., had a dissolved-solids concentration of about 130 mg/L with a discharge of 193 ft^3/s. The discharge of the New Fork River is slightly greater than that of the Green River at their confluence. Headwaters of the New Fork River are in the Wind River Range, which consists mainly of Precambrian igneous and metamorphic rocks of low solubility. Low salinity water from the New Fork River decreased the dissolved-solids concentration of the Green River upstream from Fontenelle Reservoir near La Barge, Wyo., (site 4) to about 270 mg/L.

The discharge and dissolved-solids concentration for all sites on the Green River below Fontenelle Reservoir were adjusted for reservoir effects.

Table 6.--*Discharge, specific conductance, dissolved-solids concentration, and salt loads: Upper Green subregion*

[ft³/s, cubic feet per second; μS/cm, microsiemens per centimeter at 25° Celsius; mg/L, milligrams per liter; tons/yr, tons per year; dashes indicate not applicable]

Site	Site description	U.S. Geological Survey station number	Latitude	Longitude	Sample date	Discharge (ft^3/s)		Specific conductance (μS/cm)	Dissolved solids (mg/L)			Salt load (tons/yr)	
						Measured	Adjusted		Measured	Calculated	Adjusted	Measured	Adjusted
1	Green River at Warren Bridge near Daniel, Wyo.	09188500	43°01'08"	110°07'03"	12-30-77	94	---	480	---	340	---	31,500	---
2	Green River near Big Piney, Wyo.	09192600	42°34'14"	109°56'58"	1-03-78	182	---	580	503	---	---	90,200	---
3	New Fork River near Big Piney, Wyo.	09205000	42°34'02"	109°55'46"	1-03-78	193	---	190	---	130	---	24,700	---
4	Green River near La Barge, Wyo.	09209400	42°11'34"	110°09'45"	12-30-77	494	---	480	---	270	---	131,000	---
5	Green River below Fontenelle Reservoir, Wyo.	09211200	42°01'16"	110°02'57"	12-30-77	763	494	[1]400	---	250	270	188,000	131,000
6	Big Sandy River at Gasson Bridge near Eden, Wyo.	09216050	41°56'43"	109°41'04"	12-29-77	23	---	5,000	---	3,900	---	88,400	---
7	Bitter Creek below Little Bitter Creek near Kanda, Wyo.	09216880	41°33'00"	109°18'15"	12-20-77	2.0	---	2,800	1,840	---	---	3,600	---
8	Green River near Green River, Wyo.	09217000	41°30'59"	109°26'54"	12-19-77	800	531	570	401	---	495	316,000	259,000
9	Green River below Green River, Wyo.	09217010	41°29'46"	109°26'17"	12-19-77	820	551	600	414	---	510	334,000	277,000
10	Blacks Fork near Little America, Wyo.	09224700	41°32'46"	109°41'34"	12-28-77	13	---	3,000	---	2,500	---	32,000	---
11	Henrys Fork near Linwood, Utah.	09229500	41°00'45"	109°40'20"	1-06-78	33	---	1,050	848	---	---	27,600	---
12	Green River near Greendale, Utah.	09234500	40°54'30"	109°25'20"	12-19-77	1,040	597	---	---	520	570	533,000	337,000

[1]Estimated value.

The adjustment factor for Fontenelle Reservoir resulted in a reduction of 269 ft^3/s below measured base flows and a reduction of 57,000 ton/yr below measured salt loads.

Between the sampling site below Fontenelle Reservoir (site 5) and the sampling site above Flaming Gorge Reservoir (site 9), the dissolved-solids concentration of the Green River increased 240 mg/L, and discharge increased 57 ft^3/s. The dissolved-solids concentration of the Big Sandy River (site 6), which enters the Green River about 20 mi downstream from Fontenelle Reservoir, was about 3,900 mg/L with a discharge of 23 ft^3/s. The Big Sandy River originates in the southern tip of the Wind River Mountains and from there flows southwesterly across a large, relatively flat, semiarid plain. Water from the Big Sandy River is used extensively for irrigation, and return flows raise the salinity levels in the river considerably. Saline springs fed naturally by ground water and by irrigation return flows also add salts to the river. Bitter Creek (site 7), which enters the Green River near Green River, Wyo., had a dissolved-solids concentration of 1,840 mg/L and a discharge of only 2 ft^3/s. Bitter Creek originates in the high plains east of the Green River. The drainage area of Bitter Creek is fairly large, but because precipitation over most of the drainage area is less than 8 in/yr, the discharge is small.

The Blacks Fork (site 10) and the Henrys Fork (site 11) (fig. 25) enter the Green River from the west at Flaming Gorge Reservoir. The dissolved-solids concentration of the Blacks Fork and Henrys Fork were about 2,500 and 848 mg/L respectively with discharges of 13 and 33 ft^3/s respectively. The headwaters of the Blacks Fork are in the Uinta Mountains and in the overthrust belt. Both Henrys Fork and Blacks Fork are used extensively for irrigation.

The adjustment for Flaming Gorge Reservoir was combined with the adjustment for Fontenelle Reservoir and applied to all downstream sites on the Green River. The combined adjustment factor for both Fontenelle Reservoir and Flaming Gorge Reservoir resulted in a reduction of 443 ft^3/s in measured base flows and a reduction of 196,000 ton/yr in measured salt loads. The adjusted dissolved-solids concentration in the Green River below Flaming Gorge Reservoir (site 12) was about 570 mg/L, and the adjusted discharge was 597 ft^3/s.

Estimated base-flow salt load for the upper Green subregion was about 337,000 ton/yr (fig. 26). Of this, about 115,000 ton/yr, about 34 percent of the total, was produced upstream with the confluence of the Green and New Fork and Rivers. This area produced about 63 percent of the estimated base-flow discharge for the subregion. The Big Sandy River contributed about 88,400 ton/yr of estimated base-flow salt load, which is about 26 percent of the total but produced only about 4 percent of the estimated base-flow discharge for the subregion. Bitter Creek, Blacks Fork, and Henrys Fork contributed a combined estimated base-flow salt load of about 63,200 ton/yr, or 19 percent of the total. The remaining estimated 70,400 ton/yr probably was produced by ground-water discharge to the Green River and unmeasured tributaries.

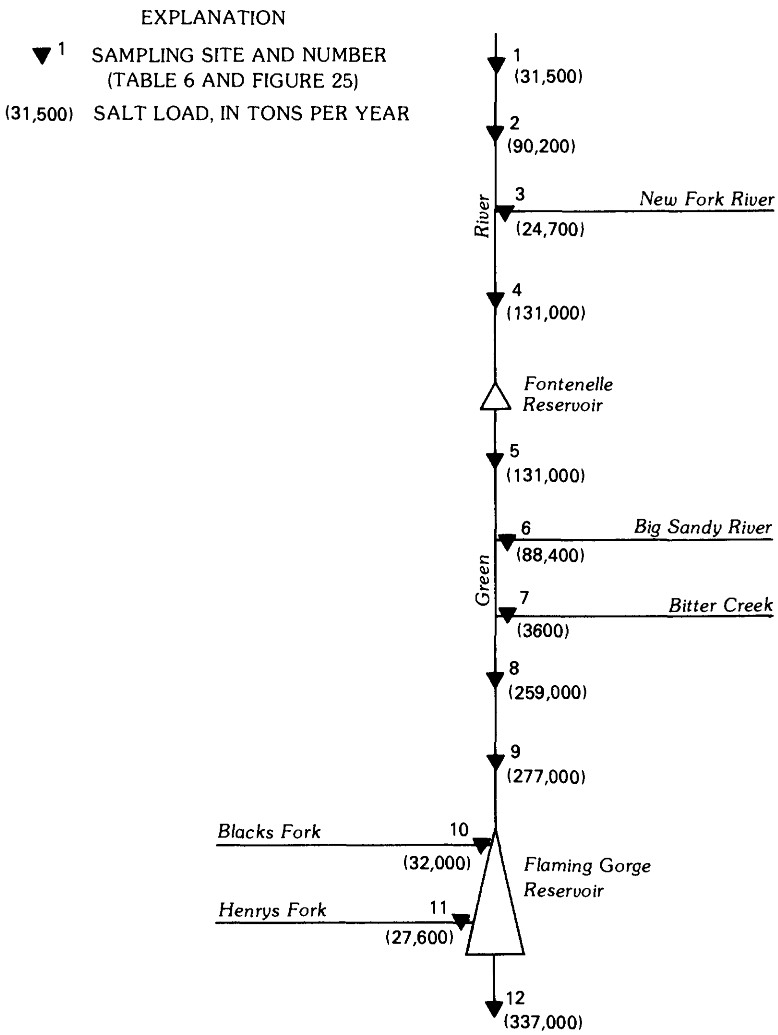


Figure 26.--Drainage system and salt load: upper Green subregion.

The plot of salt load, dissolved-solids concentration, and discharge (fig. 27) graphically depicts changes in salinity level of the main-stem upper Green River on different dates between December 19, 1977, and January 6, 1978. The two most apparent impacts are the sharp decrease in the dissolved-solids concentration in the Green River due to the addition of the New Fork River and the sharp increase in dissolved-solids concentration caused by the Big Sandy River. Downstream from the Big Sandy River there is a progressive increase in salinity level of the Green River.

A comparison of the estimated base-flow salt load of 337,000 ton/yr (fig. 26) for the upper Green subregion with a total estimated annual salt load of 1,135,000 tons reported by BLM (Bentley and others, 1978) indicates that about 30 percent of the total estimated annual salt load and about 27 percent of the discharge at this site is from ground-water sources.

Yampa Subregion

The Yampa River basin includes a drainage area of about 8,000 mi^2 (fig. 1). The Yampa River enters the Green River at Dinosaur National Monument. Annual precipitation in the basin ranges from about 12 to 50 in.

The headwaters of the Yampa River are located in the northern Colorado Rockies. The mean annual dissolved-solids concentration in the headwaters is less than 100 mg/L. The mean annual discharge of the Yampa River near its mouth is about 1.6 million acre-ft with an average annual dissolved-solids concentration of less than 200 mg/L.

The Yampa River basin is located in the southeastern corner of a regional structural depression that includes the Sand Wash and Washakie tectonic basins. The bedrock strata in the basin dip to the northwest. Precambrian igneous and metamorphic rocks underlie most of the headwaters of the Yampa River. West of Steamboat Springs, Colo., the Yampa River flows across the Mancos Shale, Mesaverde Group, and Browns Park Formation. The Little Snake River is the major tributary to the Yampa River. The headwaters region of the Little Snake River, in the southern Rocky Mountains in Wyoming, consists of igneous and metamorphic rocks. From there the Little Snake River flows west across outcrops of the Mesaverde Group, Wasatch Formation, and Browns Park Formation. Annual discharge of the Little Snake River is about 40 percent of the Yampa River. The mean annual dissolved-solids concentration of the Little Snake River is slightly greater than that of the main stem of the Yampa River.

No data were collected in the Yampa River basin as part of this study. However, the U.S. Geological Survey recently has completed a 3-year river-basin assessment in the Yampa River basin in which an extensive river water-quality sampling program was conducted. Data from 19 sites selected from this study were used to estimate the base-flow salinity contribution of the Yampa subregion (fig. 28). A linear regression of specific conductance versus dissolved-solids concentration (fig. 29) was used to calculate dissolved-solids for sites at which only specific conductance was measured. Discharge, specific conductance, dissolved-solids concentration, and salt load for each site are presented in table 7.

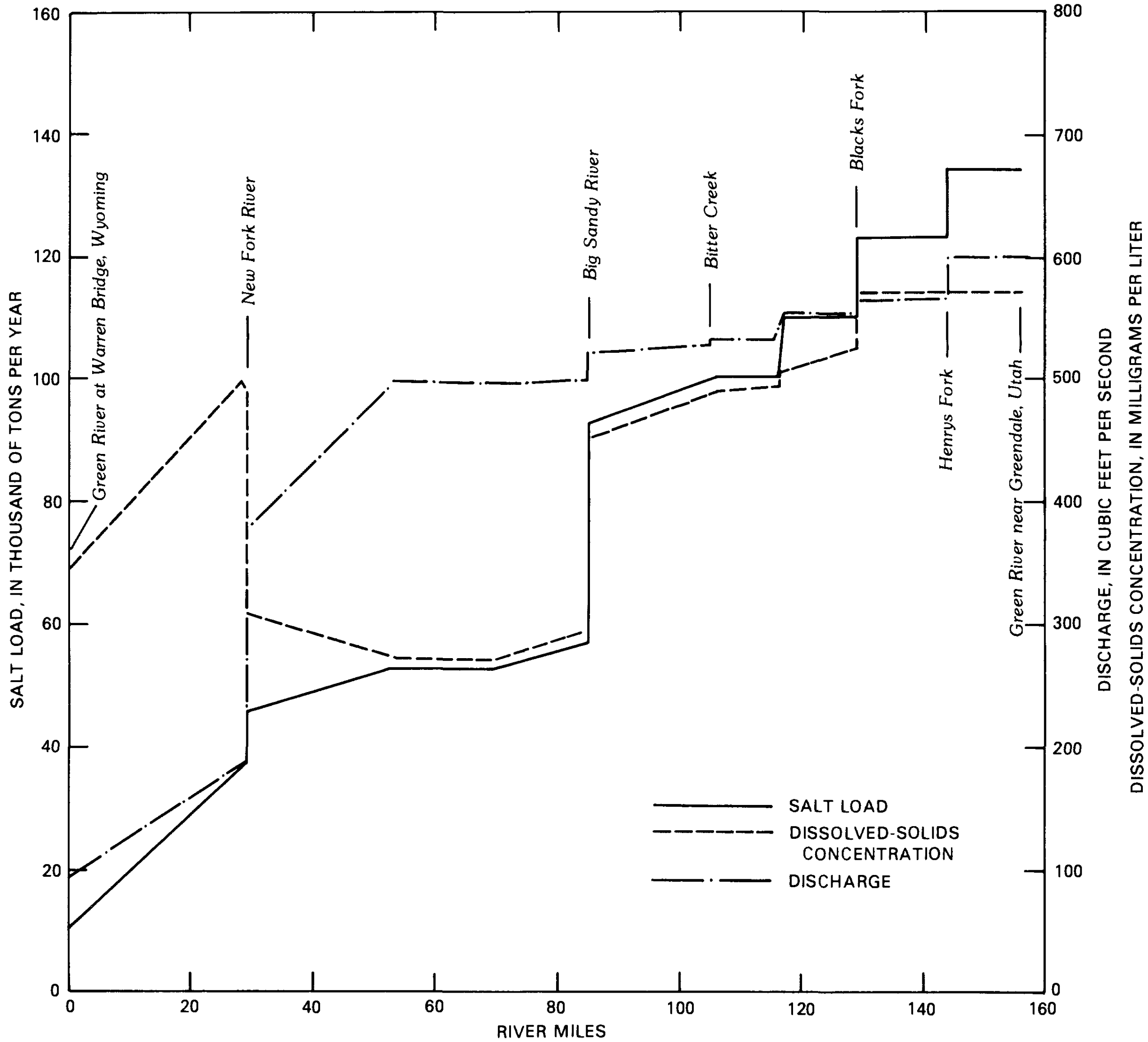


Figure 27.--Salt load, dissolved-solids concentration, and discharge: main-stem upper Green River.

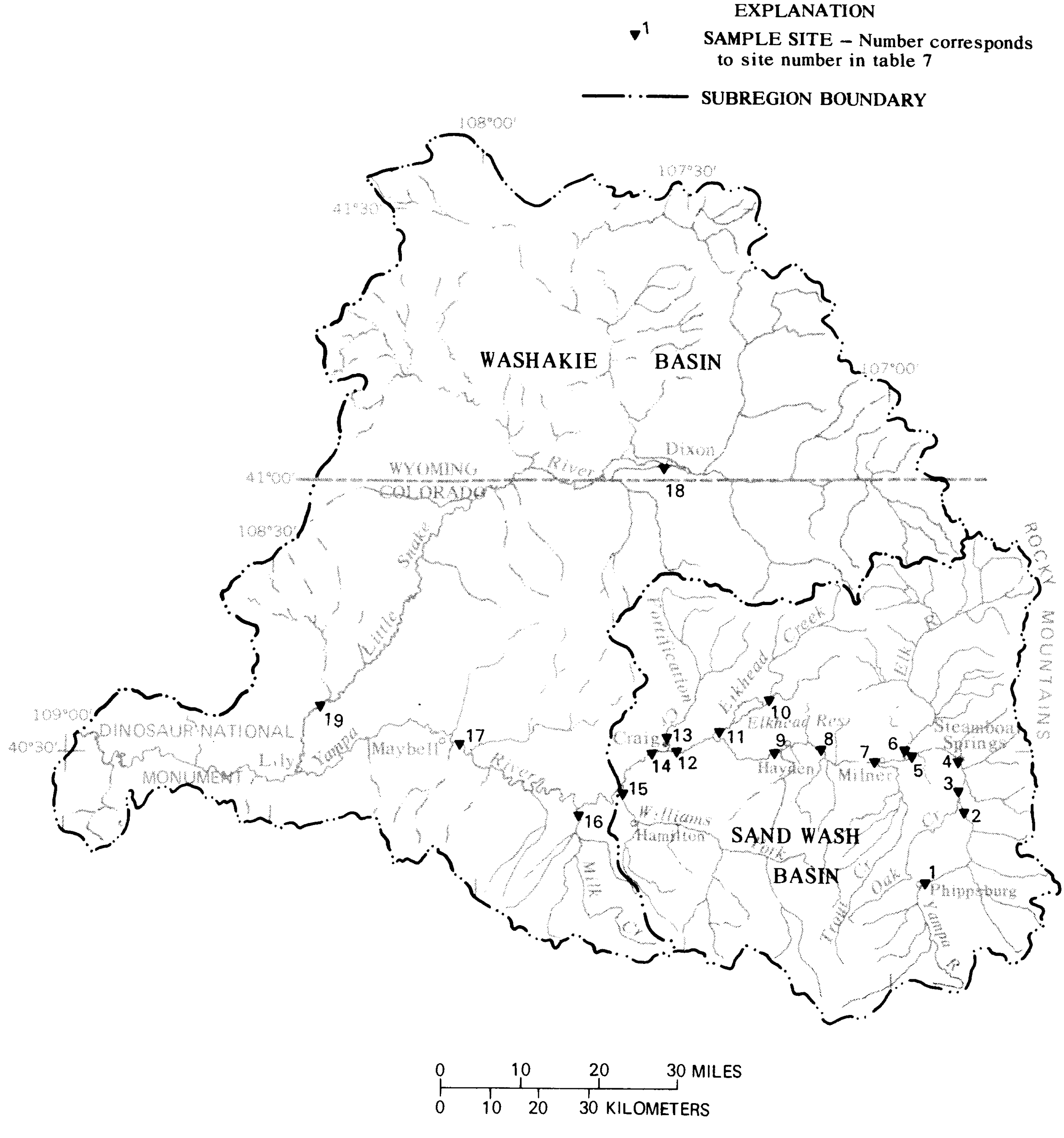


Figure 28.--Location of sites: Yampa subregion.

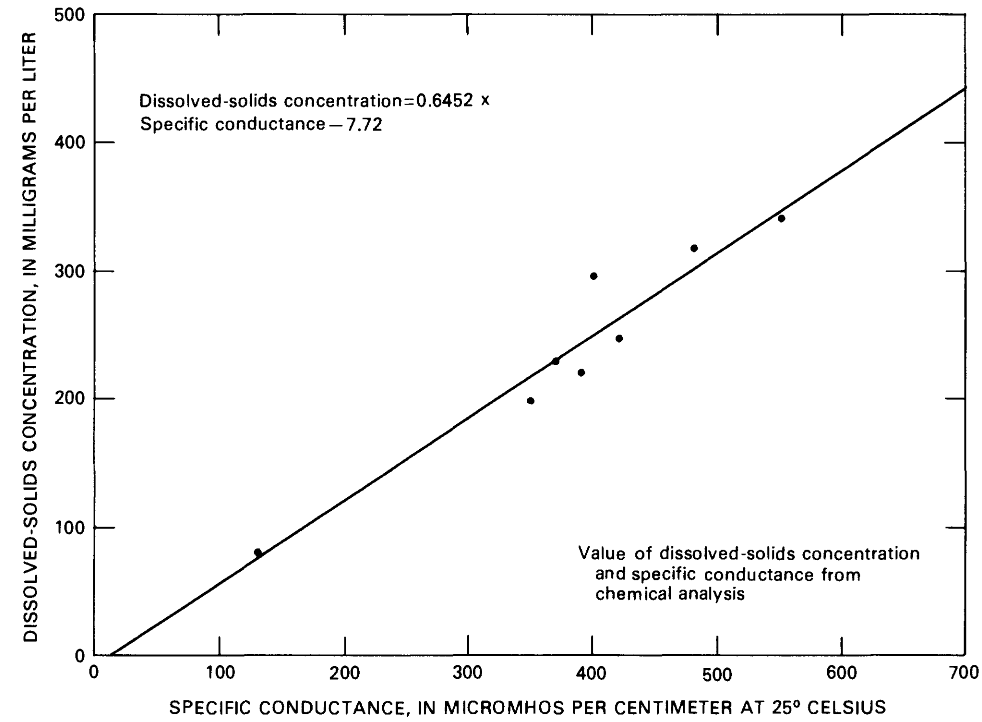


Figure 29.--Specific conductance versus dissolved-solids concentration: Yampa subregion.

Table 7.--*Discharge, specific conductance, dissolved-solids concentration, and salt loads: Yampa subregion*

[ft^3/s, cubic feet per second; μS/cm, microsiemens per centimeter at 25° Celsius; mg/L, milligrams per liter; tons/yr, tons per year; dashes indicate not applicable]

Site	Site description	U.S. Geological Survey station number	Latitude	Longitude	Sample date	Discharge (ft^3/s) Measured	Discharge (ft^3/s) Adjusted	Specific conductance (μS/cm)	Dissolved solids (mg/L) Measured	Dissolved solids (mg/L) Calculated	Dissolved solids (mg/L) Adjusted	Salt load (tons/yr) Measured	Salt load (tons/yr) Adjusted
1	Yampa River at Phippsburg, Colo.	None	40°14'18"	106°56'22"	12-8-75	60	---	330	---	200	---	11,800	---
2	Yampa River above Oak Creek.	None	40°23'56"	106°50'00"	12-2-75	76	---	320	---	200	---	15,000	---
3	Yampa River below Oak Creek.	None	42°25'44"	106°49'36"	12-9-75	91	---	290	---	180	---	16,100	---
4	Yampa River at Steamboat Springs, Colo.	09239500	40°29'01"	106°49'54"	12-1-75	69	---	270	---	170	---	11,600	---
5	Yampa River above Elk River.	None	40°29'32"	106°56'49"	12-4-75	80	---	300	---	190	---	15,000	---
6	Elk River near Trull, Colo.	09242500	40°30'53"	106°57'12"	12-3-75	103	---	130	81	---	---	8,200	---
7	Yampa River below Trout Creek.	None	40°28'54"	107°02'05"	12-5-75	185	---	300	---	190	---	34,600	---
8	Yampa River below diversion, near Hayden, Colo.	09244410	40°29'18"	107°09'33"	12-1-75	187	---	350	199	---	---	36,700	---
9	Yampa River below Hayden, Colo.	None	40°29'30"	107°17'42"	12-4-75	250	---	240	---	150	---	36,900	---
10	Elkhead Creek above Elkhead Reservoir, Colo.	None	40°35'30"	107°19'13"	12-3-75	8.2	---	370	229	---	---	1,800	---
11	Elkhead Creek near Craig, Colo.	09246500	40°31'52"	107°26'08"	12-3-75	10	---	370	---	230	---	2,300	---
12	Yampa River below Elkhead Creek near Craig, Colo.	09246550	40°29'50"	107°30'34"	12-1-75	300	---	390	220	---	---	65,000	---
13	Fortification Creek above Craig, Colo.	None	40°32'51"	107°31'42"	12-4-75	8.9	---	660	---	420	---	3,700	---
14	Yampa River below Craig, Colo.	09247600	40°29'04"	107°36'23"	12-4-75	238	---	420	248	---	---	58,100	---
15	Williams Fork at mouth at Hamilton, Colo.	09249750	40°26'14"	107°38'50"	12-4-75	51	---	400	296	---	---	14,900	---
16	Milk Creek near mouth.	None	40°21'54"	107°45'31"	12-5-75	14	---	2,100	---	1,460	---	20,100	---
17	Yampa River near Maybell, Colo.	09251000	40°30'10"	108°01'45"	12-5-75	333	---	550	341	---	---	112,000	---
18	Little Snake River near Dixon, Wyo.	09257000	41°01'42"	107°32'55"	12-5-75	88	---	340	---	210	---	18,200	---
19	Little Snake River near Lily, Colo.	09260000	40°32'50"	108°25'25"	12-8-75	157	---	480	318	---	---	49,200	---

Salt-load data for the sites in the Yampa subregion are shown in the schematic (fig. 30). Measured dissolved-solids concentration in the Yampa River above Steamboat Springs (sites 1-4) generally was less than 200 mg/L. Dissolved-solids concentration of the Yampa River between Steamboat Springs and Craig, Colo., (sites 5, 7, 8, 9, 12, and 14) increased gradually to about 250 mg/L. This slight increase in dissolved solids is primarily from ground-water discharge into the Yampa River and from channel erosion of shale layers in hydrogeologic unit 7 (table 1) and the Mesaverde Group. The Elk River (site 6), which enters the Yampa River near Milner, Colo., had a discharge of about 100 ft^3/s compared with the Yampa River discharge of only 80 ft^3/s above this point. The dissolved-solids concentration of the Elk River was about 80 mg/L. The Elk River drainage is underlain primarily by relatively insoluble igneous rocks. The lower salinity water from the Elk River reduces the dissolved-solids concentration of the Yampa River at their confluence.

Dissolved-solids concentration of the Yampa River increased about 100 mg/L to 341 mg/L between Craig, Colo., (site 14) and the confluence with the Little Snake River (site 17). Along this reach the Yampa River flows over the Mesaverde Group and the Browns Park Formation. Dissolved-solids concentration of the Williams Fork (site 15), which enters the Yampa River southwest of Craig, was about 300 mg/L. The Williams Fork predominantly drains the Mancos Shale and the Mesaverde Group, which probably accounts for the relatively higher dissolved solids. Milk Creek (site 16), which enters the Yampa River downstream from the Williams Fork, had a discharge of 14 ft^3/s with a dissolved-solids concentration of about 1,500 mg/L. The high dissolved-solids concentration of Milk Creek is due primarily to oil-field brines that discharge into the creek in the upstream part of the drainage.

The Little Snake River enters the Yampa River from the north near Lily, Colo. The dissolved-solids concentration of the Little Snake River near Dixon, Wyo., (site 18) was about 210 mg/L. Dissolved-solids concentration of the Little Snake River increased to 318 mg/L near its mouth (site 19). There are no major tributary inflows along this reach; however, the discharge of the Little Snake River increased about 70 ft^3/s to 157 ft^3/s primarily due to ground-water discharge from the Wasatch Formation.

Downstream from the Little Snake River, the Yampa River enters Dinosaur National Monument. A study of this reach of the Yampa River by Steele and others (1978) indicated little change in the water quality. The Yampa River enters the Green River near Deerpark Lodge.

Estimated base-flow salt load for the Yampa River basin was about 161,000 ton/yr. Of this, about 112,000 ton/yr was produced by the Yampa River and about 49,000 ton/yr by the Little Snake River. Only about 11,000 ton/yr is produced in the Yampa River drainage above Steamboat Springs. Most of the remaining estimated base-flow salt load, about 100,000 ton/yr, is produced along the middle and lower reaches of the Yampa River (between sites 4 and 17) as it flows across shales in the Mesaverde Group and across the Mancos Shale. Tributary inflow accounts for about 49,200 ton/yr in these reaches with Williams Fork and Milk Creek accounting for 71 percent of the inflow.

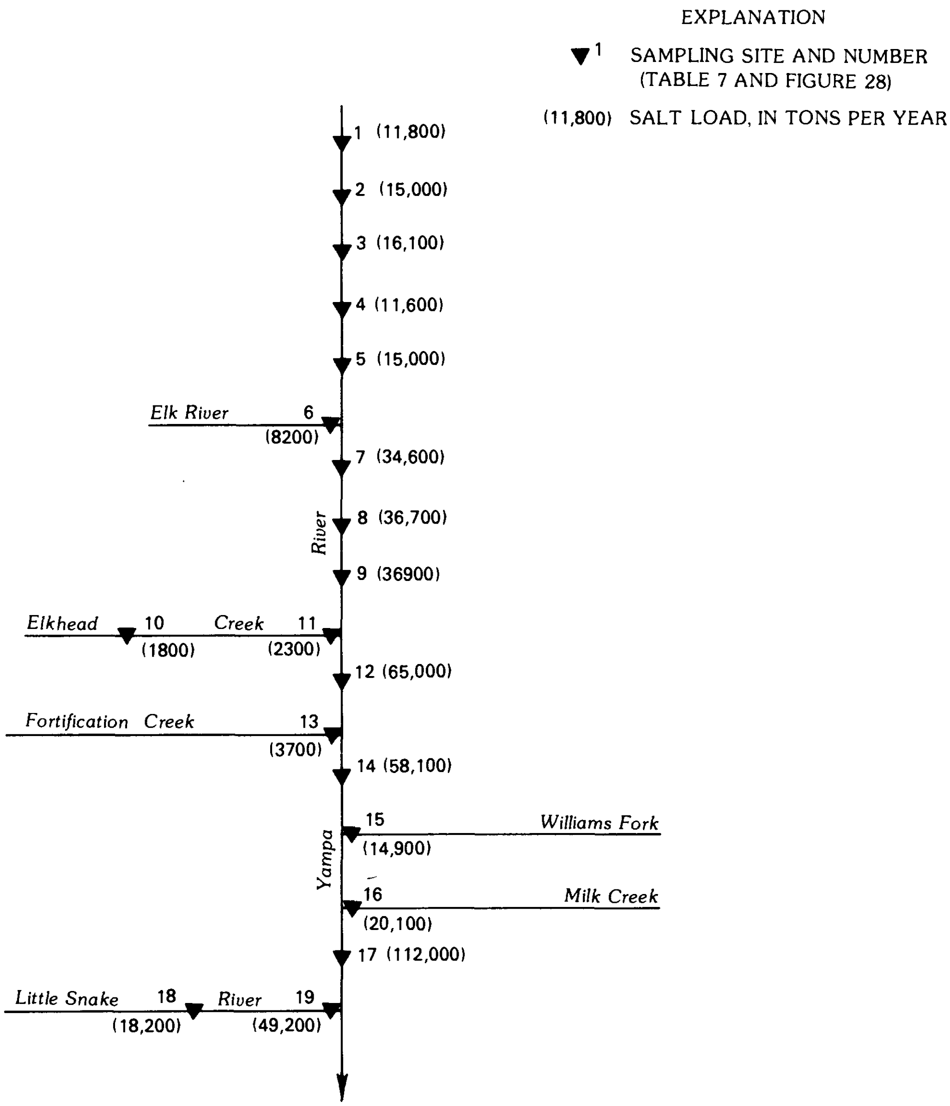


Figure 30.--Drainage system and salt load: Yampa subregion.

The Little Snake River above Dixon, Wyo., produced about 18,200 tons of estimated base-flow salt load per year, or about 37 percent of the 49,200 ton/yr of salt produced by the Little Snake River. Between Dixon, Wyo., and Lily, Colo., about 31,000 ton/yr of salt is contributed by ground-water discharge into the Little Snake River.

A plot of salt load, dissolved-solids concentration, and discharge is shown in figure 31 for the main stem of the Yampa River. Between the headwaters downstream to near Elkhead Creek, the dissolved-solids concentration shows no trend toward either increasing or decreasing. Downstream from there, a trend toward a progressive increase in salinity level is apparent.

A comparison of the estimated base-flow salt load for the Little Snake and Yampa Rivers was made with the estimated total annual salt load for these rivers reported by BLM (Bentley and others, 1978). The estimated 49,200 ton/yr of base-flow salt load in the Little Snake River was about 38 percent of the estimated 128,700 ton/yr of total salt load reported by BLM. The estimated 112,000 ton/yr of base-flow salt load contributed by the Yampa River represented about 40 percent of the estimated 283,000 ton/yr total salt load reported by BLM. The combined weighted average for the Yampa and Little Snake Rivers indicates that 39 percent of the total annual salt load and about 22 percent of the discharge is contributed by ground-water sources.

White Subregion

The White River basin includes a drainage area of approximately 5,000 mi^2 (fig. 1). Annual precipitation in the basin ranges from less than 10 to 50 in.

Most of the White River flow originates in the White River Plateau of Colorado. Downstream tributaries add little water. The dissolved-solids concentration of the headwaters is about 100 mg/L. At the lower end of the basin the runoff is small but the dissolved-solids concentration of the tributary inflow is typically between 500 and 1,000 mg/L. The largest tributary to the White River is Piceance Creek, which drains large areas of oil-shale deposits in the Piceance basin. The base-flow discharge of Piceance Creek is only about 15 ft^3/s. The White River has a mean annual discharge of about 500,000 acre-ft, which is about 120 acre-ft/mi^2. The mean annual dissolved-solids concentration is about 420 mg/L.

The headwaters region of the White River is comprised mostly of Permian rocks. Near Meeker, Colo., the White River flows across outcrops of Dakota Sandstone, Mancos Shale, and Mesaverde Group. West of Meeker to the confluence with the Green River, the White River flows across the Wasatch and Green River Formations.

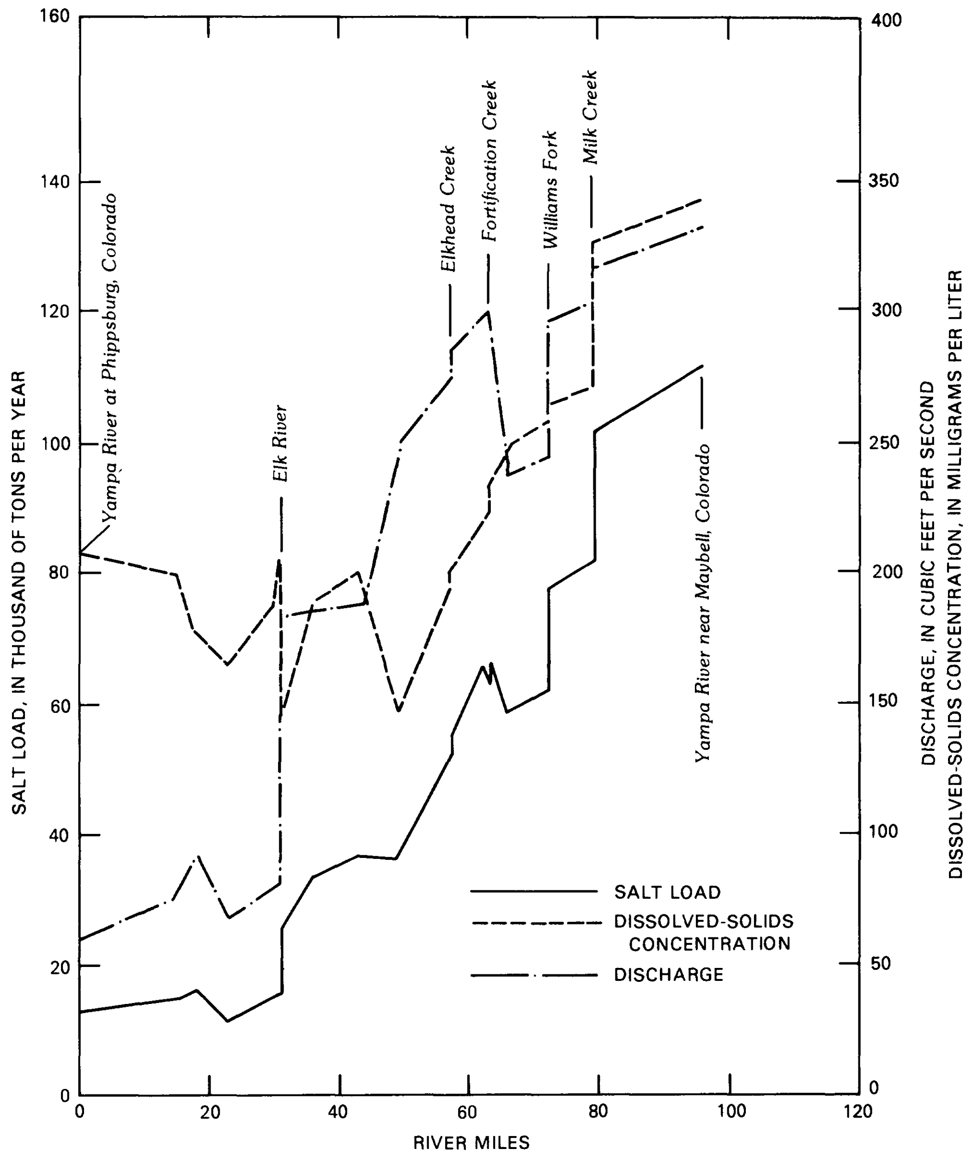


Figure 31.--Salt load, dissolved-solids concentration, and discharge: main-stem Yampa River.

No data were collected in the White River basin as part of this study. The ground-water contribution to salt load was determined from records at seven water-quality streamflow stations operated by the U.S. Geological Survey (fig. 32). Discharge, specific-conductance, dissolved-solids concentration, and salt-load values for each site are presented in table 8.

Salt-load data for the sites in the White River basin are shown in the schematic (fig. 33). The dissolved-solids concentration of the North Fork of the White River (site 1) was 236 mg/L. The dissolved-solids concentration of water in the North Fork probably is higher than that of the South Fork because parts of the North Fork drain the Maroon Formation and the Mancos Shale. Discharge of the North Fork of the White River was 119 ft^3/s.

Dissolved-solids concentration in the South Fork of the White River (site 2) was 155 mg/L, which is less than the North Fork. Discharge of the South Fork of the White River was 107 ft^3/s. This drainage is underlain by low solubility Cambrian, Ordovician, Devonian, and Mississippian rocks.

The White River near Meeker, Colo., (site 3) had a discharge of 315 ft^3/s with a dissolved-solids concentration of 445 mg/L. This increase in dissolved-solids concentration probably is due to channel erosion of the Mancos Shale that outcrops in this area. Brines from the Meeker Dome oil field and residual effects of the extensive irrigation in the area near Meeker also may be responsible for the higher dissolved-solids concentration at this site.

From below Meeker (site 3) to the confluence with the Green River (site 7), the discharge of the White River increased by 20 ft^3/s, and the dissolved-solids concentration increased by about 145 mg/L. Piceance and Yellow Creeks (sites 4 and 5) contribute discharges of 13 and 0.93 ft^3/s, respectively, and dissolved-solids concentrations of 1,310 and 2,850 mg/L, respectively. The remainder of the increase in dissolved solids probably is from ground-water discharge into the White River.

Between Meeker and the confluence with the Green River, the White River picks up an estimated 57,000 ton/yr of base-flow salt load. About 19,400 ton/yr is contributed by Piceance and Yellow Creeks. The remainder, about 37,600 ton/yr, is from ground-water discharge to the White River and unmeasured tributary flow.

An estimated 195,000 ton/yr of base-flow salt load was produced in the White River basin (fig. 33). Of this, 138,000 ton/yr which is about 71 percent of the total base-flow salt load, was produced in the drainages upstream from Meeker. The North Fork and South Fork of the White River produce only about 44,000 ton/yr, whick is about 23 percent of the total base-flow salt load of the White River. However, they produced over 67 percent of the total base-flow discharge of the White River. About 94,000 ton/yr of base-flow salt load were produced near Meeker from stream erosion of the Mancos Shale and from return flows from oil-field brines and excess irrigation water.

Salt load, dissolved-solids concentration, and discharge are shown in figure 34 for the main stem of the White River. A general progressive downstream increase in salinity levels is apparent.

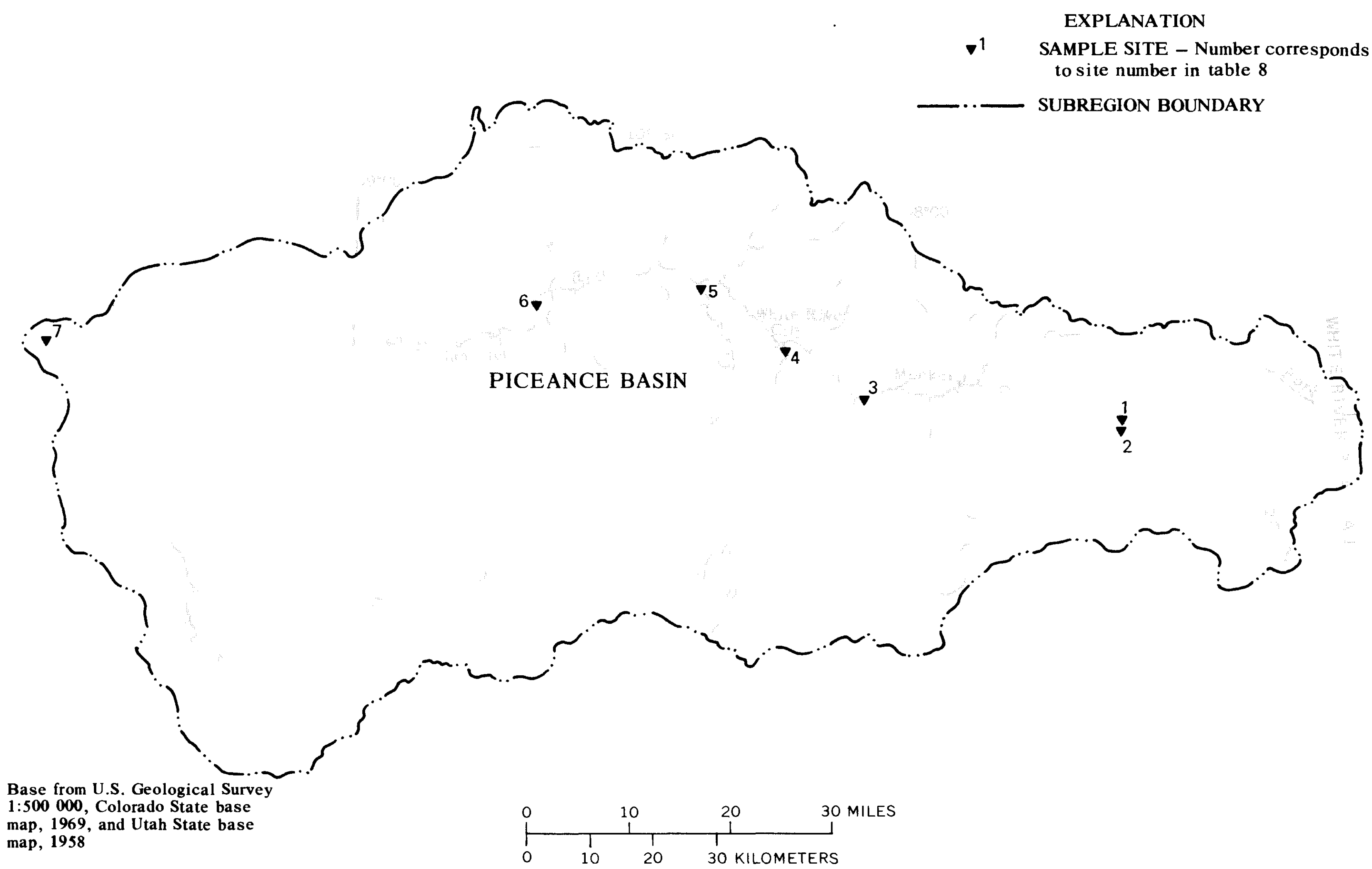


Figure 32.--Location of sites: White subregion.

Table 8.--*Discharge, specific conductance, dissolved-solids concentration, and salt loads: **White subregion***

[ft^3/s, cubic feet per second; μS/cm, microsiemens per centimeter at 25° Celsius; mg/L, milligrams per liter; tons/yr, tons per year; dashes indicate not applicable]

Site	Site description	U.S. Geological Survey station number	Latitude	Longitude	Sample date	Discharge (ft^3/s)		Specific conductance (μS/cm)	Dissolved solids (mg/L)			Salt load (tons/yr)	
						Measured	Adjusted		Measured	Calculated	Adjusted	Measured	Adjusted
1	North Fork White River at Buford, Colo.	09303000	39°59'15"	107°36'50"	12-05-77	119	---	362	236	---	---	27,700	---
2	South Fork White River at Buford, Colo.	09304000	39°58'28"	107°37'30"	12-05-77	107	---	245	155	---	---	16,300	---
3	White River below Meeker, Colo.	09304800	40°00'48"	108°05'33"	12-08-77	315	---	685	445	---	---	138,000	---
4	Piceance Creek at White River, Colo.	09306222	40°05'16"	108°14'35"	12-28-77	13	---	2,000	1,310	---	---	16,800	---
5	Yellow Creek near White River, Colo.	09306255	40°10'07"	108°24'02"	12-28-77	.93	---	4,250	2,850	---	---	2,600	---
6	White River above Rangely, Colo.	09306300	40°06'26"	108°42'44"	---	368	---	---	502	---	---	182,000	---
7	White River at mouth near Ouray, Utah.	09306900	40°03'54"	109°38'06"	12-05-77	335	---	[1]880	---	[1]590	---	195,000	---

[1]Estimated from hydrologic records.

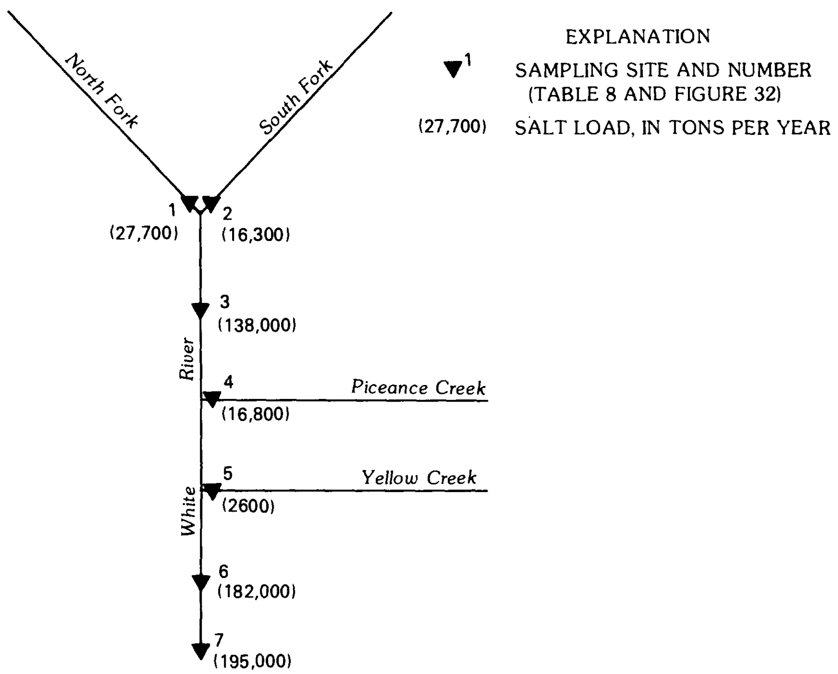


Figure 33.--Drainage system and salt load: White subregion.

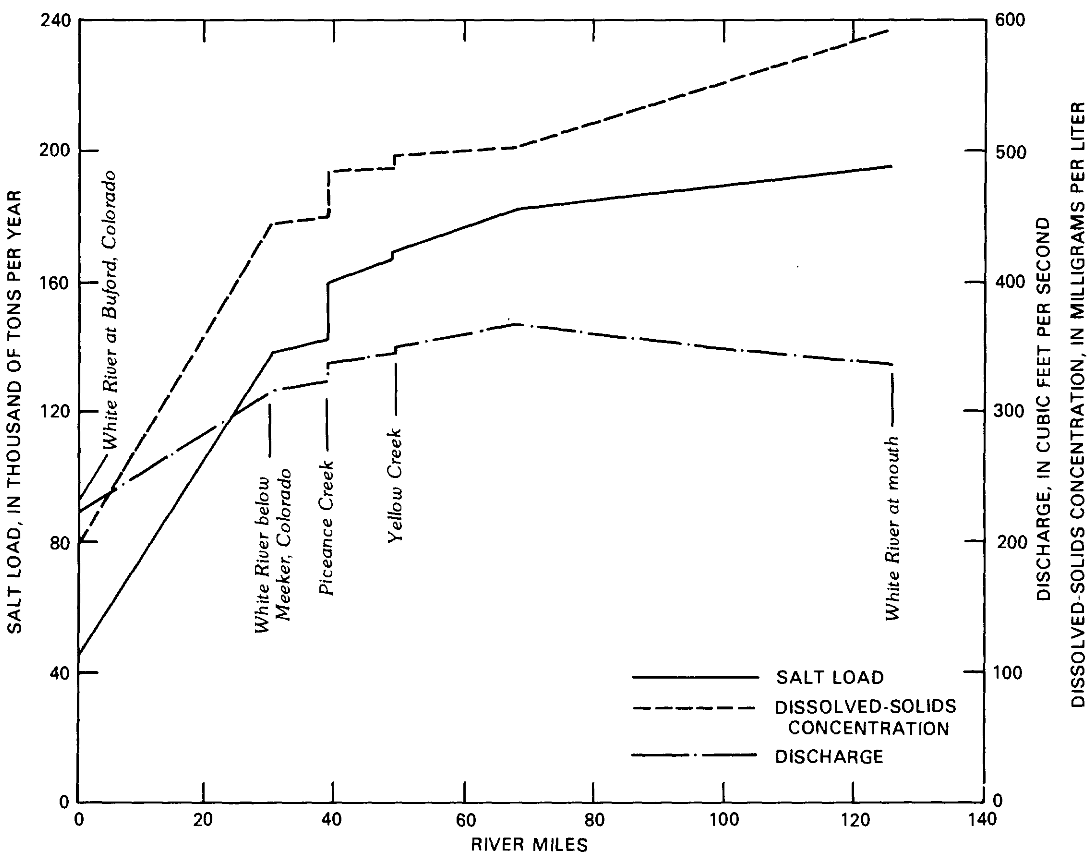


Figure 34.--Salt-load, dissolved-solids concentration, and discharge: main-stem White River.

A comparison of the estimated base-flow salt load of 195,000 ton/yr for the White River was made with the estimated total annual salt load of 275,100 ton/yr reported by BLM (Bentley and others, 1978). This indicated that 71 percent of the total annual salt load and about 50 percent of the discharge from the White River basin probably came from ground water.

Lower Green Subregion

The lower Green subregion includes the Green River downstream from the confluence with the Yampa River, excluding the White River basin (figs. 1 and 35). The drainage area of this subregion is about 19,000 mi^2. Annual precipitation in the subregion ranges from less than 8 to over 30 in. Near the confluence with the Colorado River, the Green River has a mean annual discharge of 4.5 million acre-ft (6,220 ft^3/s), and a mean annual dissolved-solids concentration of about 500 mg/L, producing a mean load of 3.06 million ton/yr.

The lower Green subregion lies within the Uinta structural basin. The Uinta uplift, which borders the basin on the north, consists mostly of Precambrian, Mississippian, and Pennsylvanian sedimentary and metamorphic rocks. The Wasatch Plateau borders the basin on the west. Most of the Plateau is underlain by formations of Cretaceous and Tertiary age. The San Rafael uplift borders on the southwest and is mostly Triassic and Jurassic formations with some Permian formations. The interior of the Uinta basin primarily is Wasatch and Green River Formations. Upper Cretaceous shales occur in a narrow band along the northern fringe of the basin and in a wide band just outside the southern fringe of the basin.

No data were collected in the lower Green subregion as part of this study. The ground-water contribution to the salt load was determined from data recorded at four streamflow water-quality stations operated by the U.S. Geological Survey in this subregion (fig. 35). Discharge, specific conductance, dissolved-solids concentration, and salt load at each site are presented in table 9.

Salt-load data for the sites in the lower Green subregion are shown in the schematic (fig. 36). The adjusted discharge and dissolved-solids concentration of the Green River entering the subregion were 597 ft^3/s and 570 mg/L respectively. The discharge and dissolved-solids concentration of the Yampa River were 490 ft^3/s and 334 mg/L, respectively. The Yampa River lowers the dissolved-solids concentration in the Green River at their confluence. The Duchesne River (site 1) had a discharge and dissolved-solids concentration of 77 ft^3/s and 1,650 mg/L, respectively. Residual irrigation effects from extensive irrigation in the lower reaches of the Duchesne River basin may contribute to the salinity level of this stream. The dissolved-solids concentration of the White River, about 590 mg/L, is about the same as that of the Green River at their confluence.

The Price River (site 2) had a discharge and dissolved-solids concentration of 11 ft^3/s and 4,590 mg/L, respectively. The very high dissolved-solids concentration of the Price River probably is due to the

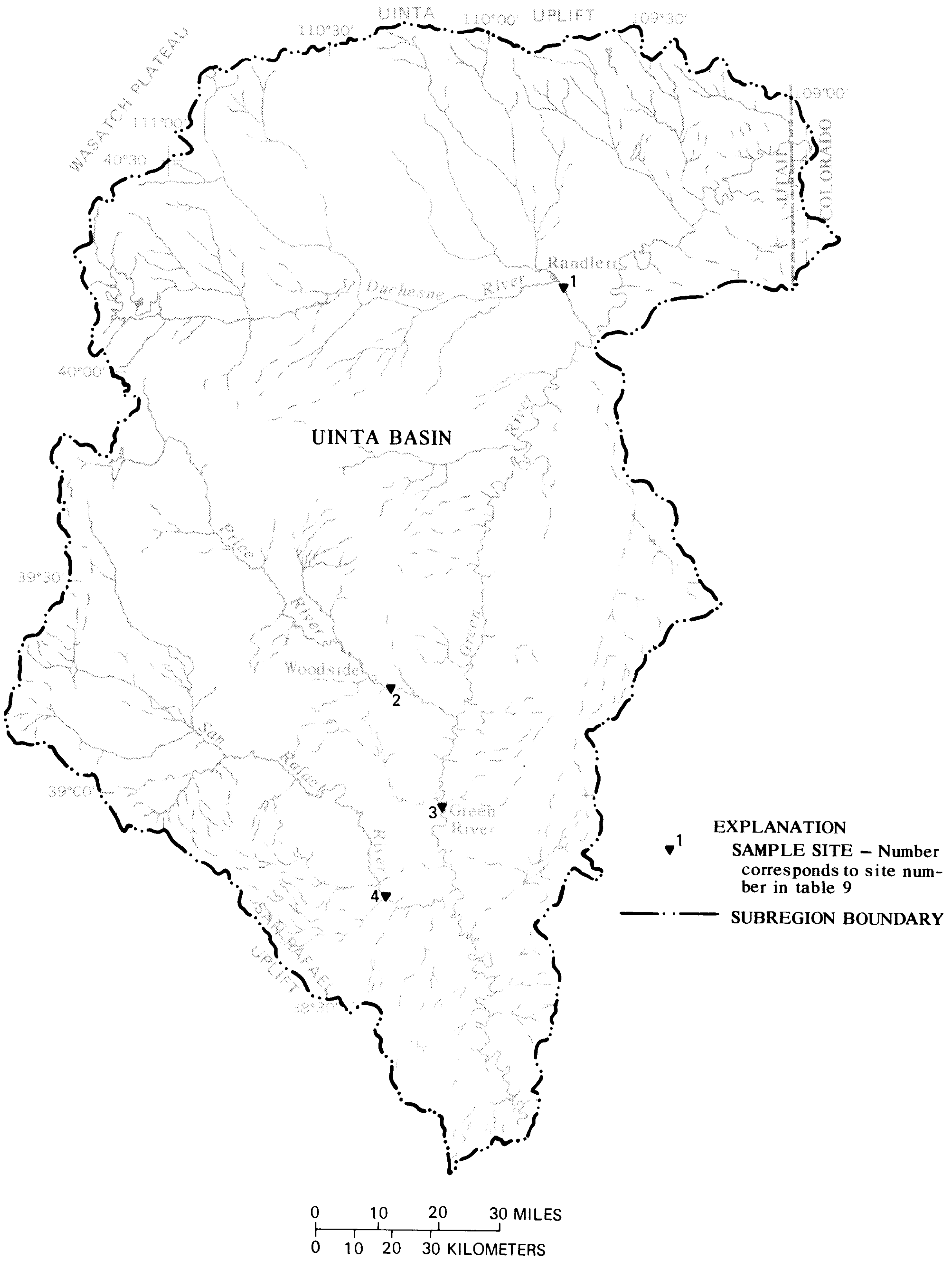


Figure 35.--Location of sites: lower Green subregion.

Table 9.--*Discharge, specific conductance, dissolved-solids concentration, and salt loads: Lower Green subregion*

[ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25° Celsius; mg/L, milligrams per liter; tons/yr, tons per year; dashes indicate not applicable]

Site	Site description	U.S. Geological Survey station number	Latitude	Longitude	Sample date	Discharge (ft^3/s)		Specific conductance (µS/cm)	Dissolved solids (mg/L)			Salt load (tons/yr)	
						Measured	Adjusted		Measured	Calculated	Adjusted	Measured	Adjusted
1	Duchesne River near Randlett, Utah.	09302000	40°12'56"	109°46'58"	11-29-77	77	---	2,210	1,650	---	---	125,000	---
2	Price River at Woodside, Utah.	09314500	39°15'50"	110°20'45"	12-07-77	11	---	5,800	4,590	---	---	49,700	---
3	Green River at Green River, Utah.	09315000	38°59'10"	110°09'02"	12-19-77	2,070	1,627	---	---	[1]640	692	1,305,000	[2]1,109,000
4	San Rafael River near Green River, Utah.	09328500	38°51'30"	110°22'10"	12-08-77	11	---	4,400	3,920	---	---	42,500	---

[1]Estimated from hydrologic records.
[2]Base-flow salt load may include an unquantified amount of salt load from residual irrigation return flow.

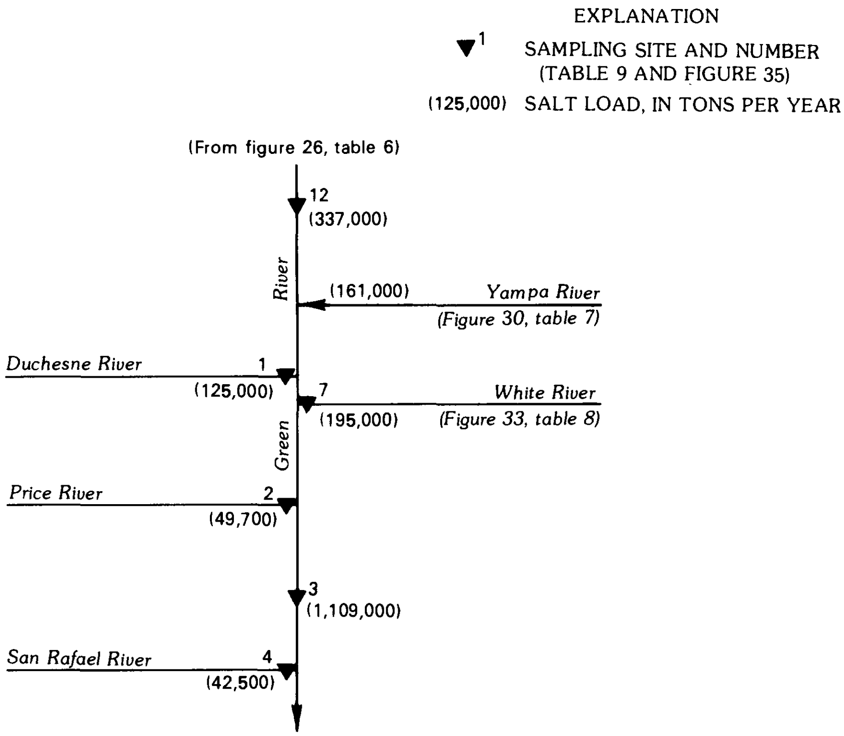


Figure 36.--Drainage system and salt load: lower Green subregion.

extensive areas of Mancos Shale that underlie the drainage basin and to the residual effects of irrigation. The Green River near Green River, Wyo., (site 3) had an adjusted discharge and dissolved-solids concentration of 1,627 ft^3/s and 692 mg/L, respectively. The San Rafael River (site 4) is the last major tributary to the Green River above the confluence with the Colorado River. The San Rafael River had a discharge of 11 ft^3/s and a dissolved-solids concentration of 3,920 mg/L. Like the Price River, the San Rafael River drains extensive outcrops of Mancos Shale and receives irrigation return flows. Late in the irrigation season, the entire discharge of the San Rafael River normally is diverted for irrigation.

An estimated 459,000 ton/yr of base-flow salt load were produced in the lower Green subregion. The Duchesne, Price, and San Rafael Rivers contributed an estimated base-flow salt load of 125,000, 49,700, and 42,500 ton/yr, respectively (fig. 36). The remainder of the estimated base-flow salt load for this subregion, 242,000 ton/yr, was contributed by unmeasured tributary flow and discharge of ground water to the Green River.

A comparison of the estimated base-flow salt load of 459,000 ton/yr for the lower Green subregion with the estimated total annual salt load of 1,213,300 tons reported by BLM (Bentley and others, 1978) indicates that about

38 percent of the total annual salt load and about 21 percent of the discharge from the lower Green subregion is from ground-water sources.

The plot of salt load, dissolved-solids concentration, and discharge are shown in figure 37 for the main-stem lower Green River. In general, dissolved-solids concentration of the Green River showed only a slight increase in this subregion. The estimate of base-flow salt load for this subregion may be affected by several serious errors. Discharge in the main-stem Green River is highly variable in this subregion because of regulation by Flaming Gorge Reservoir, and channel storage of water could severely affect salt-load estimates. Additionally, the estimate of base-flow salt load for this subregion was determined from the difference between several rather large values that could introduce a fairly large calculation error.

Comparison of the combined estimated base-flow salt load of the Green River near Green River, Wyo., and the San Rafael River with the combined estimated total annual salt load reported by BLM (Bentley and others, 1978), indicated that about 38 percent of the estimated total annual salt load and about 27 percent of the discharge for the Green River region was produced from ground-water sources.

SUMMARY AND CONCLUSIONS

The method of analysis used in this study to determine ground-water contribution of salinity to streamflow was a reconnaissance level determination. Calculation of the salt-load contribution to streamflow by ground-water discharge was made by a mass balance using point measurements of quantity and quality of streamflow. Streamflow during the low-flow winter months was considered to be supplied by ground water.

A one-time sampling program was conducted in December 1977 and January 1978. Data were collected on streamflow discharge, specific conductance, and chemical composition for 142 sites in the Upper Colorado River Basin upstream from the conflucence of the Colorado and Green Rivers. Specific conductance and streamflow measurements were made at all sites, and a water sample was taken for chemical analysis at 78 of the sites. A linear regression of specific conductance versus dissolved-solids concentration was used to calculate dissolved-solids concentrations for sites where only specific-conductance data were collected. Available data from local and regional studies and from published streamflow and water-quality measurements obtained from gaging stations operated by the U.S. Geological Survey were used and compared with other areas in the Upper Colorado River Basin.

The assumption was made that the ground-water contribution to streamflow would remain nearly constant during the year and also would remain nearly constant from year to year. The variation of the ground-water discharge to streams during the year was thought to be small, but no calculation was made to verify this. The year-to-year variation of ground-water discharge to the streams was evaluated by comparing data collected in this study with historical data at streamflow-gaging stations. In general, the variation was found to be no more than 20 percent.

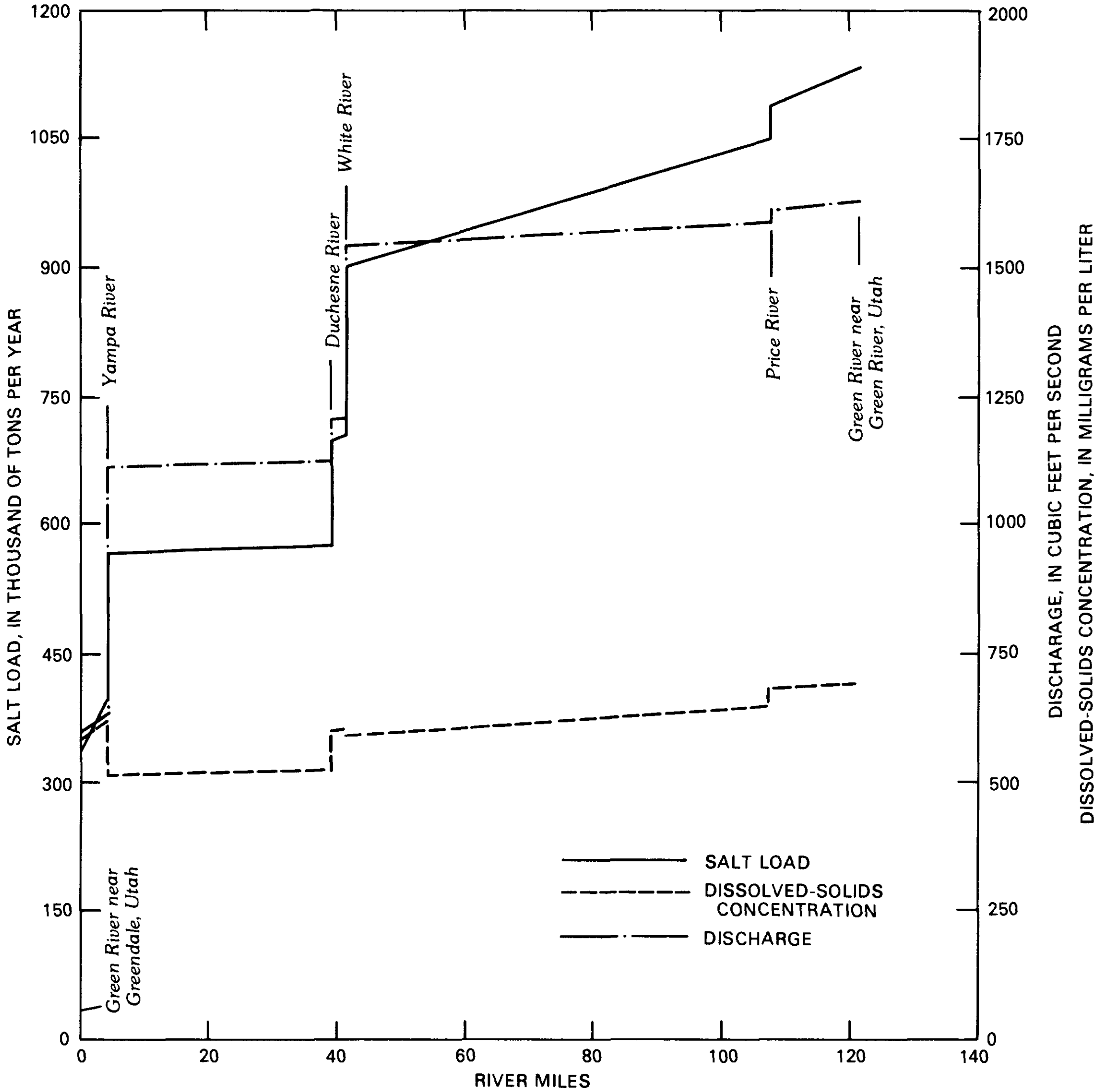


Figure 37.--Salt load, dissolved-solids concentration, and discharge: main-stem lower Green River.

The study area was divided into two major regions: the Green River and the Colorado River upstream from the confluence with the Green River. These two major regions were divided into a total of nine subregions. Estimated annual salt load contributed by ground-water sources is shown for each subregion in table 10. The estimated base-flow salt load as a percent of the total annual salt load varied for the nine subregions, from a low of 30 percent to a high of 93 percent. The percent of base-flow salt load relative to total annual salt load (obtained from BLM and previously collected U.S. Geological Survey data) was an average of 69 percent for subregions in the Colorado River region and an average of 38 percent for subregions in the Green River region. A brief summary of the significant ground-water sources of salt load for each of the subregions is given below.

The Colorado upper headwaters subregion had an estimated base-flow salt load of 974,000 ton/yr, which is about 87 percent of the estimated total annual salt load. The highly saline discharge of springs near Glenwood Springs, Colo., and Dotsero, Colo., contributes an estimated 534,000 ton/yr which is approximately 55 percent of the base-flow salt load in the Colorado upper headwaters subregion. Approximately 89 percent of the total annual salt load of the Eagle River is contributed by ground-water sources, most of which originate from the Eagle Valley Evaporite.

The Gunnison subregion had an estimated base-flow salt load of 724,000 ton/yr, which was about 53 percent of the estimated total annual salt load. About 80 percent of the base-flow salt load comes from the Uncompahgre River and the lower Gunnison River and is probably related directly to channel erosion of Mancos Shale, which is extensively exposed in these areas. There also may be some unquantified amount of irrigation return flow contributing to the base-flow salt loads.

The Colorado lower headwaters subregion had an estimated base-flow salt load of 1,037,000 ton/yr, which was about 93 percent of the estimated total annual salt load. The main source of base-flow salt load appears to be from channel erosion of Mancos Shale. Approximately 70 percent of the base-flow salt load for this subregion was produced along the lower reach of the Colorado River in the Grand Valley.

The Dolores subregion had an estimated base-flow salt load of 283,000 ton/yr, which is about 58 percent of the estimated total annual salt load. Highly saline water discharged from the Paradox Member of the Hermosa Formation contributes over 50 percent of the total estimated base-flow salt load of the Dolores River.

The Colorado subregion had a negative base-flow salt load of 385,000 ton/yr. The Colorado River in this subregion is a losing stream.

The upper Green subregion had an estimated base-flow salt load of 337,000 ton/yr, which is 30 percent of the estimated total annual salt load. One major source of base-flow salt load in this subregion is from diffuse ground-water discharge from the Green River Formation. About 26 percent of the estimated total base-flow salt load in this subregion is contributed by the Big Sandy River.

Table 10.--*Summary of salt load and discharge for the Upper Colorado River Basin, the two regions, and the nine subregions*
[Dashes indicate no data]

Region	Salt load (tons per year) Total	Salt load Base-flow	Salt load Percent of total	Discharge (acre feet per year) Total	Discharge Base-flow	Discharge Percent of total
Colorado River Subregion						
Colorado upper headwaters	1,117,300	974,000	87	2,528,000	888,200	35
Gunnison[1]	1,364,600	724,000	53	1,653,000	571,600	35
Colorado lower headwaters[1]	1,113,100	1,037,000	93	86,000	202,900	---
Dolores	489,800	283,000	58	573,700	102,900	18
Colorado	-268,800	-385,000	---	-271,700	-200,700	---
Total	3,816,000	2,633,000	69	4,569,000	1,564,900	34
Green River Subregion						
Upper Green	1,135,000	337,000	30	1,616,000	432,500	27
Yampa	411,700	161,000	39	1,599,100	355,000	22
White	275,100	195,000	71	486,300	242,700	50
Lower Green	1,213,300	459,000	38	763,700	156,500	21
Total	3,035,100	1,152,000	38	4,465,100	1,186,700	27
Upper Colorado River Basin						
Grand Total	6,851,100	3,785,000	55	9,034,100	2,751,600	30

[1]Basins contain extensive irrigated areas. Loads presented may not fully represent natural base-flow conditions.

The Yampa subregion had an estimated base-flow salt load of 161,000 ton/yr, which is about 39 percent of the estimated total annual salt load. Most of the base-flow salt load of the Yampa River is produced along the middle and lower reaches in areas underlain by Mancos Shale and shales in the Mesaverde Group. Ground-water discharge to the river from the Wasatch Formation is another source of salt in this basin.

The White subregion had an estimated base-flow salt load of 195,000 ton/yr, which is about 71 percent of the estimated total annual salt load. About 48 percent of the total estimated base-flow salt load for this subregion was produced near Meeker, Colo., from stream erosion of the Mancos Shale and from brines from the Meeker Dome oil field. About 10 percent of the estimated base-flow salt load is contributed by Piceance and Yellow Creeks, which are affected by discharge of water from the oil shale in the Green River Formation.

The lower Green subregion had an estimated base-flow salt load of 459,000 ton/yr, which is about 38 percent of the estimated total annual salt load. The Duchesne, Price, and San Rafael Rivers contributed about 47 percent of the estimated base-flow salt load. The quality of all three of these streams is affected by intensive irrigation. The Price and San Rafael Rivers also have extensive areas of Mancos Shale in their drainages.

The estimated base-flow salt load for the Upper Colorado River Basin was about 3.8 million ton/yr, which is about 55 percent of the estimated total annual salt load. Diffuse ground-water discharge to streams accounted for the majority of the base-flow salt load. However, significant salt load is contributed by point sources, such as the highly saline discharge of springs near Glenwood Springs, Colo., and near Dotsero, Colo., by stream channel erosion of marine shales and by ground-water discharge along fairly short reaches of streams from highly saline formations, such as the Paradox Member of the Hermosa Formation. If strategies can be developed and implemented to control salt production for some of these areas, the salinity level of the Colorado River might be reduced.

REFERENCES

Bentley, R. G., Jr., Eggleston, K. O., Price, Don, Frandsen, E. R., and Dickerman, A. R., 1978, The effects of surface disturbance on the salinity of public lands in the Upper Colorado River Basin: U.S. Bureau of Land Management 1977 status report, 208 p.

Iorns, W. V., Hembree, C. H., and Oakland, G. L., 1965, Water resources of the Upper Colorado River Basin--Technical report: U.S. Geological Survey Professional Paper 441, 370 p.

Iorns, W. V., Hembree, C. H., Phoenix, D. A., and Oakland, G. L., 1964, Water resources of the Upper Colorado River Basin--Basic data: U.S. Geological Survey Professional Paper 442, 1036 p.

Kircher, J. E., Dinicola, R. S., and Middelburg, R. F., 1984, Trend analysis of salt load and evaluation of the frequency of water-quality measurements for the Gunnison, the Colorado, and Dolores Rivers in Colorado and Utah: U.S. Geological Survey Water-Resources Investigations Report 84-4048, 74 p.

Lowham, H. W., Delong, L. L., Peter, K. D., Wangsness, D. J., Head, W. J., and Ringen, B. H., 1976, A plan for study of water and its relation to economic development in the Green River and Great Divide basins in Wyoming: U.S. Geological Survey Open-File Report 76-349, 110 p.

Price, Don, and Arnow, Ted, 1974, Summary appraisals of the Nation's ground-water resources--Upper Colorado Region: U.S. Geological Survey Professional Paper 813-C, p. C1-C40.

Steele, T. D., Bauer, D. P., Wentz, D. A, and Warner, J. W., 1979, The Yampa River basin, Colorado and Wyoming--A preview to expanded coal-resource development and its impacts on regional water resources: U.S. Geological Survey Water-Resources Investigations 78-126, 142 p.

Steele, T. D., Wentz, D. A., and Warner, J. W., 1978, Hydrologic reconnaissance of the Yampa River during low flow, Dinosaur National Monument, northwestern Colorado: U.S. Geological Survey Open-File Report 78-226, 24 p.

U.S. Geological Survey, 1975, Utah, 1974: Hydrologic Unit Map, scale 1:500,000.

_____1976, Colorado, 1974: Hydrologic Unit Map, scale 1:500,000.

_____1977, Wyoming, 1974: Hydrologic Unit Map, scale 1:500,000.

SUPPLEMENTAL INFORMATION

Chemical analyses of surface water from sampling sites and of water from major springs

Table 11.--*Chemical analyses of water from sampling sites*

[ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25° Celsius; mg/L, milligrams per liter; °C, degrees Celsius; Ca, calcium; Mg, magnesium; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; dashes indicate not applicable]

Site	Site description	U.S. Geological Survey station number	Latitude	Longitude	Date	Discharge (ft^3/s)	Specific conductance (µS/cm)	Dissolved-solids concentration (mg/L)
	COLORADO UPPER HEADWATERS SUBREGION							
7	Blue River near mouth.	None	40°01'55"	106°23'08"	12-8-77	161	260	111
9	Eagle River near Avon, Colo.	None	39°37'55"	106°31'18"	12-7-77	83	290	190
11	Eagle River near Gypsum, Colo.	None	39°38'58"	106°57'11"	12-7-77	164	1,170	731
12	Gypsum Creek near mouth near Gypsum, Colo.	None	39°38'42"	106°57'14"	12-7-77	34	740	494
13	Roaring Fork River near Aspen, Colo.	09073400	39°10'48"	106°48'05"	12-6-77	23	80	62
16	Roaring Fork River near Woody Creek, Colo.	None	39°17'40"	106°55'07"	12-6-77	105	455	316
21	Fryingpan River at Meredith, Colo.	09080100	39°21'45"	106°43'55"	12-6-77	20	130	86
22	Fryingpan River near Ruedi, Colo.	09080400	39°21'56"	106°49'30"	12-6-77	50	380	242
24	Crystal River near Carbondale, Colo.	None	39°24'29"	107°13'44"	12-7-77	84	640	452
25	Roaring Fork River at Glenwood Springs, Colo.	09085000	39°32'37"	107°19'44"	12-7-77	400	740	490
28	Fraser River near mouth.	None	40°05'05"	105°57'12"	12-7-77	55	160	90
29	Colorado River at Hot Sulphur Springs, Colo.	09034500	40°05'00"	106°05'15"	12-7-77	77	220	137
30	Williams Fork near Parshall, Colo.	09037500	40°00'01"	106°10'45"	12-7-77	60	175	72
34	Muddy Creek near mouth at Kremmling, Colo.	None	40°03'37"	106°23'54"	12-9-77	---	1,160	984
35	Colorado River near Kremmling, Colo.	09058000	40°02'12"	106°26'22"	12-8-77	321	260	160
38	Piney River near mouth.	None	39°51'26"	106°38'28"	12-8-77	48	320	209
39	Colorado River at Bond, Colo.	None	39°53'22"	106°42'25"	12-8-77	---	250	162
40	Rock Creek at McCoy, Colo.	None	39°55'58"	106°43'37"	12-8-77	17	290	183
44	Derby Creek near mouth.	None	39°53'09"	106°54'12"	12-8-77	31	140	107
46	Sweetwater Creek near mouth.	None	39°43'15"	107°02'11"	12-8-77	27	390	249
47	Deep Creek near mouth.	None	39°40'19"	107°04'38"	12-8-77	11	300	173
48	Colorado River near Dotsero, Colo.	09070500	39°38'40"	107°04'40"	12-7-77	706	610	379
52	Colorado River below Glenwood Springs, Colo.	09085100	39°33'18"	107°20'13"	12-6-77	1,240	1,350	813

Table 11.--*Chemical analyses of water from sampling sites*--Continued

Site	Site description	pH (units)	Temperature (°C)	Hardness (Ca + Mg) (mg/L)	Noncarbonate hardness (mg/L)	Dissolved calcium (mg/L)	Dissolved magnesium (mg/L)
	COLORADO UPPER HEADWATERS SUBREGION--Continued						
7	Blue River near mouth.	8.1	0.0	88	20	27	5.1
9	Eagle River near Avon, Colo.	8.0	.0	150	71	41	12
11	Eagle River above Gypsum, Colo.	8.3	1.0	390	260	120	23
12	Gypsum Creek near mouth near Gypsum, Colo	8.1	4.0	390	230	120	22
13	Roaring Fork River near Aspen, Colo.	7.6	.0	42	4	13	2.3
16	Roaring Fork River near Woody Creek, Colo.	8.2	1.0	250	120	75	14
21	Fryingpan River at Meredith, Colo.	7.9	5.0	66	19	20	3.9
22	Fryingpan River near Ruedi, Colo.	7.8	.0	180	130	166	4.5
24	Crystal River near Carbondale, Colo.	8.1	2.0	320	160	100	16
25	Roaring Fork River at Glenwood Springs, Colo.	8.2	2.0	330	160	100	19
28	Fraser River near mouth.	7.8	1.5	58	0	18	3.2
29	Colorado River at Hot Sulphur Springs, Colo.	8.0	2.0	66	0	21	3.3
30	Williams Fork near Parshall, Colo.	7.8	1.0	49	0	15	2.8
34	Muddy Creek near mouth at Kremmling, Colo.	8.2	.0	600	400	110	78
35	Colorado River near Kremmling, Colo.	8.1	.0	110	21	32	7.6
38	Piney River near mouth.	8.3	1.0	160	48	50	9.1
39	Colorado River at Bond, Colo.	8.0	.0	110	23	33	7.4
40	Rock Creek at McCoy, Colo.	8.1	1.5	130	8	36	10
44	Derby Creek near mouth.	7.9	.0	77	2	21	5.9
46	Sweetwater Creek near mouth.	8.1	.0	190	64	50	17
47	Deep Creek near mouth.	8.0	2.0	180	19	47	14
48	Colorado River near Dotsero, Colo.	8.1	1.0	240	120	70	16
52	Colorado River below Glenwood Springs, Colo.	7.9	2.5	320	160	97	19

Table 11.--*Chemical analyses of water from sampling sites*--Continued

Site	Site description	Dissolved sodium (mg/L)	Sodium adsorption ratio	Dissolved potassium (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Alkalinity $CaCO_3$ (mg/L)	Dissolved sulfate (mg/L)
	COLORADO UPPER HEADWATERS SUBREGION--Continued							
7	Blue River near mouth.	4.5	0.2	1.6	84	---	69	26
9	Eagle River near Avon, Colo.	3.8	.1	1.0	99	0	81	73
11	Eagle River above Gypsum, Colo.	90	2.0	3.6	170	0	140	270
12	Gypsum Creek near mouth near Gypsum, Colo.	5.2	.1	1.4	200	0	160	230
13	Roaring Fork River near Aspen, Colo.	2.8	.2	.5	46	0	38	7.9
16	Roaring Fork River near Woody Creek, Colo.	5.5	.2	1.6	150	0	120	130
21	Fryingpan River at Meredith, Colo.	2.9	.2	.7	57	---	47	20
22	Fryingpan River near Ruedi, Colo.	1.7	.1	.7	64	---	53	130
24	Crystal River near Carbondale, Colo.	19	.5	2.2	190	0	160	200
25	Roaring Fork River at Glenwood Springs, Colo.	32	.8	2.1	200	0	160	190
28	Fraser River near mouth.	5.6	.3	1.6	77	---	63	5.1
29	Colorado River at Hot Sulphur Springs, Colo.	23	1.2	2.1	96	---	79	18
30	Williams Fork near Parshall, Colo.	3.0	.2	1.2	61	---	50	7.8
34	Muddy Creek near mouth at Kremmling, Colo.	93	1.7	3.1	240	0	200	560
35	Colorado River near Kremmling, Colo.	12	.5	2.1	110	---	90	39
38	Piney River near mouth.	4.4	.2	1.6	140	---	110	55
39	Colorado River at Bond, Colo.	12	.5	2.0	110	0	90	39
40	Rock Creek at McCoy, Colo.	11	.4	4.4	150	0	120	32
44	Derby Creek near mouth.	3.6	.2	1.2	91	0	75	8.5
46	Sweetwater Creek near mouth.	4.2	.1	1.5	160	0	130	75
47	Deep Creek near mouth.	1.3	.0	.6	190	0	160	8.6
48	Colorado River near Dotsero, Colo	35	1.0	2.4	150	0	120	130
52	Colorado River below Glenwood Springs, Colo.	160	3.9	6.3	190	0	160	190

Table 11.--*Chemical analyses of water from sampling sites*--Continued

Site	Site description	Dissolved chloride (mg/L)	Dissolved fluoride (mg/L)	Dissolved silica (mg/L)	Dissolved nitrate plus nitrate as nitrogen (mg/L)	Dissolved iron (μg/L)	Dissolved manganese (μg/L)
	COLORADO UPPER HEADWATERS SUBREGION--Continued						
7	Blue River near mouth.	2.0	0.3	3.1	0.00	20	10
9	Eagle River near Avon, Colo.	2.3	.1	6.2	.30	20	360
11	Eagle River above Gypsum, Colo.	130	.2	8.8	.42	10	10
12	Gypsum Creek near mouth near Gypsum, Colo.	3.0	.1	12	.30	10	0
13	Roaring Fork River near Aspen, Colo.	1.6	.8	9.6	.07	130	20
16	Roaring Fork River near Woody Creek, Colo.	4.0	.4	10	.40	20	14
21	Fryingpan River at Meredith, Colo.	1.6	.2	7.9	.14	200	10
22	Fryingpan River near Ruedi, Colo.	1.4	.1	5.5	.13	20	0
24	Crystal River near Carbondale, Colo.	7.5	.2	12	.31	20	0
25	Roaring Fork River at Glenwood Springs, Colo.	35	.2	12	.28	40	10
28	Fraser River near mouth.	2.0	.2	15	.24	150	10
29	Colorado River at Hot Sulphur Springs, Colo.	7.7	.7	13	.14	100	0
30	Williams Fork near Parshall, Colo.	1.0	.2	11	.04	110	0
34	Muddy Creek near mouth at Kremmling, Colo.	9.1	.3	10	.37	20	120
35	Colorado River near Kremmling, Colo.	2.4	.3	9.9	.04	50	20
38	Piney River near mouth.	1.6	.1	18	.04	10	0
39	Colorado River at Bond, Colo.	3.1	.3	11	.05	80	20
40	Rock Creek at McCoy, Colo.	2.3	.2	13	.12	60	20
44	Derby Creek near mouth.	1.5	.1	20	.15	40	0
46	Sweetwater Creek near mouth.	2.1	.1	18	.39	40	0
47	Deep Creek near mouth.	2.0	.1	4.5	.37	20	0
48	Colorado River near Dotsero, Colo.	41	.2	10	.11	40	30
52	Colorado River below Glenwood Springs, Colo.	230	.4	11	1.2	40	0

Table 11.--*Chemical analyses of water from sampling sites--Continued*

Site	Site description	U.S. Geological Survey station number	Latitude	Longitude	Date	Discharge (ft^3/s)	Specific conductance (μS/cm)	Dissolved-solids concentration (mg/L)
				GUNNISON SUBREGION				
1	Taylor River below Taylor Park Reservoir, Colo.	09109000	38°49'06"	106°36'31"	12-6-77	107	120	69
2	Taylor River at Almont, Colo.	09110000	38°39'52"	106°50'41"	12-6-77	124	140	84
3	East River at Almont, Colo.	09112500	38°39'52"	106°50'51"	12-6-77	50	330	210
4	Quartz Creek at Parlin, Colo.	None	38°30'05"	106°43'23"	12-9-77	5.3	190	167
5	Cochetopa Creek near Parlin, Colo.	None	38°31'01"	106°47'11"	12-9-77	13	270	195
6	Tomichi Creek at Gunnison, Colo.	09119000	38°31'18"	106°56'25"	12-8-77	78	270	183
8	Beaver Creek near mouth.	None	38°29'42"	107°01'59"	12-8-77	5.2	80	73
11	Lake Fork Gunnison River near Gateview, Colo.	None	38°24'11"	107°14'54"	12-7-77	39	180	123
14	Curecanti Creek near mouth.	None	38°29'15"	107°24'55"	12-7-77	6.2	90	78
16	Cimarron River near mouth.	None	38°26'49"	107°33'16"	12-8-77	21	520	374
18	Smith Fork near Lazear, Colo.	09129600	38°42'27"	107°42'35"	12-7-77	2.8	2,830	2,310
19	Gunnison River above North Fork Gunnison River.	None	38°46'56"	107°50'09"	12-7-77	338	315	187
20	Muddy Creek above Paonia Reservoir, Colo.	None	38°59'18"	107°20'52"	12-6-77	7.2	305	182
21	Anthracite Creek near mouth.	None	38°56'20"	107°21'31"	12-6-77	18	155	93
22	Cottonwood Creek near Hotchkiss, Colo.	09134200	38°48'22"	107°43'53"	12-6-77	1.5	5,500	4,640
23	Leroux Creek at Hotchkiss, Colo.	09135900	38°47'53"	107°43'53"	12-6-77	3.9	1,490	1,090
24	North Fork Gunnison River near mouth.	None	38°47'00"	107°50'06"	12-7-77	63	1,600	1,170
27	Uncompahgre River at Colona, Colo.	09147500	38°19'53"	107°46'44"	12-7-77	90	800	632
32	Dry Creek near Delta, Colo.	None	38°42'02"	108°03'20"	12-7-77	63	1,700	1,320
33	Uncompahgre River at Delta, Colo.	09149500	38°44'31"	108°04'49"	12-7-77	180	2,170	1,820
34	Tongue Creek at Cory, Colo.	09144200	38°47'16"	107°59'41"	12-7-77	6.8	2,600	1,760

Table 11.--*Chemical analyses of water from sampling sites*--Continued

Site	Site description	pH (units)	Temperature (°C)	Hardness (Ca + Mg) (mg/L)	Noncarbonate hardness (mg/L)	Dissolved calcium (mg/L)	Dissolved magnesium (mg/L)
	GUNNISON SUBREGION--Continued						
1	Taylor River below Taylor Park Reservoir, Colo.	7.8	2.0	49	6	14	3.5
2	Taylor River at Almont, Colo.	7.8	.0	73	7	21	5.0
3	East River at Almont, Colo.	8.1	1.0	180	21	55	9.7
4	Quartz Creek at Parlin, Colo.	8.0	.0	150	6	40	11
5	Cochetopa Creek near Parlin, Colo.	7.9	.0	120	0	36	6.9
6	Tomichi Creek at Gunnison, Colo.	8.2	2.0	130	0	37	9.5
8	Beaver Creek near mouth.	7.8	.0	33	0	9.9	1.9
11	Lake Fork Gunnison River near Gateview, Colo.	8.9	.5	81	24	26	3.9
14	Curecanti Creek near mouth.	7.8	.0	38	0	12	2.0
16	Cimarron River near mouth.	8.5	.0	230	97	49	25
18	Smith Fork near Lazear, Colo.	8.1	.0	1,600	1,400	280	220
19	Gunnison River above North Fork Gunnison River.	8.2	3.0	140	29	36	11
20	Muddy Creek above Paonia Reservoir, Colo.	8.3	.0	140	0	43	7.7
21	Anthracite Creek near mouth.	8.0	.0	64	4	20	3.5
22	Cottonwood Creek near Hotchkiss, Colo.	7.9	2.0	2,400	2,100	400	330
23	Leroux Creek at Hotchkiss, Colo.	7.9	7.0	730	460	160	81
24	North Fork Gunnison River near mouth.	8.1	2.0	750	510	150	90
27	Uncompahgre River at Colona, Colo.	8.1	1.0	420	260	130	23
32	Dry Creek near Delta, Colo.	7.8	4.0	830	620	220	68
33	Uncompahgre River at Delta, Colo.	7.8	4.5	1,000	800	250	97
34	Tongue Creek at Cory, Colo.	7.9	3.0	1,100	750	200	140

Table 11.--*Chemical analyses of water from sampling sites*--Continued

Site	Site description	Dissolved sodium (mg/L)	Sodium adsorption ratio	Dissolved potassium (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Alkalinity $CaCO_3$ (mg/L)	Dissolved sulfate (mg/L)
	GUNNISON SUBREGION--Continued							
1	Taylor River below Taylor Park Reservoir, Colo.	2.2	0.1	0.7	53	0	43	16
2	Taylor River at Almont, Colo.	2.4	.1	.7	80	0	66	9.1
3	East River at Almont, Colo.	5.0	.2	1.2	190	0	160	35
4	Quartz Creek at Parlin, Colo.	3.7	.1	1.5	170	0	140	12
5	Cochetopa Creek near Parlin, Colo.	14	.6	3.9	150	0	120	22
6	Tomichi Creek at Gunnison, Colo.	9.6	.4	2.3	160	0	130	21
8	Beaver Creek near mouth.	2.9	.2	1.8	46	0	38	4.7
11	Lake Fork Gunnison River near Gateview, Colo.	6.3	.3	1.2	69	0	57	35
14	Curecanti Creek near mouth.	3.7	.3	1.5	42	0	43	6.5
16	Cimarron River near mouth.	30	.9	3.4	150	3	130	160
18	Smith Fork near Lazear, Colo.	110	1.2	10	300	0	250	1,500
19	Gunnison River above North Fork Gunnison River.	11	.4	2.2	130	0	110	48
20	Muddy Creek above Paonia Reservoir, Colo.	12	.4	1.2	180	0	150	11
21	Anthracite Creek near mouth.	18	.3	.5	74	0	61	14
22	Cottonwood Creek near Hotchkiss, Colo.	540	4.8	15	360	0	300	3,100
23	Leroux Creek at Hotchkiss, Colo.	75	1.2	8	330	0	270	550
24	North Fork Gunnison River near mouth.	100	1.6	6.8	290	0	240	650
27	Uncompahgre River at Colona, Colo.	33	.7	2.8	190	0	160	330
32	Dry Creek near Delta, Colo.	95	1.4	4	260	0	210	760
33	Uncompahgre River at Delta, Colo.	180	2.4	5.5	270	0	220	1,100
34	Tongue Creek at Cory, Colo.	190	2.5	13	400	-1	330	970

Table 11.--*Chemical analyses of water from sampling sites*--Continued

Site	Site description	Dissolved chloride (mg/L)	Dissolved fluoride (mg/L)	Dissolved silica (mg/L)	Dissolved nitrate plus nitrate as nitrogen (mg/L)	Dissolved iron (μg/L)	Dissolved manganese (μg/L)
	GUNNISON SUBREGION--Continued						
1	Taylor River below Taylor Park Reservoir, Colo.	0.9	0.1	5.4	0.00	50	80
2	Taylor River at Almont, Colo.	.3	.1	6.0	.01	20	10
3	East River at Almont, Colo.	.2	.1	9.5	.12	10	20
4	Quartz Creek at Parlin, Colo.	1.4	.2	13	.17	70	30
5	Cochetopa Creek near Parlin, Colo.	3.1	.5	34	.09	110	40
6	Tomichi Creek at Gunnison, Colo.	2.9	.5	21	.00	70	40
8	Beaver Creek near mouth.	.3	.1	29	.00	50	0
11	Lake Fork Gunnison River near Gateview, Colo.	.5	.2	16	.00	30	20
14	Curecanti Creek near mouth.	.3	.1	3.7	.00	110	10
16	Cimarron River near mouth.	2.9	.1	26	.12	40	40
18	Smith Fork near Lazear, Colo.	29	.9	15	.00	20	20
19	Gunnison River above North Fork Gunnison River.	3.7	.2	11	.00	20	0
20	Muddy Creek above Paonia Reservoir, Colo.	3.1	.2	14	.17	20	0
21	Anthracite Creek near mouth.	3.2	.1	8.6	.08	30	0
22	Cottonwood Creek near Hotchkiss, Colo.	56	.6	8.7	2.4	30	180
23	Leroux Creek at Hotchkiss, Colo.	14	.6	32	1.2	20	10
24	North Fork Gunnison River near mouth.	16	.5	15	.31	30	160
27	Uncompahgre River at Colona, Colo.	4.3	.5	13	.30	20	40
32	Dry Creek near Delta, Colo.	12	.9	18	2.6	20	80
33	Uncompahgre River at Delta, Colo.	16	.8	16	3.7	20	80
34	Tongue Creek at Cory, Colo.	16	.6	31	.95	30	160

Table 11.--*Chemical analyses of water from sampling sites*--Continued

Site	Site description	U.S. Geological Survey station number	Latitude	Longitude	Date	Discharge (ft^3/s)	Specific conductance (µS/cm)	Dissolved-solids concentration (mg/L)
			GUNNISON SUBREGION					
35	Roubideau Creek at mouth near Delta, Colo.	09150500	38°44'06"	108°09'40"	12-7-77	37	1,980	1,600
36	Escalante Creek near Delta, Colo.	09151500	38°45'24"	108°15'34"	12-7-77	6.6	640	382
37	East Creek near Whitewater, Colo.	None	38°58'08"	108°28'00"	12-8-77	.5	1,260	808
38	Gunnison River near Grand Junction, Colo.	09152500	38°59'00"	108°27'00"	12-8-77	680	1,510	1,080
			COLORADO LOWER HEADWATERS SUBREGION					
2	Elk Creek near mouth near New Castle, Colo.	None	39°34'47"	107°32'19"	12-6-77	14	950	721
4	Divide Creek near mouth near Silt, Colo.	None	39°32'27"	107°37'22"	12-6-77	.44	1,100	881
7	Rifle Creek near mouth near Rifle, Colo.	None	39°31'54"	107°47'12"	12-7-77	2.8	2,050	1,700
10	Roan Creek near mouth at De Beque, Colo.	None	39°19'53"	108°12'50"	12-7-77	2.3	2,700	2,340
12	Plateau Creek near Cameo, Colo.	09105000	39°11'01"	108°16'06"	12-7-77	48	580	511
			DOLORES SUBREGION					
1	Dolores River below Rico, Colo.	09165000	37°38'20"	108°03'35"	1-4-78	25	600	399
2	Stoner Creek near mouth.	None	37°35'23"	108°19'16"	1-4-78	1.1	360	166
3	West Dolores River near mouth.	None	37°35'22"	108°21'23"	1-4-78	13	750	413
4	Dolores River at Dolores, Colo.	09166500	37°28'16"	108°30'15"	1-4-78	33	650	313
5	Beaver Creek near mouth.	None	37°34'32"	108°33'31"	1-4-78	.17	640	491
6	Disappointment Creek near Slick Rock, Colo.	None	38°00'50"	108°49'50"	1-3-78	.10	8,000	6,940
7	Dolores River at Slick Rock, Colo.	None	38°01'50"	108°53'03"	1-3-78	38	800	493
10	Dolores River at Bedrock, Colo.	09169500	38°18'37"	108°53'05"	1-4-78	45	1,450	635
11	West Paradox Creek near mouth.	None	38°19'49"	108°52'27"	1-4-78	3.8	1,365	1,000
12	Dolores River near Bedrock, Colo.	09171100	38°21'29"	108°49'54"	1-4-78	48	6,800	3,800

Table 11.--*Chemical analyses of water from sampling sites*--Continued

Site	Site description	pH (units)	Temperature (°C)	Hardness (Ca + Mg) (mg/L)	Noncarbonate hardness (mg/L)	Dissolved calcium (mg/L)	Dissolved magnesium (mg/L)
	GUNNISON SUBREGION--Continued						
35	Roubideau Creek at mouth near Delta, Colo.	7.8	3.0	1,000	830	260	93
36	Escalante Creek near Delta, Colo.	8.1	2	290	47	73	25
37	East Creek near Whitewater, Colo.	8.3	.0	330	0	65	40
38	Gunnison River near Grand Junction, Colo.	8.1	2	630	450	150	62
	COLORADO LOWER HEADWATERS SUBREGION--Continued						
2	Elk Creek near mouth near New Castle, Colo.	8.1	2.5	550	320	130	54
4	Divide Creek near mouth near Silt, Colo.	8.3	4	360	0	62	50
7	Rifle Creek near mouth near Rifle, Colo.	7.7	1	940	600	180	120
10	Roan Creek near mouth at De Beque, Colo.	7.4	3	1,000	570	150	160
12	Plateau Creek near Cameo, Colo.	8.2	2	300	4	59	37
	DOLORES SUBREGION--Continued						
1	Dolores River below Rico, Colo.	8.0	0.0	320	150	100	16
2	Stoner Creek near mouth.	8	.0	160	26	47	9.7
3	West Dolores River near mouth.	7.9	.0	230	53	67	14
4	Dolores River at Dolores, Colo.	8	.0	230	76	73	12
5	Beaver Creek near mouth.	7.9	.5	370	100	94	34
6	Disappointment Creek near Slick Rock, Colo.	7.9	1	2,800	2,500	440	420
7	Dolores River at Slick Rock, Colo.	8	.0	280	130	80	20
10	Dolores River at Bedrock, Colo.	8	.0	290	130	80	23
11	West Paradox Creek near mouth.	8.1	3	740	510	140	94
12	Dolores River near Bedrock, Colo.	7.9	1	460	280	100	51

Table 11.--*Chemical analyses of water from sampling sites*--Continued

Site	Site description	Dissolved sodium (mg/L)	Sodium adsorption ratio	Dissolved potassium (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Alkalinity $CaCO_3$ (mg/L)	Dissolved sulfate (mg/L)
	GUNNISON SUBREGION--Continued							
35	Roubideau Creek at mouth near Delta, Colo.	99	1.3	3.9	250	0	210	970
36	Escalante Creek near Delta, Colo.	30	.8	4.1	290	0	240	79
37	East Creek near Whitewater, Colo.	51	3.9	7.2	420	0	340	290
38	Gunnison River near Grand Junction, Colo.	110	1.9	4.7	220	0	180	610
	COLORADO LOWER HEADWATERS SUBREGION--Continued							
2	Elk Creek near mouth near New Castle, Colo.	31	0.6	2.3	280	0	230	340
4	Divide Creek near mouth near Silt, Colo.	180	4.1	6.6	520	0	430	230
7	Rifle Creek near mouth near Rifle, Colo.	210	3.0	4.6	420	---	340	920
10	Roan Creek near mouth at De Beque, Colo.	400	5.4	5	570	---	470	1,300
12	Plateau Creek near Cameo, Colo.	73	1.8	5.6	360	---	300	120
	DOLORES SUBREGION--Continued							
1	Dolores River below Rico, Colo.	9.6	0.2	1.8	200	---	160	160
2	Stoner Creek near mouth.	1.4	.0	1.2	160	---	130	22
3	West Dolores River near mouth.	63	1.8	7.7	210	---	170	47
4	Dolores River at Dolores, Colo.	22	.6	3.1	190	---	160	69
5	Beaver Creek near mouth.	32	.7	3.9	330	---	270	150
6	Disappointment Creek near Slick Rock, Colo.	1,100	9	14	430	---	350	4,600
7	Dolores River at Slick Rock, Colo.	62	1.6	3.9	190	---	160	140
10	Dolores River at Bedrock, Colo.	110	2.8	5.9	200	0	160	140
11	West Paradox Creek near mouth.	42	.7	4.2	280	0	230	530
12	Dolores River near Bedrock, Colo.	1,200	24	66	220	0	180	270

Table 11.--*Chemical analyses of water from sampling sites*--Continued

Site	Site description	Dissolved chloride (mg/L)	Dissolved fluoride (mg/L)	Dissolved silica (mg/L)	Dissolved nitrate plus nitrate as nitrogen (mg/L)	Dissolved iron (μg/L)	Dissolved manganese (μg/L)
	GUNNISON SUBREGION--Continued						
35	Roubideau Creek at mouth near Delta, Colo.	9.4	1.3	24	3.7	20	60
36	Escalante Creek near Delta, Colo.	15	.3	12	.14	30	20
37	East Creek near Whitewater, Colo.	29	1.1	7.9	.06	40	130
38	Gunnison River near Grand Junction, Colo.	16	.6	13	1.8	20	40
	COLORADO LOWER HEADWATERS SUBREGION--Continued						
2	Elk Creek near mouth near New Castle, Colo.	11	0.1	6.5	1.8	30	10
4	Divide Creek near mouth near Silt, Colo.	66	1.1	26	.65	60	80
7	Rifle Creek near mouth near Rifle, Colo.	33	.5	16	.84	40	200
10	Roan Creek near mouth at De Beque, Colo.	28	.7	14	.54	30	80
12	Plateau Creek near Cameo, Colo.	8.8	.5	28	.29	40	20
	DOLORES SUBREGION--Continued						
1	Dolores River below Rico, Colo.	1.0	0.5	11	0.13	30	200
2	Stoner Creek near mouth.	.9	.1	4.3	.09	10	0
3	West Dolores River near mouth.	100	.2	9.3	.15	20	20
4	Dolores River at Dolores, Colo.	31	.2	8	.12	10	10
5	Beaver Creek near mouth.	6.9	.2	6.9	.01	20	260
6	Disappointment Creek near Slick Rock, Colo.	150	.3	6.7	.32	50	260
7	Dolores River at Slick Rock, Colo.	87	.2	6	.01	10	0
10	Dolores River at Bedrock, Colo.	170	.2	6.6	.15	20	20
11	West Paradox Creek near mouth.	37	.3	13	.96	20	80
12	Dolores River near Bedrock, Colo.	2,000	.2	7	.10	20	60

Table 11.--*Chemical analyses of water from sampling sites*--Continued

Site	Site description	U.S. Geological Survey station number	Latitude	Longitude	Date	Discharge (ft^3/s)	Specific conductance (µS/cm)	Dissolved-solids concentration (mg/L)
			DOLORES SUBREGION--Continued					
13	San Miguel River near Telluride, Colo.	None	37°56'39"	107°53'56"	1-4-78	16	360	228
16	Big Bear Creek near mouth at Vanadium, Colo.	None	37°57'58"	107°58'13"	1-4-78	.5	380	227
18	San Miguel River near Placerville, Colo.	09172500	38°02'05"	108°07'15"	1-4-78	50	375	288
19	Beaver Creek near mouth near Norwood, Colo.	None	38°06'22"	108°11'17"	1-4-78	1.8	400	249
21	Naturita Creek near mouth at Naturita, Colo.	None	38°13'04"	108°32'42"	1-3-78	.75	2,100	1,970
22	San Miguel River at Naturita, Colo.	09175500	38°13'04"	108°13'04"	1-3-78	69	740	528
23	Dry Creek near mouth near Naturita, Colo.	None	38°13'53"	108°36'00"	1-3-78	.30	4,100	4,770
26	San Miguel River at Uravan, Colo.	09177000	38°21'26"	108°42'44"	1-4-78	72	900	637
27	Mesa Creek near mouth near Uravan, Colo.	None	38°36'19"	108°50'12"	1-4-78	.37	1,240	823
28	Roc Creek near mouth.	None	38°37'14"	108°51'46"	1-3-78	4.3	1,590	824
29	Blue Creek near mouth near Gateway, Colo.	None	38°31'58"	108°53'33"	1-3-78	.91	580	300
30	Salt Creek near mouth near Gateway, Colo.	None	38°33'42"	108°55'10"	1-3-78	.10	50,000	43,000
31	West Creek near mouth.	None	38°40'52"	108°53'21"	1-3-78	4.7	420	231
32	Dolores River at Gateway, Colo.	None	38°40'53"	108°58'47"	1-3-78	96	3,300	1,740
33	Dolores River near Cisco, Utah.	09180000	38°47'50"	109°11'40"	1-5-78	142	3,575	2,020

Table 11.--*Chemical analyses of water from sampling sites*--Continued

Site	Site description	pH (units)	Temperature (°C)	Hardness (Ca + Mg) (mg/L)	Noncarbonate hardness (mg/L)	Dissolved calcium (mg/L)	Dissolved magnesium (mg/L)
	DOLORES SUBREGION--Continued						
13	San Miguel River near Telluride, Colo.	7.9	0.0	170	95	59	5.5
16	Big Bear Creek near mouth at Vanadium, Colo.	8.1	.0	190	58	56	12
18	San Miguel River near Placerville, Colo.	7.9	.0	210	130	72	7.6
19	Beaver Creek near mouth near Norwood, Colo.	8	.5	220	43	60	16
21	Naturita Creek near mouth at Naturita, Colo.	7.8	.0	1,100	840	200	150
22	San Miguel River at Naturita, Colo.	8.1	---	370	240	100	28
23	Dry Creek near mouth near Naturita, Colo.	7.9	1	2,100	1,800	430	250
26	San Miguel River at Uravan, Colo.	8.1	-.5	440	300	110	39
27	Mesa Creek near mouth near Uravan, Colo.	8	3	390	79	84	49
28	Roc Creek near mouth.	8.1	-1	230	82	59	20
29	Blue Creek near mouth near Gateway, Colo.	8	.0	270	26	53	34
30	Salt Creek near mouth near Gateway, Colo.	7.7	1.5	3,400	3,300	710	400
31	West Creek near mouth.	8.1	5	190	11	61	9.6
32	Dolores River at Gateway, Colo.	7.8	1.5	470	320	110	48
33	Dolores River near Cisco, Utah.	8	2.5	470	320	110	48

Table 11.--*Chemical analyses of water from sampling sites*--Continued

Site	Site description	Dissolved sodium (mg/L)	Sodium adsorption ratio	Dissolved potassium (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Alkalinity $CaCO_3$ (mg/L)	Dissolved sulfate (mg/L)
	DOLORES SUBREGION--Continued							
13	San Miguel River near Telluride, Colo.	7.2	0.2	1.7	91	0	75	100
16	Big Bear Creek near mouth at Vanadium, Colo.	5	.2	1.3	160	0	130	65
18	San Miguel River near Placerville, Colo.	5.9	.2	1.2	100	0	82	140
19	Beaver Creek near mouth near Norwood, Colo.	12	.4	1.4	210	0	170	42
21	Naturita Creek near mouth at Naturita, Colo.	190	2.5	5.2	340	0	280	1,200
22	San Miguel River at Naturita, Colo.	26	.6	1.9	150	0	120	280
23	Dry Creek near mouth near Naturita, Colo.	640	6.1	11	310	0	250	3,100
26	San Miguel River at Uravan, Colo.	29	.6	2.1	160	0	130	360
27	Mesa Creek near mouth near Uravan, Colo.	130	2.9	5.7	380	0	310	320
28	Roc Creek near mouth.	210	6	12	180	0	150	63
29	Blue Creek near mouth near Gateway, Colo.	15	.4	3.6	300	0	250	20
30	Salt Creek near mouth near Gateway, Colo.	15,000	112	610	170	0	140	2,200
31	West Creek near mouth.	9.9	.3	2.1	220	0	180	17
32	Dolores River at Gateway, Colo.	450	9	24	180	0	150	330
33	Dolores River near Cisco, Utah.	550	11	29	180	0	150	320

Table 11.--*Chemical analyses of water from sampling sites*--Continued

Site	Site description	Dissolved chloride (mg/L)	Dissolved fluoride (mg/L)	Dissolved silica (mg/L)	Dissolved nitrate plus nitrate as nitrogen (mg/L)	Dissolved iron (μg/L)	Dissolved manganese (μg/L)
	DOLORES SUBREGION--Continued						
13	San Miguel River near Telluride, Colo.	2.4	0.2	6.8	0.04	20	110
16	Big Bear Creek near mouth at Vanadium, Colo.	1.4	.1	6.6	.05	10	0
18	San Miguel River near Placerville, Colo.	1.7	.2	8.4	.37	10	0
19	Beaver Creek near mouth near Norwood, Colo.	4.5	.2	8.9	.03	10	0
21	Naturita Creek near mouth at Naturita, Colo.	50	.6	11	.01	20	20
22	San Miguel River at Naturita, Colo.	7.1	.4	9.1	.36	20	50
23	Dry Creek near mouth near Naturita, Colo.	170	.5	8.6	1.1	20	120
26	San Miguel River at Uravan, Colo.	8.8	.3	7.2	.28	20	70
27	Mesa Creek near mouth near Uravan, Colo.	36	.4	15	.04	20	30
28	Roc Creek near mouth.	360	.2	10	.05	300	20
29	Blue Creek near mouth near Gateway, Colo.	19	.2	6.9	.01	10	20
30	Salt Creek near mouth near Gateway, Colo.	24,000	.2	4.3	.63	40	80
31	West Creek near mouth.	5.4	.6	16	.15	20	10
32	Dolores River at Gateway, Colo.	680	.2	6.1	.59	10	100
33	Dolores River near Cisco, Utah.	860	.3	7.1	.90	20	80

Table 12.--*Chemical analyses of water from major springs*

[gal/min, gallons per minute; µS/cm, microsiemens per centimeter at 25° Celsius; mg/L, milligrams per liter; °C, degrees Celsius; Ca, calcium; Mg, magnesium; $CaCO_3$, calcium carbonate; dashes indicate not applicable]

Site description	Latitude	Longitude	Date	Discharge (gal/min)	Specific conductance (µS/cm)	Dissolved-solids concentration (mg/L)
Ouray Pool Hot Spring	38°01'00"	107°40'41"	6-8-78	200	2,200	1,670
Cebolla Hot Springs A	38°16'26"	107°05'54"	6-8-78	5	2,100	1,470
Waunita Hot Spring C	38°30'50"	106°30'27"	6-8-78	---	750	582
Waunita Hot Spring D	38°30'50"	106°30'28"	6-8-78	---	800	597
Lower Waunita Hot Spring A	38°31'02"	106°30'56"	6-8-78	---	800	563
Hotchkiss Fish Hatchery Spring	38°46'32"	107°46'03"	6-9-78	1,800	949	628
Ranger Warm Spring	38°48'57"	106°52'28"	6-7-78	---	770	488
Cement Creek Warm Spring	38°50'06"	106°49'34"	6-7-78	---	650	414
Penny Hot Springs	39°13'33"	107°13'28"	6-8-78	75	3,400	2,970
Glenwood Big Hot Spring	39°32'59"	107°19'18"	6-7-78	---	29,500	20,600
Dotsero Warm Springs	39°37'39"	107°06'22"	6-7-78	---	17,500	10,500
Hot Sulphur Spring A	40°04'33"	106°06'43"	6-9-78	20	1,800	1,200
Heart Hot Spring	40°28'58"	106°49'37"	6-6-78	---	1,490	908
Steamboat-Sulphur Spring	40°29'37"	106°50'31	6-6-78	45	8,500	4,270

Table 12.--*Chemical analyses of water from major springs*--Continued

Site description	pH (units)	Temperature (°C)	Hardness (Ca + Mg) (mg/L)	Noncarbonate hardness (mg/L)	Dissolved calcium (mg/L)	Dissolved magnesium (mg/L)
Ouray Pool Hot Spring	7.4	69.0	940	830	370	4
Cebolla Hot Springs A	7.2	40.0	500	0	130	42
Waunita Hot Spring C	8.2	76.0	17	0	6.5	.1
Waunita Hot Spring D	8.4	55.0	19	0	5.8	1
Lower Waunita Hot Spring A	8.0	66.0	23	0	8.7	.4
Hotchkiss Fish Hatchery Spring	8.0	13.0	340	0	61	45
Ranger Warm Spring	7.5	26.0	290	1	79	22
Cement Creek Warm Spring	7.6	24.0	280	38	79	21
Penny Hot Springs	6.9	51.0	1,200	700	400	44
Glenwood Big Hot Spring	7.0	50.0	1,500	840	430	94
Dotsero Warm Springs	7.3	31.0	690	320	270	4.3
Hot Sulphur Spring A	7.6	45.0	45	0	15	1.8
Heart Hot Spring	7.8	40.0	47	0	18	.4
Steamboat-Sulphur Spring	7.1	22.5	350	170	130	7.1

Table 12.--*Chemical analyses of water from major springs*--Continued

Site description	Dissolved sodium (mg/L)	Sodium adsorption ratio	Dissolved potassium (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Alkalinity $CaCO_3$ (mg/L)	Dissolved sulfate (mg/L)
Ouray Pool Hot Spring	120	1.7	9.5	130	---	110	990
Cebolla Hot Springs A	320	6.2	65	1,160	---	950	120
Waunita Hot Spring C	160	17	10	130	---	110	170
Waunita Hot Spring D	160	16	11	130	---	110	190
Lower Waunita Hot Spring A	160	14	10	160	---	130	170
Hotchkiss Fish Hatchery Spring	85	2	16	420	---	340	160
Ranger Warm Spring	65	1.7	7.7	350	---	290	96
Cement Creek Warm Spring	39	1	6.2	300	---	250	83
Penny Hot Springs	390	4.9	36	580	---	480	1,200
Glenwood Big Hot Spring	7,400	84	150	760	---	620	1,100
Dotsero Warm Springs	3,700	61	40	450	---	370	460
Hot Sulphur Spring A	440	29	22	810	---	660	130
Heart Hot Spring	300	19	11	100	---	82	130
Steamboat-Sulphur Spring	2,000	46	140	220	---	180	550

Table 12.--*Chemical analyses of water from major springs*--Continued

Site description	Dissolved chloride (mg/L)	Dissolved fluoride (mg/L)	Dissolved silica (mg/L)	Dissolved nitrate plus nitrate as nitrogen (mg/L)	Dissolved iron (µg/L)	Dissolved manganese (µg/L)
Ouray Pool Hot Spring	58	2.7	49	0.05	30	80
Cebolla Hot Springs A	130	4.9	87	.14	10	60
Waunita Hot Spring C	22	19	130	.05	0	0
Waunita Hot Spring D	15	20	130	.06	20	0
Lower Waunita Hot Spring A	21	17	97	.05	10	40
Hotchkiss Fish Hatchery Spring	5.9	.9	40	1.6	80	0
Ranger Warm Spring	24	1.8	19	.15	0	10
Cement Creek Warm Spring	17	2	18	.16	20	0
Penny Hot Springs	260	3.8	350	.05	1,300	350
Glenwood Big Hot Spring	11,000	2.2	30	.07	80	70
Dotsero Warm Springs	5,800	.6	14	.12	50	0
Hot Sulphur Spring A	150	12	34	.05	0	70
Heart Hot Spring	330	11	58	.06	0	0
Steamboat-Sulphur Spring	1,300	3	22	1.8	10	360

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