HYDROLOGY OF THE U.S. ARMY PINON CANYON MANEUVER SITE, LAS ANIMAS COUNTY, COLORADO

By Paul von Guerard, P.O. Abbott, and Raymond C. Nickless

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 87-4227

Prepared in cooperation with the

U.S. DEPARTMENT OF THE ARMY

FORT CARSON MILITARY RESERVATION

Denver, Colorado
1987

DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

District Chief
U.S. Geological Survey
Box 25046, Mail Stop 415
Denver Federal Center
Denver, CO 80225-0046

Copies of this report can be purchased from:

U.S. Geological Survey
Books and Open-File Reports
Federal Center, Bldg. 810
Box 25425
Denver, CO 80225-0425

CONTENTS

PLATES

FIGURES

TABLES

GLOSSARY

Water-resource terms are defined in the GLOSSARY and are italicized when first used in this report.

adjudicated.--Decreed by a court action that water use is acknowledged.

alluvium.--Material deposited by a stream or flowing water.

anion.--A negatively charged ion, atom, or molecule.

anticline.--A fold, the core of which contains the stratigraphically older rocks; it is convex upward.

aquifer.--Formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield substantial quantities of water to wells and springs.

arch.--A broad, open anticlinal fold on a regional scale.

artesian.--Referring to ground water confined under hydrostatic pressure.

base streamflow.--Sustained streamflow that usually is composed of ground-water recharge to a stream.

calcareous.--When applied to a rock name, as much as 50 percent of the rock is calcium carbonate.

cation.--A positively charged ion, atom, or molecule.

confining unit.--A layer of rock material that retards but does not necessarily prevent the flow of water from or to an adjacent aquifer.

crossbedded.--Single beds thicker than 0.5 in. inclined at an angle to the main planes of stratification.

dike.--A tabular igneous intrusion that cuts across the bedding or foliation of the local rock.

discharge.--Referring to the quantity of streamflow, dissolved solids, or suspended sediment that is transported per unit time. For example, streamflow discharge is reported in cubic feet per second.

dome.--An uplift or anticlinal structure, either circular or eliptical in outline, in which rocks dip gently away in all directions.

dune sand.--A type of blown sand that has been piled up by the wind into a sand dune, usually consisting of rounded quartz grains having diameters ranging from 0.01 to 1 millimeter.

ephemeral stream.--A stream that flows only in direct response to precipitation and in which the stream channel is above the water table at all times.

evaporation.--The process, also called vaporization, by which a substance passes from the liquid or solid state to the vapor state.

evapotranspiration.--The sum total of water lost from the land by evaporation and plant transpiration.

fissile.--Layers of rock less than 2 millimeters thick that are capable of being easily split along closely spaced planes.

fold.--A curve or bend of a planar structure such as rock strata.

formation.--A mappable or traceable body of rock that is generally characterized by some degree of internal lithologic homogeneity or distinctive lithologic features.

fossiliferous.--Bearing or containing fossils.

gross alpha and beta radiation.--Measures of certain types of radiation released from radioactive isotopes or substances in water.

hogback.--Any ridge with a sharp summit and steep slopes of nearly equal inclination on both flanks. A sharp crested ridge formed by the outcropping edges of steeply inclined resistant rocks and produced by differential erosion.

hydrograph.--A graph showing stage, flow, velocity, or other property of water with respect to time.

interbedded.--Beds lying between or alternating with others of different character.

intermittent stream.--A stream that flows only at certain times of the year when it receives water from springs or from surface sources.

ironstone.--Any rock containing a substantial proportion of an iron compound. Customarily applied to a hard, coarsely bonded or nonbonded and non-cherty sedimentary rock of post Precambrian age.

load.--The annual load of material that is transported by a stream, such as dissolved-solids load, in tons.

milliequivalents.--The concentration of a given constituent, in milligrams per liter, multiplied by its equivalent weight (formula weight of ion/ionic charge).

nonmetallic element.--A naturally occurring substance that does not have metallic properties such as luster, conductivity, opaqueness, and malleability.

plug.--A vertical, pipelike body of magma that represents the conduit to a former volcanic vent.

potentiometric surface.--An imaginary surface representing the static head of ground water, defined by the levels to which water will rise in tightly cased wells.

radium-226.--The disintegration product of uranium-238, the dominant radium isotope in natural waters.

radium-228.--A disintegration product of thorium.

riparian.--Pertaining to, or situated on the bank of a river or body of water.

saline water.--Water with dissolved-solids concentration greater than 1,000 mg/L.

sill.--A tabular intrusive structure that parallels the planar structure of the surrounding rock.

storage coefficient.--Volume of water that an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in hydraulic head.

stratigraphy.--The science of rock strata.

streamflow-gaging station.--A selected cross section of a stream channel where one or more variables are measured continuously or periodically to index water discharge and/or other properties or constituents.

subsurface water.--Water in the lithosphere in solid, liquid, or gaseous form.

tectonic.--The regional assembly of structural or deformational features.

transpiration.--The loss of water in vapor form from a plant, mostly through the stomata and lentices.

trap efficiency.--The proportion of the sediment retained by a reservoir.

water table.--The potentiometric surface in an unconfined aquifer at which the water pressure is atmospheric. The surface is defined by the levels at which water stands in wells that penetrate the aquifer enough to hold standing water.

WATSTORE.--The national water-data storage and retrieval system of the U.S. Geological Survey.

METRIC CONVERSION FACTORS

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

Multiply inch-pound unit	*By*	*To obtain metric unit*
acre-foot (acre-ft)	0.001233	cubic hectometer
acre-foot per mile (acre-ft/mi)	0.000764	cubic hectometer per kilometer
acre-foot per square mile (acre-ft/mi^2)	0.000476	cubic hectometer per square kilometer
acre-foot per year (acre-ft/yr)	0.001233	cubic hectometer per year
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
foot per mile (ft/mi)	0.1894	meter per kilometer
foot squared per day (ft^2/d)	25.9	meter squared per day
gallon per minute (gal/min)	3.785	liter per minute
inch (in.)	25.40	millimeter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
ton (short)	0.9072	megagram
ton per acre-foot (ton/acre-ft)	735.77	megagram per cubic hectometer
ton per square mile (ton/mi^2)	0.3503	megagram per square kilometer

To convert degrees Celsius (°C) to degrees Fahrenheit (°F) use the following formula:

$$°F = (°C \times 9/5) + 32.$$

To convert degrees Fahrenheit (°F) to degrees Celsius (°C) use the following formula:

$$°C = (°F - 32) \times 5/9.$$

The following terms and abbreviations also are used in this report:
- milligrams per liter (mg/L),
- micrograms per liter (µg/L),
- microsiemens per centimeter at 25 °Celsius (µS/cm at 25 °C), and
- picocuries per liter (pCi/L).

Suspended-sediment concentrations are given only in milligrams per liter (mg/L) because these values are (within the range of values presented) numerically equal to concentrations expressed in parts per million.

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

HYDROLOGY OF THE U.S. ARMY PINON CANYON MANEUVER SITE,

LAS ANIMAS COUNTY, COLORADO

by Paul von Guerard, P.O. Abbott, and Raymond C. Nickless

ABSTRACT

The U.S. Department of the Army has acquired 381 square miles of semiarid rangeland in southeastern Colorado for mechanized military maneuvers. The area known as the Pinon Canyon Maneuver Site drains into the Purgatoire River, a major tributary of the Arkansas River. A multidisciplined hydrologic investigation began in October 1982 to describe the hydrology of the Maneuver Site. One hundred fourteen wells and springs were inventoried and water-quality samples were collected at 24 wells and 1 spring. Streamflow and water-quality data were collected at 11 streamflow-gaging stations in and near the Maneuver Site. Suspended-sediment data were collected at six streamflow-gaging stations. Storage capacities of 48 stock-watering reservoirs were surveyed, and sediment volumes and sediment yields were determined at 29 of these reservoirs.

The primary aquifer at the Maneuver Site is the Dakota-Purgatoire aquifer. Recharge is primarily from precipitation and subsurface inflow, and discharge is by well pumpage, spring flow, evapotranspiration, and ground-water flow. Values of transmissivity ranged from 14 to 882 feet squared per day, and values of storage coefficient ranged from 0.0001 to 0.10.

Well yields generally range from 10 to 500 gallons per minute. Water levels measured at selected wells during water year 1985 indicated that fluctuations generally were less than 1 foot. Dissolved-solids concentrations in water from wells ranged from 195 to 6,150 milligrams per liter. Drinking-water standards for concentrations of dissolved solids, dissolved sulfate, dissolved iron, dissolved manganese, and some radiochemical constituents were exceeded at more than one-half of the ground-water sites sampled.

Streamflow in the Purgatoire River is perennial. Tributaries that drain the Maneuver Site are intermittent or ephemeral. The majority of the streamflow from the Maneuver Site results from rainfall runoff during May through October. During the 1984 and 1985 water years, streamflow in tributaries in and near the Maneuver Site was about 3,760 acre-feet or about 4.4 percent of the streamflow at the Purgatoire River at Rock Crossing, near Timpas. Flood frequencies were calculated using the log-Pearson III procedure and compared well with those obtained using a regional estimating technique that was developed using physical drainage-basin characteristics. This regional technique is considered fairly reliable for estimating flood discharges in streams in the study area that have effective drainage areas greater than 75 square miles.

Chemical-quality data for the 1983 to 1985 water years are presented for two perennial stations on the Purgatoire River and five intermittent and ephemeral streams tributary to the Purgatoire River in and near the Maneuver Site. Calcium, magnesium, and sulfate are the predominant ions in the surface water of the area. Time-series plots indicate that instream water-quality standards for nitrate and metals were exceeded. Dissolved-solids *load* was computed for the 1985 water year. Tributary inflow from the Maneuver Site contributed about 2 percent of the total dissolved-solids load transported at the Purgatoire River at Rock Crossing, near Timpas. Suspended-sediment load was computed at two stations on the Purgatoire River and at four intermittent and ephemeral streams tributary to the Purgatoire River in and near the Maneuver Site. Most of the suspended-sediment load occurs during periods of rainfall runoff. Gaged ephemeral tributaries in and near the Maneuver Site contributed about 22 and about 3 percent of the suspended-sediment load transported at the Purgatoire River at Rock Crossing, near Timpas during the 1984 and 1985 water years.

Historic sediment yields were measured for 29 small drainage basins; sediment yields ranged from 9.5 to 1,700 tons per square mile. Sediment yields were estimated by a multiple-linear-regression model developed using physical drainage-basin characteristics and by the Pacific Southwest Inter-Agency Committee method.

INTRODUCTION

The U.S. Department of the Army has acquired 381 mi^2 of semiarid rangeland in southeastern Colorado for doing mechanized military maneuvers. The area, known as the Pinon Canyon Maneuver Site (fig. 1), hereafter referred to as the Maneuver Site, is located in Las Animas County on the northwestern side of the Purgatoire River between the towns of Trinidad and La Junta. During the last 100 years, the area has been used primarily for livestock grazing. The effects of livestock grazing on a semiarid ecosystem can increase runoff and sediment yields (Lusby, 1970); mechanized military training may further increase these effects. The magnitude of these effects, which are of concern to the military and to downstream water users, could not be predicted in the original environmental impact statement (U.S. Army Corps of Engineers, 1981) because limited data existed for ground water, surface water, water quality, and sediment yields at the Maneuver Site. The House of Representatives Armed Services Committee, in Report No. 97-44, Military Construction Authorization Act, Fiscal Year 1982, page 7, recognized that commitments made by the U.S. Department of the Army in the environmental impact statement should be met and thus directed the U.S. Department of the Army to take the necessary steps to ensure the fulfillment of those commitments, including:

> "...ensuring the establishment of a system of water-quality monitoring, in cooperation with the U.S. Geological Survey to collect baseline data upon acquistion of the training area to record the effects of varying degrees of use of land on the quality of water on the land and flowing from the land acquired..."

In order to determine the effects of military training on the hydrology of the Maneuver Site, data were needed to describe existing hydrologic conditions.

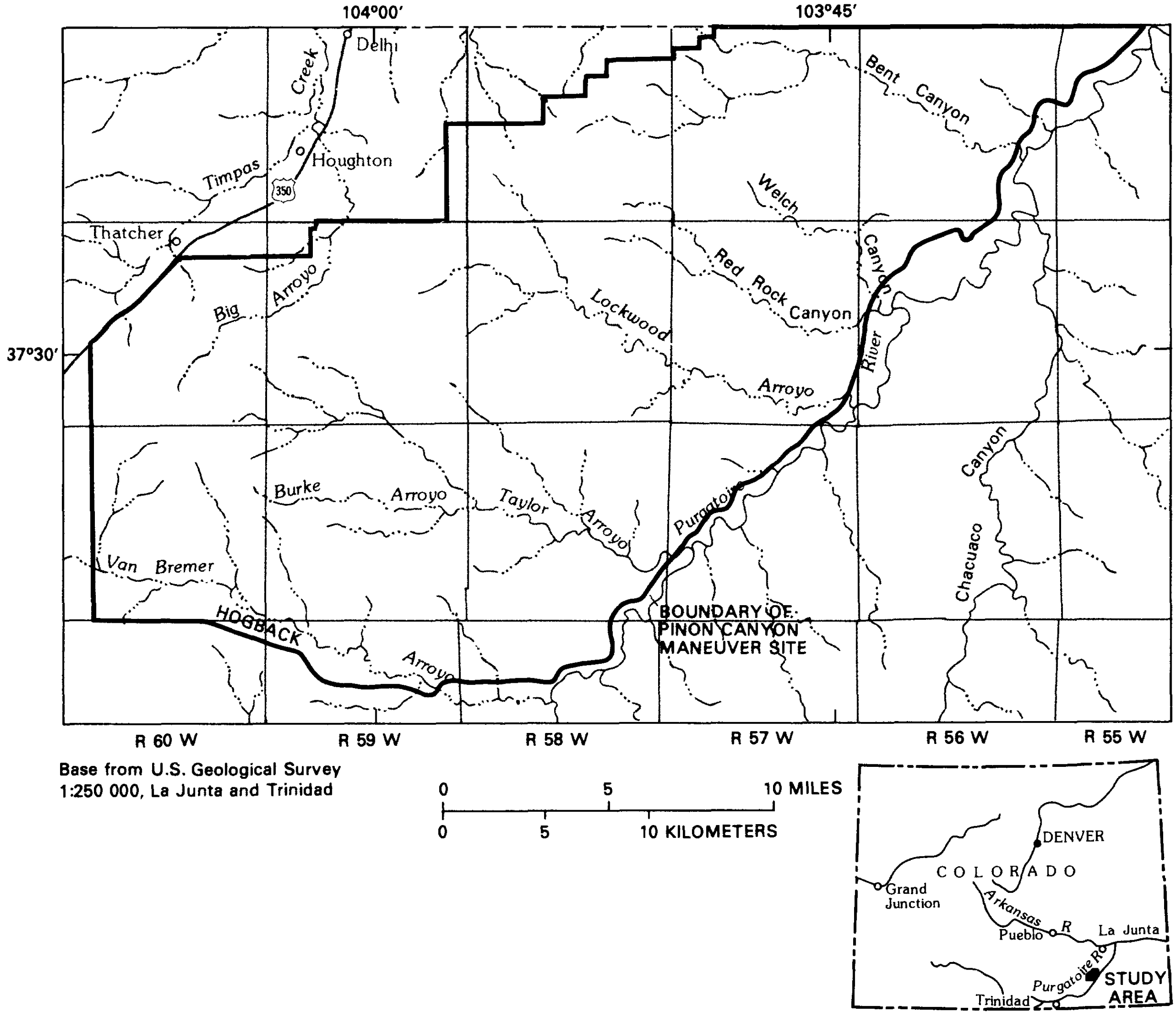


Figure 1.--Location of the Pinon Canyon Maneuver Site.

Purpose and Scope

This report presents an assessment of the baseline hydrologic conditions at the Maneuver Site prior to the commencement of military maneuvers that began during July 1985. The primary purposes of this report are: (1) To assess the quantity and quality of the ground-water resources of the Maneuver Site, and (2) to assess the quantity and quality of the surface-water resources of the Maneuver Site.

In order to assess the baseline hydrologic conditions, it was necessary to characterize the geology, ground-water occurrence and movement, ground-water quality, surface-water runoff, surface-water quality, and sediment yields in the area. Onsite data collection for the ground-water segment of this report was done during 1983-85. Previous work was used extensively in describing the geology of the area. Geology of parts of the Maneuver Site has been described by Bass (1947), Scott (1968), and Johnson (1969). Geology and ground-water resource studies of nearby areas include: Baca County (McLaughlin, 1954); Huerfano County (McLaughlin, 1966); Otero County and the southern part of Crowley County (Weist and others, 1965); and Prowers County (Voegeli and Hershey, 1965). Geologic mapping at the Maneuver Site was based on the above sources, inspection of aerial photographs and drillers logs, and onsite verification. Geohydrologic information was collected from 114 existing wells and springs, but no tests were made to determine the water-bearing characteristics of the aquifers. Water-quality samples were collected and analyzed from 24 wells and 1 spring.

Onsite collection of surface-water data began during the 1983 water year (October 1982 to September 1983), and is scheduled to continue through the 1988 water year. Only data collected through the 1985 water year are presented in this report. Existing streamflow-gaging stations 07126200, Van Bremer Arroyo near Model (site S3, table 1, pl. 1), and 07126300, Purgatoire River near Thatcher (site S4), were incorporated into a network of 11 streamflow-gaging stations (table 1, pl. 1); 8 of these 11 streamflow-gaging stations were installed during the 1983 water year. In order to monitor irrigation-return flows entering the Maneuver Site from the southwest, the streamflow-gaging station 07126130, Van Bremer Arroyo near Thatcher (site S2, pl. 1) was moved downstream during the 1985 water year to its present location, station 07126140, Van Bremer Arroyo near Tyrone (site 2A). Data collected at these stations include: (1) Continuous streamflow, (2) continuous specific conductance and water temperature, and (3) periodic chemical water quality. Daily suspended-sediment data were collected only at six streamflow-gaging stations (pl. 1). Precipitation data were collected from a network of four annual recording precipitation sites (pl. 1). The system of numbering streamflow-gaging stations is described in the "System of Numbering Streamflow-Gaging Stations" subsection in the "Supplemental Information" section at the back of the report.

Most of the 381-mi^2 Maneuver Site drains from the northwest directly into the Purgatoire River. The streamflow-gaging station at the Purgatoire River near Thatcher (site S4) monitors streamflow of the Purgatoire River upstream from the Maneuver Site, with the exception of Van Bremer Arroyo, which enters the Purgatoire River upstream from site S4. The streamflow-gaging station Purgatoire River at Rock Crossing, near Timpas (site S10), located approximately 40 river miles downstream from the streamflow-gaging station near Thatcher, monitors streamflow of the Purgatoire River downstream from the Maneuver Site.

Streamflow-gaging stations are located on all major tributaries that drain the Maneuver Site, including the streamflow-gaging station Big Arroyo near Thatcher (site S1) that drains 15.5 mi^2 north into Timpas Creek (pl. 1). In order to monitor streamflow that enters the Purgatoire River between site S4 and site S10 other than that which flows from the Maneuver Site, a streamflow gaging station is located at Chacuaco Creek at mouth, near Timpas (site S8). Chacuaco Creek drains 424 mi^2, an area comparable in size to the Maneuver Site. Chacuaco Creek (site S8) enters the Purgatoire River from the south approximately 12.5 mi upstream from the Purgatoire River at Rock Crossing, near Timpas (site S10).

Table 1.--*Summary of information for streamflow-gaging, water-quality, and suspended-sediment stations located on or near the Pinon Canyon Maneuver Site*

[e, ephemeral; i, intermittent; p, perennial].

Site number on plate 1	U.S. Geological Survey station identification number	U.S. Geological Survey station name	Drainage area (square miles)	Period of record	Stream type	Daily suspended sediment collected
S1	07120620	Big Arroyo near Thatcher	15.5	March 1983-	e	yes
S2	07126130	Van Bremer Arroyo near Thatcher.	80.6	March 1983 to May 1985.	e	no
S2A	07126140	Van Bremer Arroyo near Tyrone.	132	May 1985-	i	no
S3	07126200	Van Bremer Arroyo near Model.	175	July 1966-	i	no
S4	07126300	Purgatoire River near Thatcher.	1,935	[1]July 1966 to 1976; 1977-	p	yes
S5	07126325	Taylor Arroyo below Rock Crossing, near Thatcher.	48.4	March 1983-	e	yes
S6	07126390	Lockwood Canyon Creek near Thatcher.	41.4	April 1983-	i	no
S7	07126415	Red Rock Canyon Creek at mouth, near Thatcher.	48.8	May 1983-	e	no
S8	07126470	Chacuaco Creek at mouth, near Timpas.	424	May 1983-	e	yes
S9	07126480	Bent Canyon Creek at mouth, near Timpas.	56.2	May 1983-	e	yes
S10	07126485	Purgatoire River at Rock Crossing, near Timpas.	2,635	June 1983-	p	yes

[1]Construction of Trinidad Reservoir completed August 1977.

Many stock-watering reservoirs had been constructed in the area prior to its acquisition by the U.S. Department of the Army. A network of 49 reservoirs, 39 on the Maneuver Site and 10 offsite, was established for this study during the 1983 and 1984 water years (pl. 1). Current contents of each reservoir were surveyed. In order to determine historic sediment yields, volume of accumulated sediments was measured at 29 of these reservoirs (pl. 1).

Description of Study Area

The Maneuver Site (fig. 1) is in the Great Plains province of the Interior Plains. It is located on the divide between the Raton section to the southwest and the Colorado Piedmont to the northeast (Fenneman, 1931). Structurally, the crest of this divide is the Apishapa *arch*. On the west and north, the Maneuver Site generally is bounded by uplands, by the Big Arroyo Hills on the west, and by the Bear Springs Hills on the north. A *hogback*, a *dike*-supported range of hills, occurs along the southern boundary of the Maneuver Site. The eastern boundary is the canyon of the Purgatoire River. Between the uplands and the canyons are rolling plains. Structural *folds* that are associated with the Apishapa arch form the prominent northwest-southeast trending Black Hills across the northeastern one-third of the site (pl. 2).

Altitude of the Maneuver Site ranges from 5,905 ft at the highest point on Big Arroyo Hills to about 4,350 ft where the Purgatoire River flows out of the area. Depths of the Purgatoire River canyon range from 400 to 500 ft. The hogback has a maximum altitude of 5,668 ft and a relief of about 450 ft. The highest point on the Black Hills is 5,363 ft.

The uplands, Big Arroyo Hills, Bear Springs Hills, and the Black Hills are forested with pinon pine and juniper trees. Short-grass prairie occupies the area between the uplands and the canyons. *Riparian* vegetation occurs in the canyons.

The Maneuver Site is entirely within the Arkansas River drainage basin. The streams in the study area originate on the slopes of the highlands and flow eastward to the Purgatoire River, except for Van Bremer Arroyo that originates west of the study area and Big Arroyo that flows north from the north side of Big Arroyo Hills. The streams are ephemeral and occur in shallow valleys across the rolling plains of the area. Near the confluence with the Purgatoire River, the tributary stream channels become entrenched into the sandstone of the canyon rim and form side canyons to the main canyon. Near the upper end of the canyon, the channels of many of the tributary streams intersect the *water table*, and the streams become perennial or intermittent downstream from that point.

The climate at the Maneuver Site is semiarid; mean annual precipitation for 1951-80 was about 12 in. (Colorado Climate Center, 1984). Precipitation measured at the precipitation-network sites (pl. 1) during the 1984 and 1985 water years averaged 10.4 in. Warm daytime temperatures and minimal relative humidity cause large *evaporation* rates at the Maneuver Site. From 1972 through 1984, evaporation rates were measured during the months of April through October at Springfield, Colo., 70 mi east of the Maneuver Site, and these rates averaged 70 in.

Precipitation is seasonally distributed between rain and snowfall, and about 80 percent of the annual precipitation occurs as rainfall during March through May and July through October (fig. 2). Early spring snowstorms may contribute substantial quantities of moisture. However, the majority of precipitation occurs as a result of convective thunderstorms that produce high-intensity, localized cells of precipitation. Convective thunderstorms occur in the area on an average of 60 days annually (U.S. Department of the Interior, 1970).

Long-term temperature records are available for the Las Animas County Airport located 25 mi southwest of the Maneuver Site. Records for 1972 to 1983 indicate an annual mean temperature of 52.7 °F; the maximum mean monthly temperature was 88.9 °F occurring during July, and the minimum mean monthly temperature was 28.6 °F occurring during January.

The near-surface geology and climate determine the type of soils that develop in the area. The surface geology at the Maneuver Site is predominantly sedimentary limestone, shale, and sandstone; basalt dikes occur along the southern boundary. Four major soils groups predominate at the Maneuver Site (fig. 3). Soils are well drained, and depths range from 5 to 60 in.

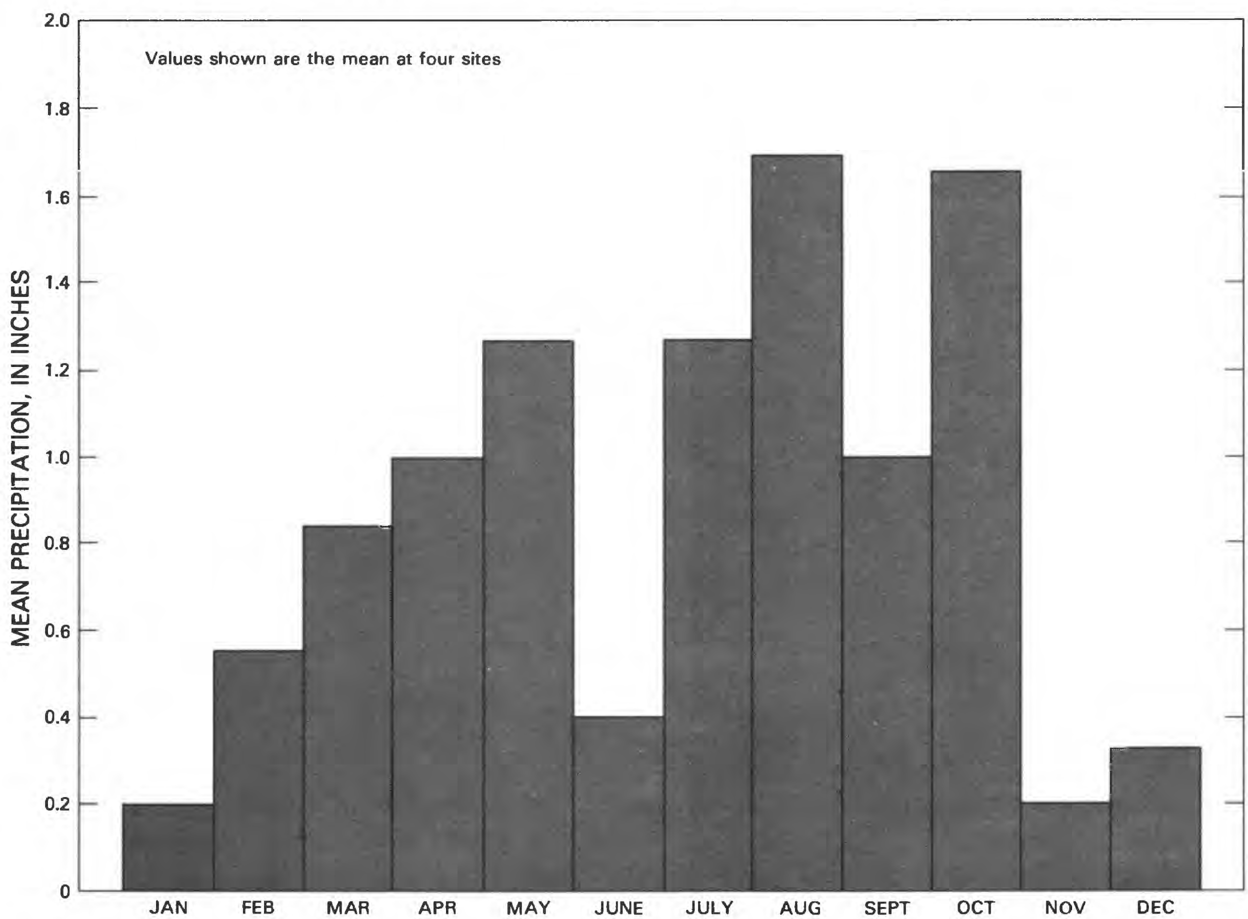
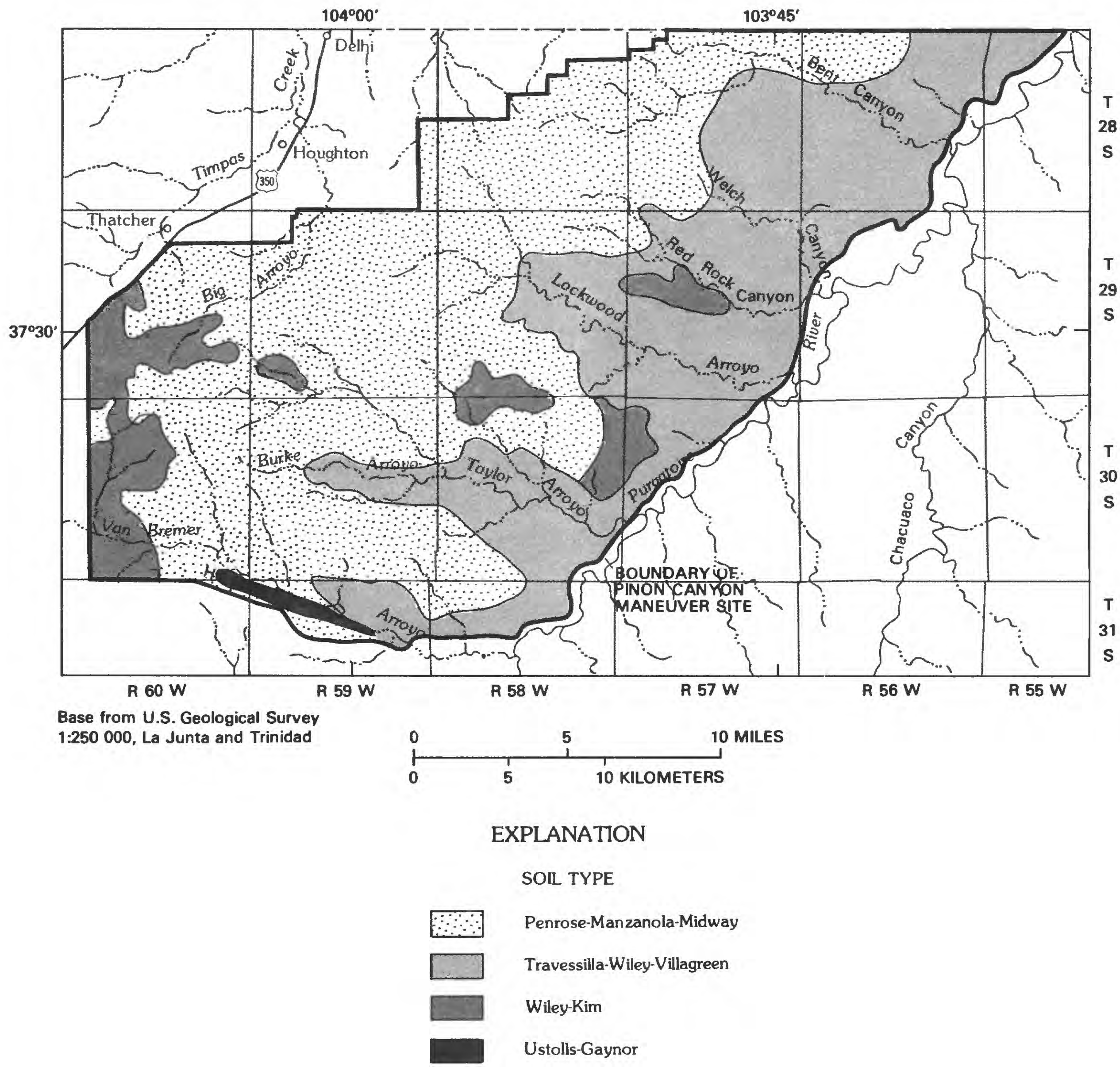


Figure 2.--Mean monthly precipitation at the Pinon Canyon Maneuver Site for water years 1984 and 1985.

Soils developed in areas underlain by shale and limestone are silty and have a fine texture; soils underlain by sandstone tend to be sandy and loamy. The Penrose-Manzanola-Midway and the Wiley-Kim soils groups are developed mostly in areas underlain by limestone and shale. The Penrose-Manzanola-Midway group is classified as having substantial erosion potential. Soils are slightly to moderately salt and alkali affected, except for the Ustolls-Gaynor group that is associated with the igneous basalt *formations* (U.S. Soil Conservation Service, 1983).



Modified from U.S. Soil Conservation Service, 1983

Figure 3.--Generalized soils.

GEOLOGIC SETTING

Geologic maps of the Maneuver Site at a scale of 1:250,000 (Scott, 1968; Johnson, 1969) provide a regional overview of the geologic formations and structure of the Maneuver Site. Site-specific descriptions of geologic formations and structure were available for the western part of the Maneuver Site (Bass, 1947). These descriptions and onsite measurements and observations made during the study, provide additional detail about the geologic setting of the study area.

Geologic Formations

The generalized surficial geology of the Maneuver Site is shown in figure 4. The primary formations exposed at the land surface in descending order are the Niobrara Formation, Carlile Shale, Greenhorn Limestone, Graneros Shale, Dakota Sandstone, and Purgatoire Formation. The generalized *stratigraphy* of the rocks that crop out at the Maneuver Site, and their approximate thicknesses, physical descriptions, and water-supply potential are listed in table 2. Other formations that crop out are of limited extent and are associated with the canyon areas along the eastern border of the Maneuver Site. Rocks of the Permian, Triassic, and Jurassic Systems are the oldest within the geologic section and are exposed only along the deeper canyon walls of the Purgatoire River.

The Dakota Sandstone and the Purgatoire Formation occur throughout a large part of the Maneuver Site and are the principal source of ground water in the area. The Dakota-Purgatoire aquifer is discussed further in the "Ground Water" section. The Purgatoire Formation consists of the Cheyenne Sandstone Member and the Kiowa Shale Member. The Cheyenne Sandstone Member, often called "Second Dakota" in the logs of local well drillers, is a massive, white-to-yellowish-brown, *crossbedded* sandstone, from 70 to 110 ft thick. It forms white cliffs along the Purgatoire River canyon and is distinguishable from the Dakota Sandstone, which occurs near the rim of the canyon, by the whiter color and more rounded, weathered form of the Cheyenne Sandstone. The Kiowa Shale Member consists of *fossiliferous*, marine, dark-gray claystone, siltstone, and sandstone (Scott, 1968), and is about 40 to 70 ft thick in the study area. In the canyon of the Purgatoire River, the Kiowa Shale Member is concealed beneath debris originated by slope wash.

At the Maneuver Site, the Dakota Sandstone is a yellowish-brown, crossbedded sandstone. The weathered surface generally is coated with a thin film of iron and manganese oxides called desert varnish. In many places, the Dakota Sandstone contains layers and nodules of hard, dark-brown *ironstone*. The formation has weathered into steep ledges and cliffs that form the rim of the Purgatoire River canyon in many places. The Dakota Sandstone ranges from 75 to 140 ft thick, although on the canyon rim and in some other areas, its thickness has been decreased by erosion.

The Carlile Shale, Greenhorn Limestone, and Graneros Shale Formations overlie the Dakota Sandstone and the Purgatoire Formation and occupy all but the highest areas in the western half of the Maneuver Site. The youngest consolidated sedimentary unit is the Niobrara Formation that forms the higher ridges in the northwestern part of the study area. It yields only small quantities of water to wells. Intrusive dikes, *dune sand*, and *alluvium* are present in the study area to a more limited extent.

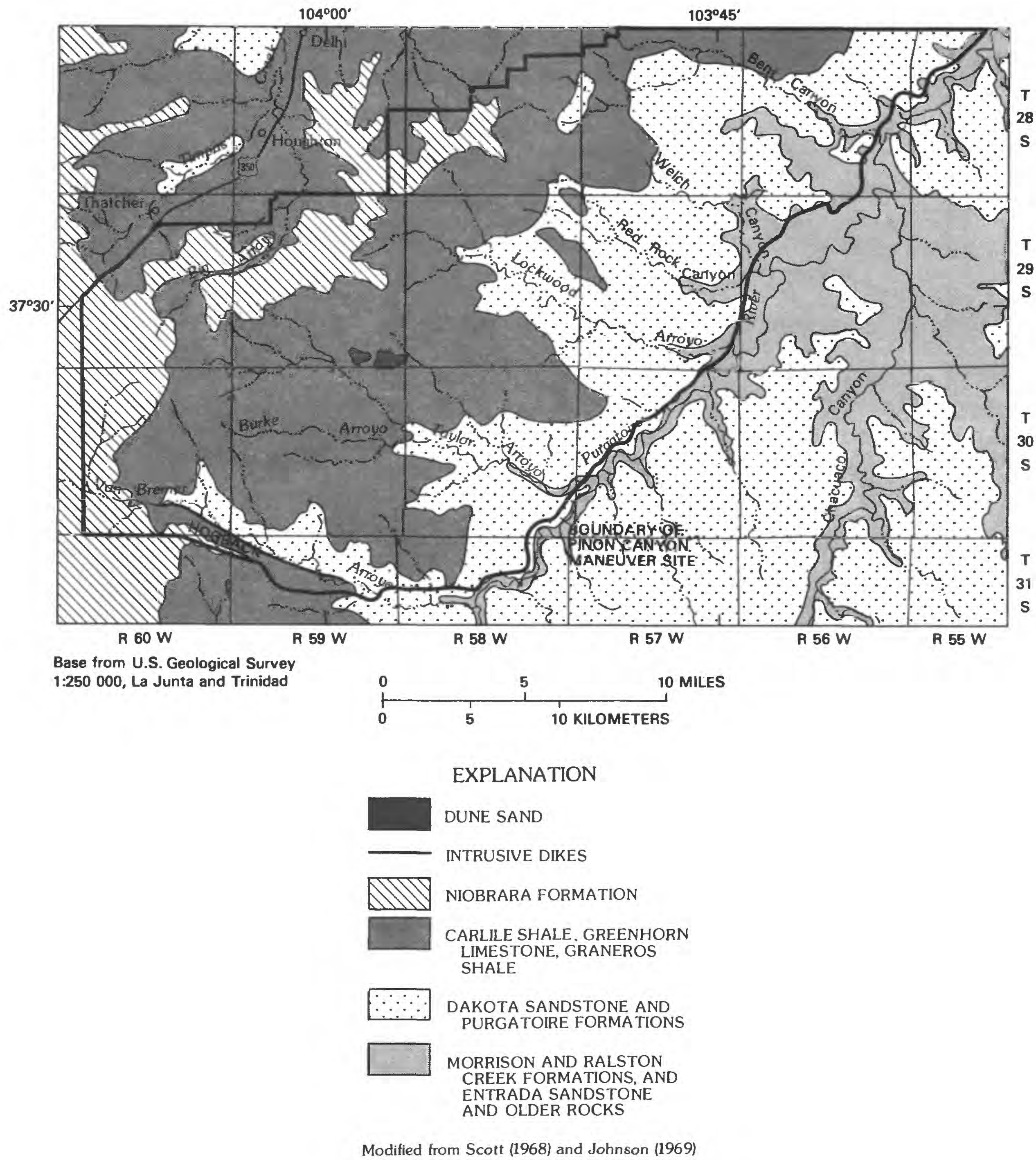


Figure 4.--Generalized geology.

Table 2.--*The generalized stratigraphy and water-supply potential at the Pinon Canyon Maneuver Site*

[Modified from Bass (1947), McLaughlin (1954, 1966), Voegeli and Hershey (1965), Weist and others (1965), Scott (1968), Johnson (1969), and Mark and Requist (1969), using onsite measurements; --, no data available]

System	Series	Formation	Member	Approximate thickness (feet)	Physical description	Water-supply potential
Quaternary	Holocene	Alluvium	--	Variable	Gray, poorly sorted stony sand and silt forming flood plain.	Yields small quantities of water to shallow wells on site.
	Pleistocene	Dune sand	--	Variable	Yellow, fine-grained sand, forming localized dunes.	Not known to yield water to wells on site.
Tertiary	Oligocene and Eocene	Basic *plugs*, dikes, and *sills*	--	--	Dark gray, finely crystalline, olivine, basalt dikes.	Not known to yield water to wells on site.
Cretaceous	Upper Cretaceous	Niobrara Formation	Smoky Hill Shale Member	Variable	Yellowish-gray, fossiliferous, calcareous shale and silty limestone.	Not known to yield water to wells on site.
			Fort Hays Limestone Member	50-60	Beds of chalk 0.5 to 3 feet thick separated by beds of dark-gray chalky shale 1 to 2 inches thick.	Yields small quantities of water to wells.
		Carlile Shale	Codell Sandstone Member	5-20	Upper part is thin lenses of dark limestone *interbedded* with a limey shale. The basal 2.5 to 3 feet is a dense, near-black, fossiliferous limestone.	Yields small quantities of water to wells in southeastern Colorado.
			Blue Hill Shale Member	70-80	Dark *fissile* shale with large calcareous concretions.	Not known to yield water to wells.
			Fairport Chalk Member		Tan to black, chalky, calcareous shale.	Not known to yield water to wells.
		Greenhorn Limestone	Bridge Creek Limestone Member	30-40	Interbedded, fossiliferous limestone and limey shale.	Yields small quantities of water to stock wells in other areas of southeastern Colorado.
Cretaceous			Hartland Shale Member	20-30	Light gray limey shale with thin beds of Bentonite.	Not known to yield water to wells.
			Lincoln Limestone Member	15-30	Limey shale with platy limestone beds near base and top.	Yields small quantities of water to wells in other areas of southeastern Colorado.
	?	Graneros Shale	--	90-150	Dark-gray to black, fissile, noncalcareous shale, with two beds of dense, dark limestone.	Not known to yield water to wells.
	Lower Cretaceous	Dakota Sandstone		75-140	Yellowish-brown, crossbedded cliff-forming sandstone.	Yields adequate quantities of water for domestic and stock use.
		Purgatoire Formation	Kiowa Shale Member	40-70	Fossiliferous, marine, dark-gray claystone, siltstone and sandstone.	Acts as *confining unit* between Dakota Sandstone and Cheyenne Sandstone Member.
			Cheyenne Sandstone Member	70-110	Massive white to yellowish-brown, crossbedded sandstone.	Yields adequate quantities of water for domestic and stock use.
Jurassic	Upper Jurassic	Morrison Formation	--	100-300	Varicolored claystone, brown-weathering sandstone and gray limestone.	Yields some water to springs and wells in other areas of southeastern Colorado.
		Ralston Creek Formation	--	20-50	Greenish-gray claystone, gray limestone with jasper and agate.	Not known to yield water to wells.
		Entrada Sandstone	--	20-100	Massive, white crossbedded sandstone.	Possible aquifer but not known to yield water to wells in or near study area.
Triassic and Permian		Undivided	--	--	Mostly reddish-brown sandstone and shale with dolomite and limestone.	Possible aquifer but not known to yield water to wells in or near study area.

Geologic Structures

The axis of the Apishapa arch crosses the northeastern part of the Maneuver Site (fig. 5). The Apishapa arch is an *anticline* that originates near the Las Animas arch southeast of the Maneuver Site and extends northwestward across Las Animas and Huerfano Counties (McLaughlin, 1966). The Apishapa arch separates the Raton basin on the south from the Denver basin on the north. Rocks in the Pinon Canyon area dip either northeast or southwest away from the arch. However, there are small but prominent variations in regional dips because of subsidiary folds. The apex of the Apishapa arch crosses the Maneuver Site from southeast to northwest in township 28 south, range 57 west. The topographic feature formed by this arch is known as the Black Hills (fig. 1). Exposure of the oldest rocks in the study area occurs where the Apishapa arch crosses the canyon of the Purgatoire River. The structure of the area, as indicated by contours on the top of the Cheyenne Sandstone Member of the Purgatoire Formation, is shown in figure 6.

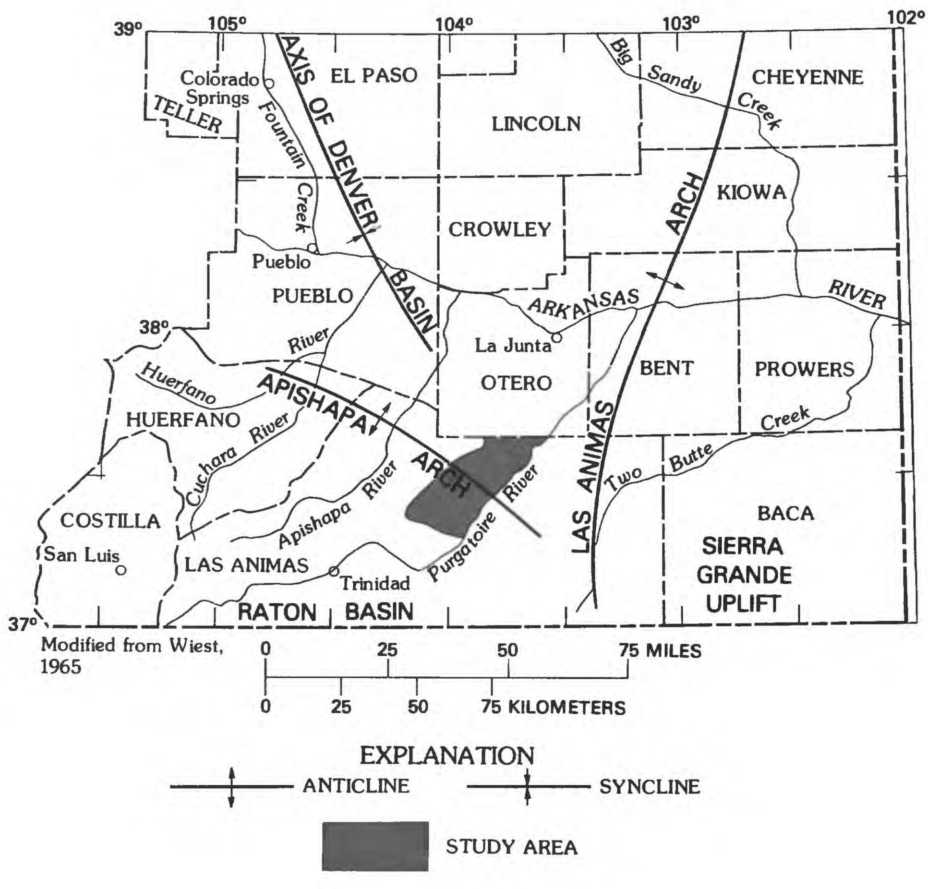


Figure 5.--Major tectonic features in southeastern Colorado.

The southern part of the north-trending Model anticline is located on the west side of the Maneuver Site (fig. 6). Four separate *domes*, three of which are in the study area, are superimposed along the ridge of this anticline. No oil is associated with the structure, but gas has been obtained from the two southern domes. The gas contains no hydrocarbon gases and is composed of nitrogen, carbon dioxide, oxygen, and helium (Bass, 1947).

Two eastward-trending dikes of dense, dark, olivine basalt (Scott, 1968) cross the southwestern edge of the study area (fig. 4). These dikes affect local structure and may affect the direction of ground-water movement. The larger of the dikes forms the crest of the hogback; the smaller dike is less obvious and trends almost due west along the extreme western boundary of the Maneuver Site.

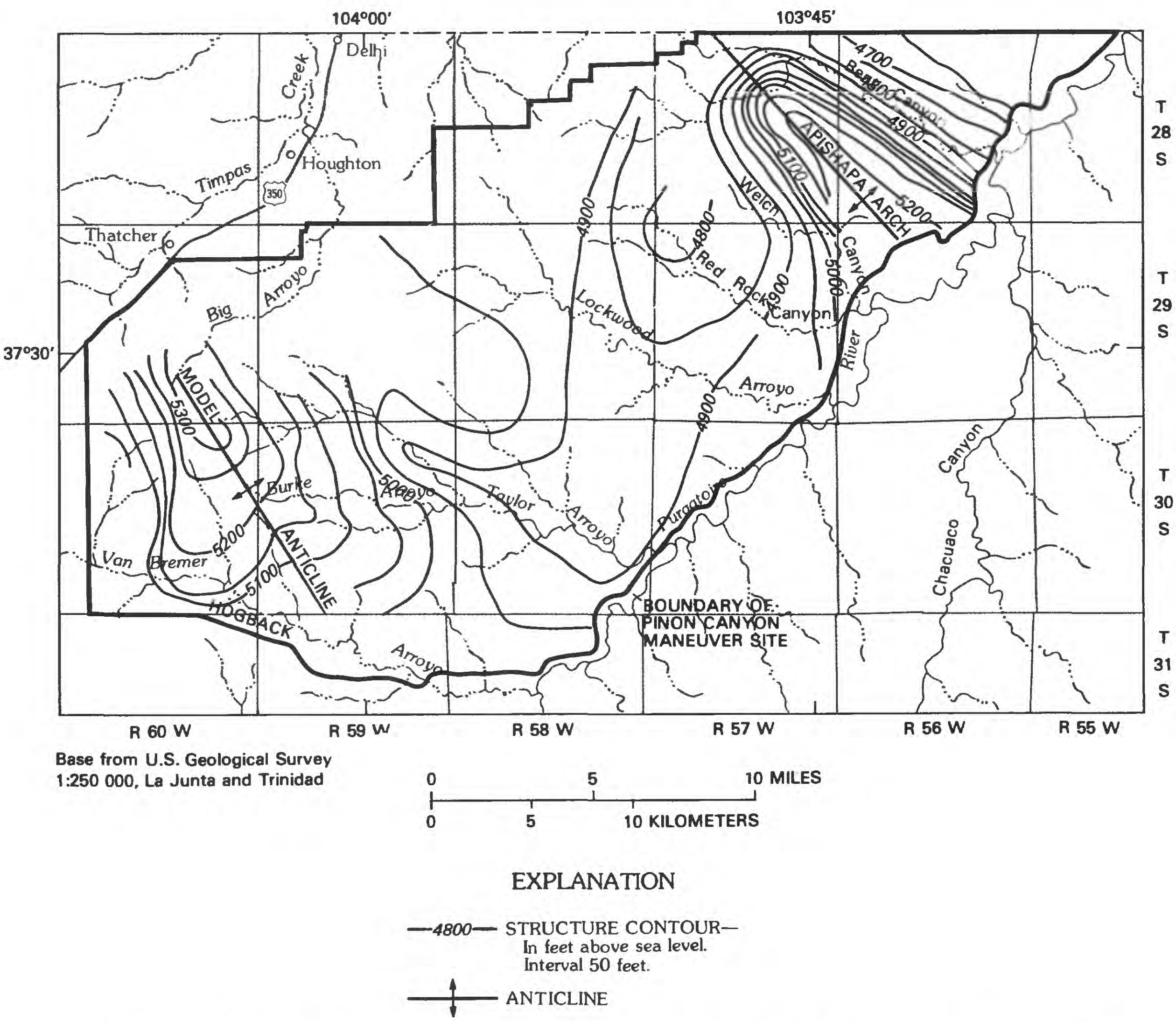


Figure 6.--Structure contours of the top of the Cheyenne Sandstone Member of the Purgatoire Formation

GROUND WATER

Because surface-water sources typically are unreliable in semiarid climates, ground water historically has been the predominant source of water supply in the study area. This supply, which has been developed primarily for domestic purposes and for livestock watering, was obtained from springs (either natural or improved) and wells (either hand-dug or drilled). Inspection of drillers' logs and onsite inspection during the well inventory indicated that most wells were completed in the Dakota-Purgatoire aquifer. Currently (1987) there are approximately 19 springs (table 3) and 95 wells (table 4) located at the Maneuver Site. Locations of the springs and wells are shown on plate 2. The system of numbering well locations is described in the "System of Numbering Well Locations" subsection and shown in figure 29 in the "Supplemental Information" section at the back of the report. As of July 1984, the Colorado State Engineer listed 13 of these wells as *adjudicated*; appropriation dates ranged from December 31, 1885, to December 31, 1951. The well number, location, and decreed quantity of flow as reported in the adjudication documents are listed in table 5. The number of the nearest well, as determined during the 1984 and 1985 inventory by the U.S. Geological Survey (table 4), also is listed in table 5. The nearest inventoried well is listed because of uncertainty about the exact location of the adjudicated well.

Beginning in 1967 through the early 1980's, a system of pipelines (pl. 2) that would originate at the more productive springs and wells was installed to improve the efficiency and areal distribution of the domestic- and stock-water supply. At that time, less productive wells were abandoned and soon became inoperable because of lack of maintenance. Similarly, many remaining wells will require rehabilitation for operation in the future. The condition of each well during the 1984 to 1985 inventory is described in table 4.

The primary sources of ground water in the study area are the Dakota Sandstone Formation and the Cheyenne Sandstone Member of the Purgatoire Formation (table 2). As previously discussed in the "Geologic Setting" section, these two units commonly are referred to as the Dakota-Purgatoire aquifer and they underlie all of the Maneuver Site. The following sections will: (1) describe the Dakota-Purgatoire aquifer and other potential aquifers in the area; (2) characterize the general chemical quality of the ground water at the Maneuver Site; and (3) discuss appropriate considerations should further ground-water development be contemplated.

Table 3.--*Location, altitude, and summary description of springs at the Pinon Canyon Maneuver Site inventoried by the U.S. Geological Survey during 1984 and 1985*

Number on plate 2	Local number	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Altitude of land surface (feet)	Description of site at time of inventory
SP1	SC02805607CAB	37 37 16	103 43 42	4,650	Undeveloped; pool in rock.
SP2	SC02805717ACD	37 36 30	103 48 39	4,890	Undeveloped; seep in channel.
SP3	SC02805726BBB	37 35 07	103 45 53	5,210	Undeveloped; pool, under ledge, Sugarloaf Spring.
SP4	SC02805733DBA	37 33 47	103 47 28	4,910	Undeveloped; pool in rock channel.
SP5	SC02805816BBD	37 36 47	103 54 37	5,175	Undeveloped; seep in channel.
SP6	SC02905705CBC	37 32 51	103 49 19	4,870	East Red Rock Ranch Spring.
SP7	SC02905706DAD	37 32 48	103 49 28	4,850	West Red Rock Ranch Spring.
SP8	SC02905730BDB	37 29 38	103 50 08	4,810	Developed; pool under ledge.
SP9	SC02905812ADC	37 32 11	103 50 41	4,900	Undeveloped; pool under ledge.
SP10	SC02905823ADD	37 30 22	103 51 38	4,895	Undeveloped; pool in channel.
SP11	SC02905918DBB	37 31 12	104 02 58	5,470	Undeveloped; seep in shale channel.
SP12	SC02906035ABB	37 29 02	104 05 10	5,555	Undeveloped; seep in channel, pool.
SP13	SC03005708BAD2	37 27 05	103 48 53	4,990	Undeveloped; pool in channel.
SP14	SC03005718ADC	37 25 57	103 49 35	4,920	Undeveloped; pool in channel, below fall.
SP15	SC03005718DCC	37 25 32	103 49 41	5,010	Undeveloped; pool under rock ledge.
SP16	SC03005801AAC	37 27 57	103 50 37	4,990	Undeveloped; in channel, affected by stock pond.
SP17	SC03005815CAC	37 25 44	103 53 23	4,990	Big Water Arroyo Spring, pumped to pipeline.
SP18	SC03105904CBB	37 22 22	104 01 32	5,166	Developed.
SP19	SC03105910DAB	37 21 26	103 59 42	5,035	Undeveloped; pool in channel.

Table 4.--*Location, altitude, water level, and summary description of wells at the Pinon Canyon Maneuver Site inventoried by the U.S. Geological Survey during 1984 and 1985*

[--, no data available]

Number on plate 2	Local number	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Altitude of land surface (feet)	Water level (feet)	Description of site at time of inventory
W1	SC02705634BAA	37 39 23	103 39 58	4,690	119.0	Submersible pump, pressure tank in pit.
W2	SC02805603CBC1	37 38 03	103 40 46	4,700	87.48	Submersible pump, pressure tank in pit.
W3	SC02805603CBC2	37 38 03	103 40 46	4,700	88.87	Cased hole only.
W4	SC02805623DDD	37 35 18	103 38 48	4,410	96.51	Submersible pump.
W5	SC02805630BAD	37 34 58	103 43 43	5,350	--	Oil test, deep, casing only.
W6	SC02805710ADA1	37 37 31	103 45 58	4,865	17.15	Dug well, windmill.
W7	SC02805710ADA2	37 37 31	103 45 58	4,865	18.70	Drilled well, submersible pump.
W8	SC02805717CAC	37 36 17	103 48 53	4,910	--	Submersible pump, pressue tank in pit.
W9	SC02805717DBA	37 36 26	103 48 35	4,895	10.97	Dug well, windmill, sucker rod missing.
W10	SC02805734CDD	37 33 31	103 46 38	4,835	21.73	Cased hole only, parts of downed windmill.
W11	SC02805815ADD	37 36 35	103 52 37	5,150	--	Windmill, apparently operative.
W12	SC02805824CCD	37 35 14	103 51 16	5,058	158.3	Windmill, sucker rod broken.
W13	SC02805832DDA	37 33 28	103 54 58	5,158	--	Windmill, tower blown down.
W14	SC02805835DAA	37 33 49	103 51 30	5,000	--	Windmill, apparently operative.
W15	SC02805924BBA	37 36 08	103 57 50	5,108	154.4	Submersible pump, pipe broken.
W16	SC02905630BCC	37 29 22	103 44 04	4,758	221.0	Windmill, in poor repair.
W17	SC02905701DBD	37 32 40	103 44 15	4,660	--	Pump jack.
W18	SC02905708BCD	37 32 08	103 49 05	4,820	16.54	Submersible pump, Red Rock Ranch.
W19	SC02905708BDC	37 32 11	103 49 04	4,818	14.06	Submersible pump, supplies pipeline.
W20	SC02905710ABA	37 32 27	103 46 21	5,026	73.85	Windmill, in very poor repair.
W21	SC02905718BBB	37 31 34	103 50 25	4,935	--	Submersible pump, supplies pipeline.
W22	SC02905728ADB1	37 29 37	103 47 22	4,989	63.72	Windmill, apparently operative.
W23	SC02905728ADB2	37 29 37	103 47 22	4,989	66.75	Casing only.
W24	SC02905728ADB3	37 29 37	103 47 22	4,989	63.54	Tower missing.
W25	SC02905807ABC	37 32 21	103 56 19	5,150	--	Windmill, sucker rod broken.
W26	SC02905807BAD	37 32 17	103 56 32	5,150	6.55	Windmill, dug well.
W27	SC02905813AAA	37 31 34	103 50 26	4,936	--	Tower, tank, rebored as SC02905718BBB.
W28	SC02905815ADC	37 31 14	103 52 46	4,990	25.92	Windmill, dug well.
W29	SC02905815BCA	37 31 22	103 53 25	5,032	62.10	Windmill, operating.
W30	SC02905815DAA	37 31 10	103 52 43	4,980	15.89	Concrete cover, dug well, no tower.
W31	SC02905821DCA	37 30 03	103 53 59	5,030	65.16	Windmill in bad repair.
W32	SC02905826DCA	37 29 08	103 51 49	5,015	93.20	Windmill, sucker rod broken.
W33	SC02905828CDB	37 29 12	103 54 32	5,110	--	Tower leg bases, concrete slab, hole plugged.
W34	SC02905829AAA	37 29 50	103 54 49	5,085	126.4	Cased hole and tank only.
W35	SC02905904CAD	37 32 48	104 00 47	5,515	--	Destroyed. Location confirmed by Federal Aviation Administration personnel on site at time well was drilled.
W36	SC02905905DAC	37 32 47	104 01 30	5,322	9.38	Windmill and electric pump, dug well.
W37	SC02905926CCC	37 29 01	103 59 12	5,235	--	Pump jack in bad repair.
W38	SC02905928CAD	37 29 20	104 00 53	5,295	--	Cased hole only.
W39	SC02906017DBA	37 31 10	104 08 22	5,520	--	Submersible pump, supplies pipeline.
W40	SC02906024DDA	37 30 07	104 03 35	5,635	--	Submersible pump.
W41	SC02906032ABB	37 29 04	103 48 12	5,690	419.4	Aquifer test site.
W42	SC03005704BBC	37 28 00	103 48 12	5,049	109.3	Windmill, apparently operative.
W43	SC03005706ACC	37 27 43	103 49 45	5,060	211.0	Cased hole only.
W44	SC03005706BAA	37 28 06	103 50 01	5,040	--	Cased hole only.
W45	SC03005707DBD	37 26 38	103 49 42	5,070	150.5	Windmill, apparently operative.
W46	SC03005708BAD1	37 27 05	103 48 53	4,990	--	Cased hole only.
W47	SC03005801BBC	37 27 57	103 51 31	5,030	--	Submersible pump, pit below old tower.
W48	SC03005802BBA	37 28 03	103 52 22	5,041	131.6	Windmill, in bad repair.
W49	SC03005808CAC	37 26 39	103 55 37	5,027	80.97	Windmill, apparently operative.
W50	SC03005810CCA	37 26 33	103 53 31	4,980	70.06	Windmill, discharge pipe to missing tank on platform.

Table 4.--*Location, altitude, water level, and summary description of wells at the Pinon Canyon Maneuver Site inventoried by the U.S. Geological Survey during 1984 and 1985*--Continued

Number on plate 2	Local number	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Altitude of land surface (feet)	Water level (feet)	Description of site at time of inventory
W51	SC03005811DDA	37 26 30	103 51 42	5,045	130.3	Windmill, in very poor repair.
W52	SC03005818BBB	37 26 19	103 57 01	5,085	111.1	Cased hole only.
W53	SC03005819ACC	37 25 08	103 56 31	5,104	117.6	Windmill, in poor repair.
W54	SC03005826CCC	37 23 44	103 52 40	5,096	181.5	Windmill, possibly operative.
W55	SC03005827ADA	37 24 14	103 52 56	5,060	134.1	Ranch domestic well, in pumphouse, operating.
W56	SC03005827CBC	37 24 01	103 53 51	5,069	--	Drop pipe and casing only, tanks.
W57	SC03005830CDC	37 23 44	103 56 46	5,122	52.22	Windmill tower blown down.
W58	SC03005833CCC	37 22 51	103 55 00	5,128	109.80	Windmill, apparently operative.
W59	SC03005834CDD	37 22 56	103 53 23	5,110	--	Windmill, ranch domestic well.
W60	SC03005901ACB1	37 27 47	103 57 30	5,186	--	Cased hole only, rebored as SC03005901ACB2.
W61	SC03005901ACB2	37 27 47	103 57 30		280.0	Submersible pump, supplies pipeline, domestic stock.
W62	SC03005902CBD	37 27 29	103 59 01	5,155	--	Windmill, apparently operative.
W63	SC03005910CAA	37 26 43	103 59 54	5,206	199.6	Windmill, apparently operative.
W64	SC03005913CAB	37 25 48	103 57 53	5,093	--	Rock-lined, dug well, filled to 11 feet.
W65	SC03005916BAD	37 26 07	104 00 56	5,242	74.29	Cased hole only.
W66	SC03005919DBD	37 24 56	104 02 53	5,342	170.8	Windmill, sucker rod broken.
W67	SC03005921DAA	37 24 56	104 00 27	5,265	114.9	Windmill, apparently operative.
W68	SC03005924BBC	37 25 18	103 58 10	5,130	116.0	Windmill, sucker rod broken.
W69	SC03005927CAC	37 23 57	104 00 02	5,255	172.8	Windmill, operative.
W70	SC03005931DBA	37 23 13	104 02 58	5,225	58.20	Windmill, operative.
W71	SC03005932ABC	37 23 32	104 02 00	5,260	119.6	Windmill, operative.
W72	SC03005934DBC1	37 23 05	103 59 47	5,205	112.8	Open casing under wooden tower.
W73	SC03005934DBD2	37 23 08	103 59 47	5,205	115.2	Windmill, apparently operative.
W74	SC03005934DCA	37 23 02	103 59 47	5,200	121.8	Cased hole through slab.
W75	SC03005935DAC	37 23 08	103 58 31	5,178	88.10	Windmill, apparently operative.
W76	SC03006005BDA	37 27 55	104 08 40	5,649	385.8	Windmill, operative.
W77	SC03006009ABD	37 27 08	104 07 18	5,630	--	Windmill, operative.
W78	SC03006014ABD	37 26 17	104 05 07	5,425	--	Windmill, apparently operative.
W79	SC03006019ABA	37 25 30	104 09 30	5,466	--	Windmill, apparently operative.
W80	SC03006023DAD	37 24 56	104 04 54	5,340	152.1	Windmill, operative.
W81	SC03006026DBD	37 24 02	104 05 10	5,313	--	Cased hole under windmill tower.
W82	SC03006028DAD	37 24 03	104 07 06	5,325	112.2	Submersible pump, supplies pipeline, tower.
W83	SC03006035ABD	37 23 34	104 05 10	5,285	98.50	Windmill, apparently operative.
W84	SC03105802BBD	37 22 40	103 53 02	5,060	--	Submersible pump, supplies pipeline.
W85	SC03105803CBB	37 22 19	103 54 15	5,118	132.8	Submersible pump in pit.
W86	SC03105804CAA	37 22 19	103 54 55	5,098	47.99	Windmill, possibly operative.
W87	SC03105805DDC	37 21 54	103 55 37	5,085	117.8	Windmill, operative.
W88	SC03105808CDD	37 21 04	103 55 57	5,070	110.1	Windmill, sucker rod broken.
W89	SC03105809ACC	37 21 30	103 54 42	5,045	89.07	Cased hole through slab only.
W90	SC03105901ABA	37 22 49	103 57 33	5,124	66.25	Windmill, apparently operative.
W91	SC03105902CDB	37 22 10	103 59 05	5,141	60.40	Windmill, apparently operative.
W92	SC03105904CAA	37 22 18	104 01 10	5,165	53.87	Cased hole under old tower.
W93	SC03105904CBC	37 22 12	104 01 31	5,145	20.16	Windmill, operative.
W94	SC03105906AAA	37 22 46	104 02 46	5,195	37.40	Windmill, operative.
W95	SC03105908DCD	37 21 05	104 01 58	5,289	128.6	Windmill, standby pump jack.

Table 5.--*Name, location, decreed quantity, and appropriation date of adjudicated wells at the Pinon Canyon Maneuver Site*

Number of well	Location of decree: Township	Range	Section	Decreed quantity (cubic foot per second)	Appropriation date	Nearest well(s) inventoried by the U.S. Geological Survey, 1984-85 (See plate 2 for location)
Kitch-1	29S	57W	08SWNW[1]	0.0066	December 31, 1936	SC02905708BCD SC02905708BCD
Kitch-2	29S	57W	22SWSE	.0022	December 31, 1936	([2])
Kitch-3	29S	58W	07NWSE	.0089	December 31, 1951	SC02905807ABC SC02905807BAD
Kitch-4	29S	59W	05SESE	.0066	December 31, 1912	SC02905905DAC
Kitch-5	28S	58W	32SESE	.0066	December 31, 1948	SC02905832DDA
Kitch-6	29S	58W	21SESW	.0089	December 31, 1949	SC02905821DCA
Kitch-7	29S	58W	29NENW	.0066	December 31, 1932	SC02905829AAA
Kitch-8	28S	59W	24NWNE	.0089	December 31, 1948	SC02805924BBA
Kitch-9	29S	58W	07NENW	.0178	December 31, 1944	SC02905807ABC SC02905807BAD
Kitch-10	28S	58W	15NWSW	.0110	December 31, 1885	SC02805815ADD
Kitch-11	28S	58W	35SENE	.0133	December 31, 1945	SC02805835DAA
Kitch-12	29S	58W	13NENE	.0133	December 31, 1944	SC02905813AAA
Kitch-13	29S	57W	11NWNE	.0044	December 31, 1936	([2])

[1]SW quarter of the NW quarter of section 8.
[2]No well inventoried within township, range, and section.

Dakota-Purgatoire Aquifer

Ground water in the Dakota-Purgatoire aquifer occurs in the interstices and fractures of the fine- to medium-grained massive sandstones that make up the aquifer. The aquifer is unconfined in outcrop areas (fig. 7), and water-table or unsaturated conditions exist. Where the aquifer is overlain by consolidated rocks, it is confined and *artesian* conditions exist, resulting in flowing wells where the pressure head is above land surface. However, none of the wells in the study area were flowing during the 1984 to 1985 inventory.

Contours of the *potentiometric* surface for the aquifer, based on water-level measurements obtained during 1984 and 1985, are shown in figure 7. The surface represents the approximate altitude of the water level in a tightly cased well that penetrates the Dakota-Purgatoire aquifer. Though based on somewhat limited data, this surface indicates that ground-water movement in the northeastern parts of the Maneuver Site generally is toward the northeast, and ground-water movement throughout the remainder of the Maneuver Site is toward the east and southeast.

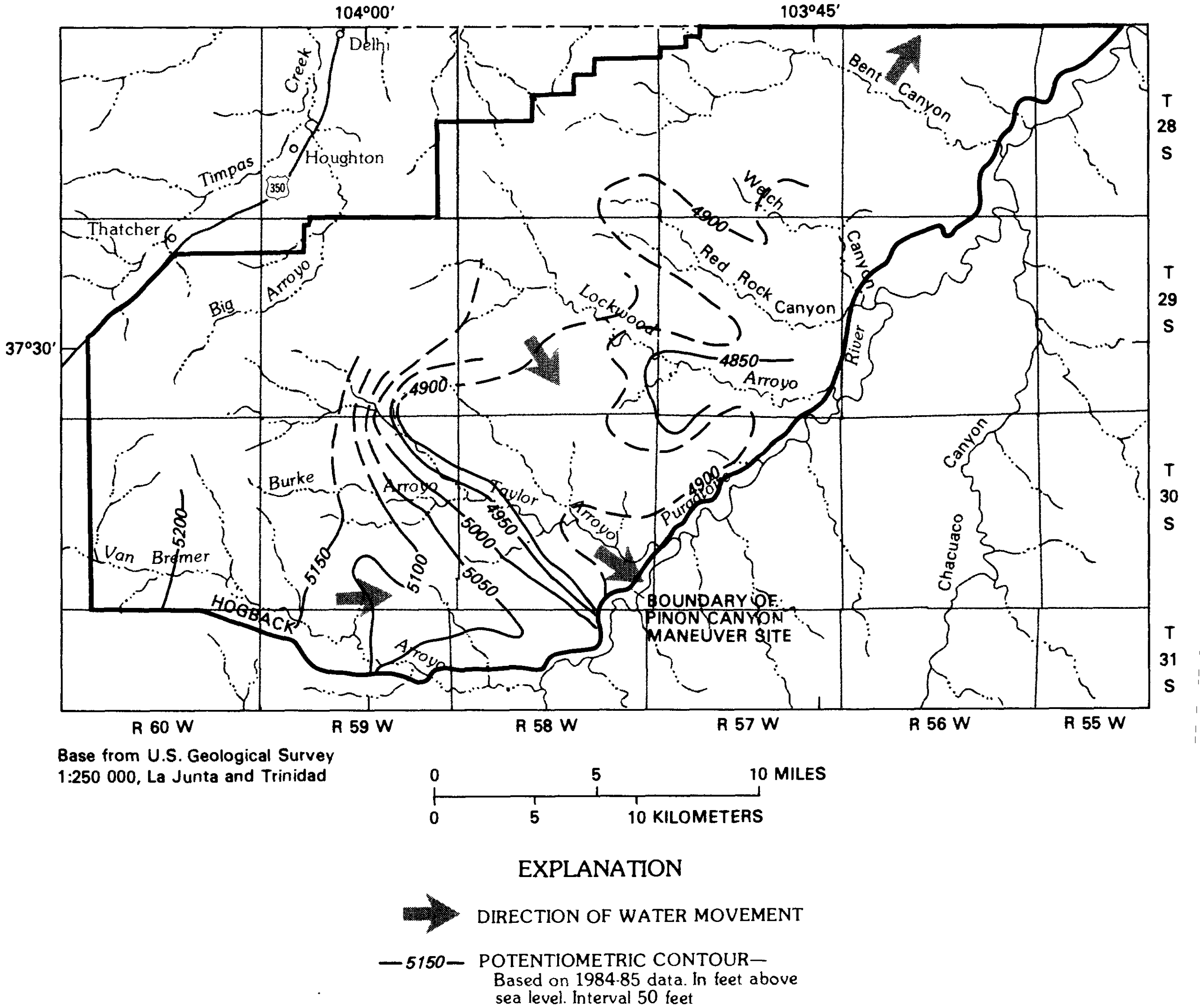


Figure 7.--Potentiometric level and direction of movement of water in the Dakota-Purgatoire aquiferfor water years 1984 and 1985.

The Dakota-Purgatoire aquifer is recharged primarily in areas about 60 mi west of the Maneuver Site, where the Dakota Sandstone and the Cheyenne Sandstone Member of the Purgatoire Formation crop out near the base of the Front Range of the Rocky Mountains. The regional direction of ground-water flow in southeastern Colorado is toward the northeast (Robson and Banta, 1987). On the Maneuver Site, recharge of the aquifer is primarily from precipitation and from subsurface inflow from adjoining areas. Because of the semiarid environment, only a very small fraction of the annual precipitation reaches the aquifer. Where outcrop areas are traversed by ephemeral streams, occasional flood flows provide some local recharge of very limited areal extent.

Discharge from the aquifer is by well pumpage, spring flow, *evapotranspiration*, and ground-water flow out of the study area. Because no pumping records are available, quantification of pumpage is not possible. However, on the basis of the number of wells known to exist, and assuming a liberal pumping rate of 5 gal/min, the annual discharge by pumpage is less than 800 acre-ft/yr. Spring flow also is fairly substantial in the study area and occurs in topographically low areas of the Dakota Sandstone and where stream channels intersect the local water table. Discharge by evapotranspiration only occurs in limited areas where water levels are at or near land surface. In these areas, direct evaporation or *transpiration* by vegetation (grasses, desert plants, cottonwood trees) results in loss of *subsurface water*.

Hydraulic Properties

The hydraulic properties of the Dakota-Purgatoire aquifer were determined in 16 aquifer tests (table 6). These tests were made in wells that obtain water from either the Dakota Sandstone Formation or the Purgatoire Formation,

Table 6.--*Aquifer test results, Dakota-Purgatoire aquifer, southeastern Colorado*

[All data are from Wilson (1965) unless otherwise indicated; --, no data available]

Local well number	County	Date of test	Formation penetrated by well	Transmissivity (feet squared per day)	Storage coefficient
SC02904316DDD	Baca	05-22-49	Purgatoire	508	--
SC02904334BBB	Baca	09-08-47	Purgatoire	118	0.0001
SC03004204CBB	Baca	08-29-47	Dakota Sandstone	882	--
SC03004312DBC	Baca	09-06-47	Purgatoire	679	--
SC02305210BBB	Bent	05-06-60	Dakota Sandstone and Purgatoire.	71	--
SC02305210BBC	Bent	07-24-61	Dakota Sandstone and Purgatoire.	43	--
SC02305216CCC	Bent	08-14-61	Purgatoire	120	--
[1]SC02906127BBB1	Las Animas	06-14-83	Dakota Sandstone	174	
SC02305420AAC	Otero	03-04-61	Dakota Sandstone and Purgatoire.	14	.10
SC02405819ABD	Otero	09-28-60	Purgatoire	107	--
SC02204535CCD	Prowers	10-12-57	Dakota Sandstone	120	.001
SC02204535DBA	Prowers	08-22-57	Dakota Sandstone	160	.001
SC02304502AAC	Prowers	10-12-57	Dakota Sandstone	374	--
SC02304602DBA	Prowers	10-22-57	Dakota Sandstone	187	--
SC02106523DDA	Pueblo	09-23-64	Dakota Sandstone and Purgatoire.	108	--
SC02206503CD	Pueblo	11-11-64	Dakota Sandstone	174	--

[1]U.S. Geological Survey, unpublished data, 1987.

or both, and are located in the general vicinity of the Maneuver Site; values for transmissivity ranged from 14 to 882 ft^2/d; *storage coefficients* ranged from 0.0001 to 0.10. Such large variations in hydraulic properties are related to the character of these sandstones, which are nonhomogeneous and fractured, and which occasionally contain interbedded siltstones and shales.

Well Yields

Wells in the Dakota-Purgatoire aquifer have reported yields that range generally from less than 10 to 500 gal/min; yields are largest where the sandstones have been extensively fractured. Fractured areas of the aquifer are not known to exist at the Maneuver Site. Well yields in unfractured parts of the Dakota-Purgatoire aquifer are likely to be less than 300 gal/min (Crouch and others, 1984).

Water Levels

Based on periodic measurements made at eight wells during the 1985 water year, water levels in the aquifer did not fluctuate to a great extent and generally did not rise or decline. Results of the measurements are shown in figure 8. Of the eight selected wells, only two had water-level changes greater than 1 ft. Water levels in well SC02805603CBC2 rose 2 ft during the year, while the levels declined 1.5 ft in well SC02905815DAA. Of the eight wells, water levels rose in three wells, declined in two wells, and remained relatively stable in three wells. Water levels presented in figure 8 represent a short period of record and do not indicate any long-term trends.

Other Aquifers

Several other aquifers exist at the Maneuver Site, although they are very minor relative to the ground-water resource of the Dakota-Purgatoire aquifer. A few sandhill areas exist on the Maneuver Site that may contain small quantities of ground water (fig. 14). Similarly, there are localized alluvial deposits along downstream reaches of the major ephemeral streams, and these, too, may contain limited quantities of ground water. Several bedrock formations that occur in the area also are known to supply small quantities of water to wells in other areas of southeastern Colorado (table 2). It is possible that these formations could be tapped for small quantities of ground water at the Maneuver Site.

Ground-Water Quality

Analysis of 26 water-quality samples collected at 24 wells and 1 spring that obtain water from the Dakota-Purgatoire aquifer were used to characterize the quality of ground water at the Maneuver Site. Onsite measurements of water temperature, specific conductance, and pH were made at the time of sampling. Dissolved-oxygen concentrations were measured at three wells; measurements were obtained using a portable dissolved-oxygen meter. The dissolved-oxygen sensor was placed into a sealed bucket to prevent atmospheric

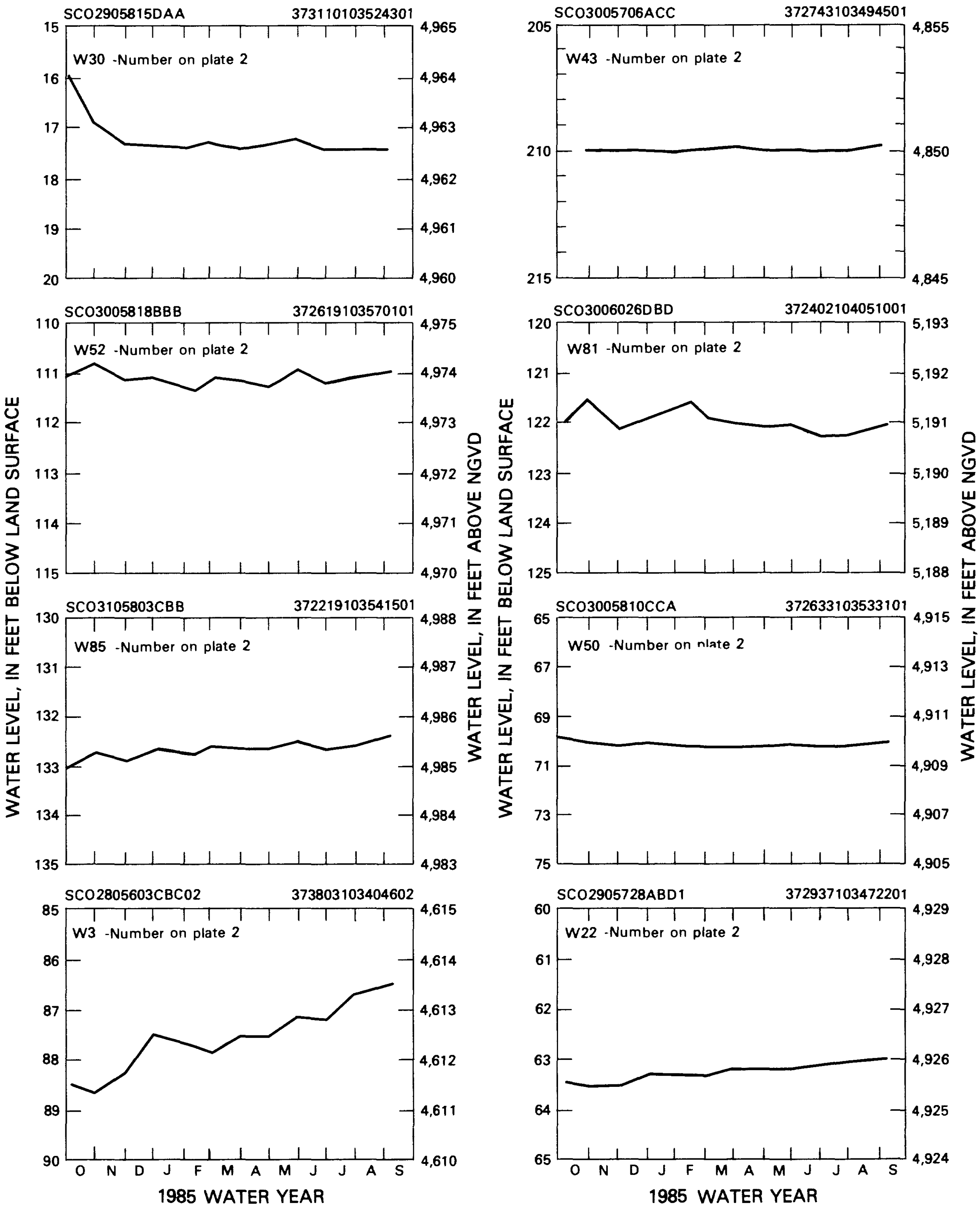


Figure 8.--Water levels for eight selected wells at the Pinon Canyon Maneuver Site for water year 1985.

aeration of the sample (Wood, 1976). Ground water was pumped through the bucket during the measurement of dissolved oxygen. Chemical constituents analyzed included alkalinity, major ions, dissolved solids, and dissolved concentrations of iron, manganese, arsenic, and selenium. Additionally, radiochemicals were analyzed at selected wells because large concentrations of radioactivity are typical of water from the Dakota-Purgatoire aquifer (Femlee and Cadigan, 1979; Leonard, 1984).

The locations of the sampled wells and spring are shown in figure 9. Three of the wells and the spring were used for domestic purposes; the remaining wells were used for livestock watering prior to acquisition of the Maneuver Site by the U.S. Department of the Army. A single sample was collected at each well and spring, with the exception of well number SC03005931DBA (W70; table 4, pl. 2), where two samples were collected.

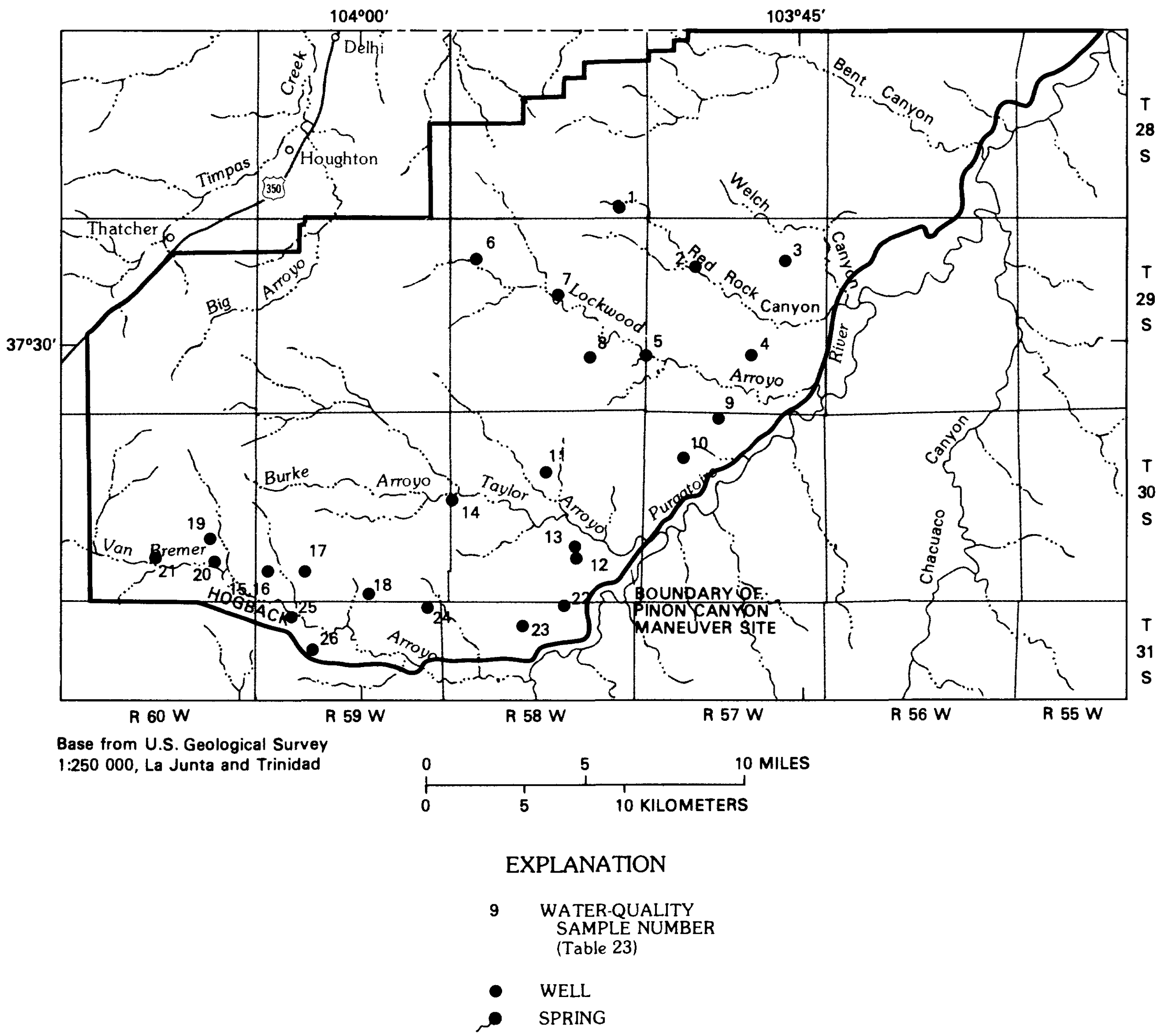


Figure 9.--Areal distribution of ground-water samples collected from the Dakota-Purgatoire aquifer.

Samples collected from wells between August 1984 and October 1985 were obtained from operational wells that have windmills or submersible pumps. Samples collected between October 1985 and February 1986 were obtained from nonoperational wells using a portable submersible pump. All sample results are listed in table 23 (in the "Supplemental Information" section at the back of the report) and are summarized in table 7.

Table 7.--*Summary of ground-water-quality data for the Pinon Canyon Maneuver Site*

[N, number of samples; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 °Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter]

Constituent	Units	N	Median	Range	
				Minimum	Maximum
Temperature	°C	26	15.0	11.5	18.0
Specific conductance	µS/cm	26	1,850	410	6,250
pH, field	Standard units	26	6.7	3.4	7.6
Dissolved oxygen	mg/L	4	1.4	0.0	7.8
Alkalinity, laboratory	mg/L as $CaCO_3$	24	220	3	330
Dissolved nitrate plus nitrite	mg/L as N	26	.32	<.10	37
Dissolved phosphorus	mg/L	25	<.01	<.01	.03
Dissolved calcium	mg/L	24	130	42	490
Dissolved magnesium	mg/L	24	75	13	490
Dissolved sodium	mg/L	25	190	28	770
Dissolved potassium	mg/L	25	11	1.6	35
Dissolved chloride	mg/L	25	25	5.2	470
Dissolved sulfate	mg/L	25	770	26	3,700
Dissolved fluoride	mg/L	25	1.0	.10	9.0
Dissolved silica	mg/L	24	8.8	4.7	33
Dissolved solids	mg/L	19	1,420	195	6,150
Dissolved iron	µg/L	25	1,600	4	420,000
Dissolved manganese	µg/L	25	110	<1	3,400
Dissolved arsenic	µg/L	20	<1	<1	10
Dissolved selenium	µg/L	21	1	<1	67
Dissolved *gross alpha*	pCi/L as U-natural.	20	94	9.4	290
Suspended total gross alpha	pCi/L as U-natural.	4	<.4	<.4	<.4
Dissolved *gross beta*	pCi/L as Cs-137	15	67	14	150
Suspended total gross beta	pCi/L as Cs-137	4	<.4	<.4	<.4
Dissolved gross beta	pCi/L as Sr/Yt-90.	20	48	10	95
Suspended total gross beta	pCi/L as Sr/Yt-90.	4	<.4	<.4	<.4
Dissolved *radium-226*	pCi/L	4	5.4	1.2	15
Dissolved uranium	µg/L	4	.75	.50	6.0

Table 8.--*Water-quality standards for selected constituents*

[Modified after Crouch and others, 1984)

Constituent	Units	Standard[1]	Type of standard[2]	Reason for standard
pH	Standard pH units	6.5-8.5	Secondary drinking-water standard.[3]	pH values outside this range may cause corrosion of pipes and difficulties in water-treatment processes.[4]
Nitrate	Milligrams per liter as nitrogen	10	Primary drinking-water standard.[5]	Water with greater concentrations may cause methemoglobinemia (blue-baby disease) when used for infant feeding.[4]
Sodium	Milligrams per liter	20	No formal standard	Persons on a diet of very restricted sodium intake should not consume water with concentrations greater than the criteria.[4]
Chloride	Milligrams per liter	250	Secondary drinking-water standard.[3]	Water with greater concentrations may have a salty taste.[6]
Sulfate	Milligrams per liter	250	Secondary drinking-water standard.[3]	Water with greater concentrations may cause objectionable tastes, have a laxative effect on new users, and contribute to scale in boilers.
Fluoride	Milligrams per liter	4	Primary drinking-water standard.[5]	Water with greater concentrations may cause crippling disease.[3]
Dissolved solids	Milligrams per liter	500	Secondary drinking-water standard.[3]	Water with greater concentrations of dissolved solids may have objectionable mineral taste.[4]
Iron	Micrograms per liter	300	Secondary drinking-water standard.[3]	Water with greater concentrations may cause objectionable tastes and stains on laundry or porcelain.[4]
Manganese	Micrograms per liter	50	Secondary drinking-water standard.[3]	Water with greater concentrations may cause objectionable taste and stains on laundry or porcelain.[4]
Iron plus manganese.	Micrograms per liter	300	(See iron and manganese above.)	
Arsenic	Micrograms per liter	50	Primary drinking-water standard.[5]	Small quantities are toxic to humans[4].
Selenium	Micrograms per liter	10	Primary drinking-water standard.[5]	Water with greater concentrations may cause selenium toxicity.[4]
Gross alpha radiation.	Picocuries per liter	15	Primary drinking-water standard.[5]	Effect of radiation on humans is harmful.[6]
Gross beta radiation.	Picocuries per liter	([7])	([7])	([7])
Radium-226	Picocuries per liter	([7])	([7])	([7])

[1]Value which should not be exceeded, unless a range is given.

[2]Primary drinking water standards are based primarily on anticipated health effects, and secondary drinking-water standards are based primarily on the aesthetic character of the water. While no formal standard exists for sodium, information is included here because of widespread interest in this constituent.

[3]U.S. Environmental Protection Agency (1986b).

[4]U.S. Environmental Protection Agency (1976).

[5]U.S. Environmental Protection Agency (1986a).

[6]National Academy of Sciences, National Academy of Engineering (1972).

[7]There is no drinking-water standard for dissolved gross beta radiation and dissolved radium-226. See text for discussion.

Without treatment, ground water in the study area generally is not suitable for domestic or public-supply use. Water-quality standards for selected constituents in water used for domestic or public supply and the reasons for the standards and references for the standards are listed in table 8 (page 25). As much as 95 percent of the ground-water sites sampled had concentrations of selected constituents that exceeded water-quality standards for domestic or public-supply use (table 9). The following sections provide discussions of the water-quality results from all wells sampled.

Table 9.--*Percent of ground-water sites from which water samples exceeded water-quality standards for domestic or public-supply use*

Constituent	Number of ground-water sites sampled for indicated constituents	Sites from which water exceeded water-quality standards	
		Number of sites	Percent of sites sampled
Nitrite plus nitrate[2]--	25	2	8
Chloride---------------	25	2	8
Sulfate----------------	25	22	88
Fluoride---------------	24	4	17
Dissolved solids-------	19	16	84
Iron-------------------	25	16	64
Manganese--------------	25	20	80
Selenium---------------	21	3	14
Gross alpha radiation--	21	20	95
Gross beta radiation---	19	([3])	([3])
Radium-226-------------	4	([3])	([3])

[1]Standards are listed in table 8.

[2]Drinking-water standard is for nitrate, but nitrogen in ground water usually is not present in significant quantities as nitrite, so it is reasonable to assume that most or all dissolved nitrite plus nitrate in ground water will be present as nitrate.

[3]There is no drinking-water standard for dissolved gross beta radiation and dissolved radium-226. See "Radiochemicals" section for discussion.

Specific Conductance

Onsite measurements of specific conductance were made for each ground-water sample. The specific conductance of water is a measure of the ability of water to conduct an electric current. As dissolved-solids concentrations increase, the specific conductance of the solution increases. Therefore, measurement of specific conductance provides a relatively simple indication of dissolved-solids concentration. Relations of specific conductance to dissolved-solids concentration from 19 wells are shown in figure 10. The figure indicates that a good relation exists between specific conductance and dissolved solids.

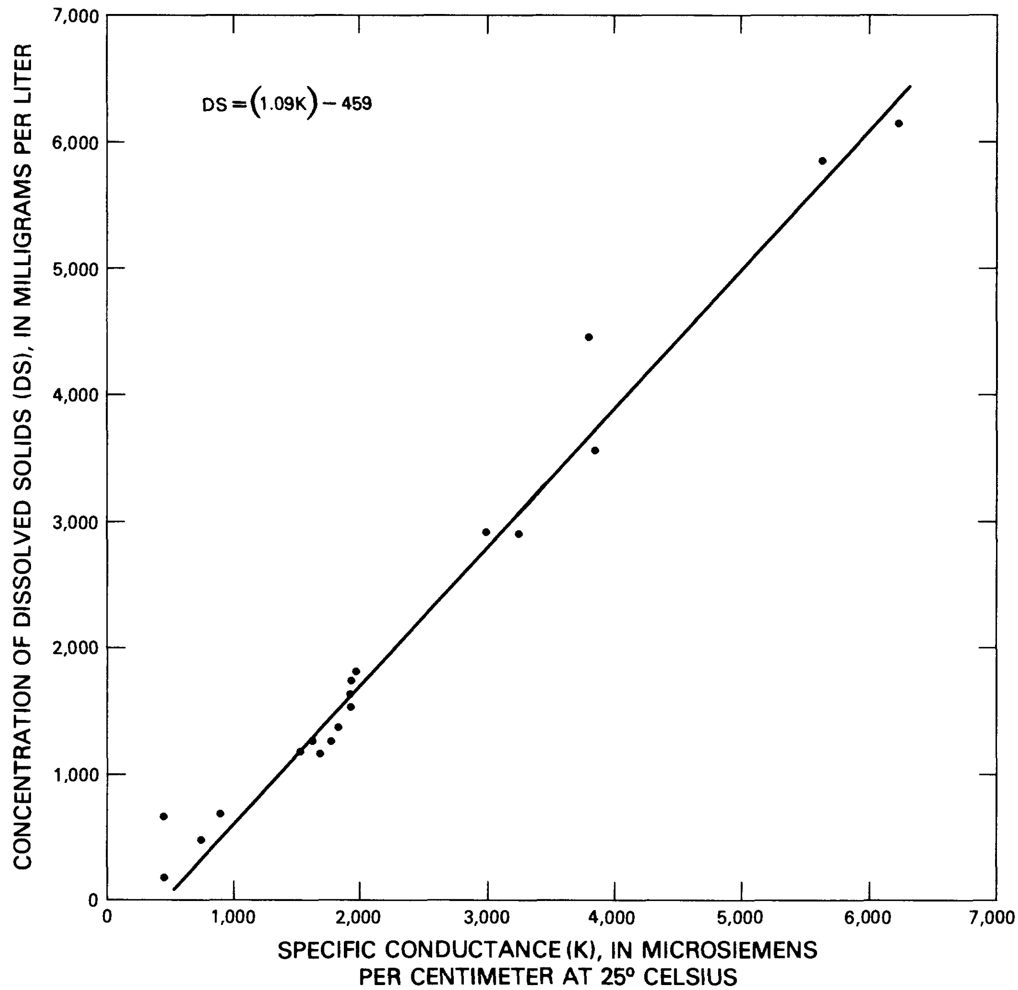


Figure 10.--Relation of specific conductance (K) to concentrations of dissolved solids (DS) of water from selected wells in the Dakota-Purgatoire aquifer at the Pinon Canyon Maneuver Site.

Major Ions and Dissolved Solids

There is no dominant *cation* in the ground water analyzed from 20 wells, but sulfate is the dominant *anion* (fig. 11*A*). The median sulfate concentration was 770 mg/L, which is more than 3 times larger than the secondary drinking-water standard (tables 7 and 8). Calcium, magnesium, and sodium constitute an almost equal percent of the cations (based on *milliequivalents* per liter) analyzed from 20 wells (fig. 11*B*). Water that has large concentrations of sodium may be unsuitable for irrigation. When sodium constitutes more than 50 percent of the cations, displacement of calcium and magnesium in soils can occur, which makes it more difficult for plants to absorb water from the soil (Hem, 1985). Sodium concentrations (in milliequivalents per liter) were nearly 50 percent of the total cation concentrations for samples 7, 10, 24, and 25 (fig. 9 and table 23). Sodium concentrations (in millequivalents per liter) as a percentage of total cations were 48.9, 44.0, 48.0, and 47.6 percent for these four samples.

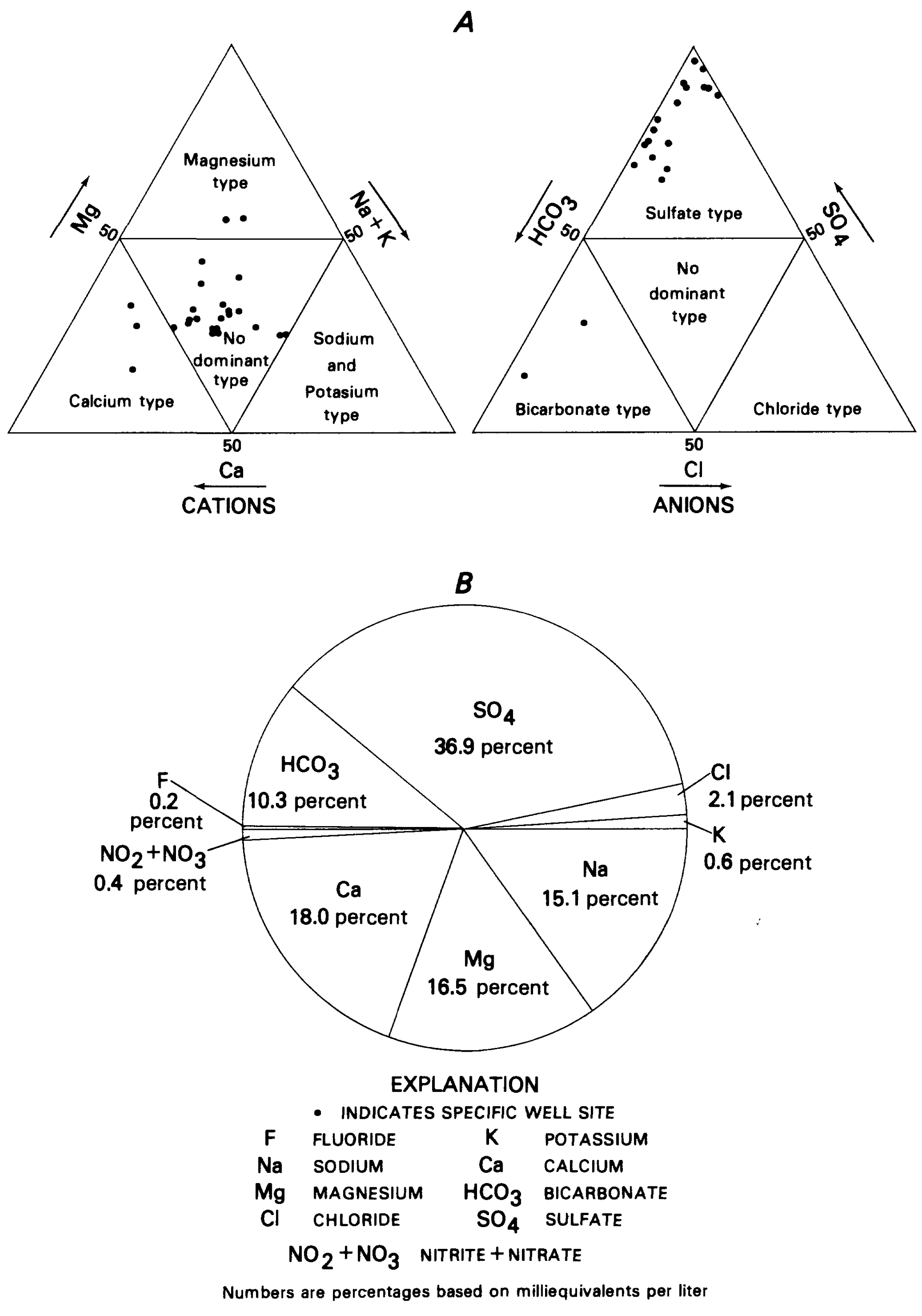


Figure 11.--A, Major water type; and B, major-ion composition of water samples from 20 wells at the Pinon Canyon Maneuver Site.

Eighty-four percent of the ground-water sites sampled had dissolved-solids concentrations that exceeded the water-quality standard for domestic or public-supply use (table 9). Dissolved-solids concentrations ranged from 195 to 6,150 mg/L. Eleven of the wells could be classified as slightly *saline* (Hem, 1985), because they had dissolved-solids concentrations that ranged from 1,130 to 2,900 mg/L; four other wells had dissolved-solids concentrations that ranged from 3,540 to 6,150 mg/L and were classified as moderately saline (table 23 in the "Supplemental Information" section at the back of the report). The only spring sample (number 5) had a dissolved-solids concentration of 655 mg/L (which is not considered to be saline). Large concentrations of dissolved solids may be a result of long residence times that enable the solution of minerals in the water in the Dakota-Purgatoire aquifer.

Iron and Manganese

Sixty-four percent of ground-water sites sampled in the Dakota-Purgatoire aquifer throughout the Maneuver Site exceeded the secondary drinking-water standard for dissolved iron (table 9). Six wells had concentrations of 10,000 µg/L or greater, and these concentrations were about 30 to 1,400 times greater than the secondary drinking-water standard (table 8 and table 23). However, little of the dissolved iron remains in solution upon exposure to the atmosphere. The sample from the spring had a dissolved-iron concentration of 30 µg/L. A source of large concentrations of dissolved iron may be the ironstone that occurs throughout the Dakota-Purgatoire aquifer (Mclaughlin, 1954). This condition is illustrated further by coatings of iron oxide (desert varnish) that occur upon weathering of the Dakota Sandstone. A lesser possible source of large concentrations of dissolved iron may be corrosion of the well casing and plumbing associated with the well.

Dissolved-manganese concentrations exceeded the secondary drinking-water standard for 80 percent of the ground-water sites sampled (table 9). Water-quality analyses for most sites indicate that concentrations of dissolved manganese that exceed the drinking-water standard are associated with large concentrations of dissolved iron, which indicate that manganese and iron may be contributed by the same deposits. Large concentrations of dissolved manganese, especially in association with dissolved iron, are common in ground water (Hem, 1985).

Selenium

Small concentrations of the *nonmetallic element* selenium may be toxic to humans and livestock (table 8). Concentrations of dissolved selenium were analyzed for in water samples collected from 20 wells (table 9; table 23) Selenium concentrations were not analyzed for the single spring included in the network. Three of the wells sampled for dissolved selenium exceeded the primary drinking-water standard of 10 µg/L. Sources of selenium are unknown but probably are associated with the Dakota-Purgatoire Formation.

Radiochemicals

Water samples were analyzed for dissolved gross alpha radiation at 18 of the 24 wells and at 1 spring and were analyzed for dissolved gross beta radiation as Cesium-137 at 14 of the 24 wells and at 1 spring. Concentrations of gross alpha radiation (as natural uranium) are reported as micrograms per liter in table 23, but drinking-water standards for radiochemical constituents are reported in picocuries per liter. Gross alpha radiation (as natural uranium) is converted from micrograms per liter to picocuries per liter by multiplying micrograms per liter by the conversion factor 0.68 (Thatcher and others, 1977). Therefore, concentrations of gross alpha radiation exceeded 15 pCi/L (or about 22 μg/L) in two of the domestic wells sampled (fig. 12); concentration of dissolved gross alpha radiation for one well sampled was reported as less than 92 μg/L. Water from this sample may or may not exceed the drinking-water standard of 15 pCi/L. Fifteen ground-water sites had concentrations of dissolved gross alpha radiation greater than 15 pCi/L (table 23). Because of these large concentrations of gross alpha radiation, it would be prudent to have complete radiochemical analyses of the water before using it as a drinking-water supply.

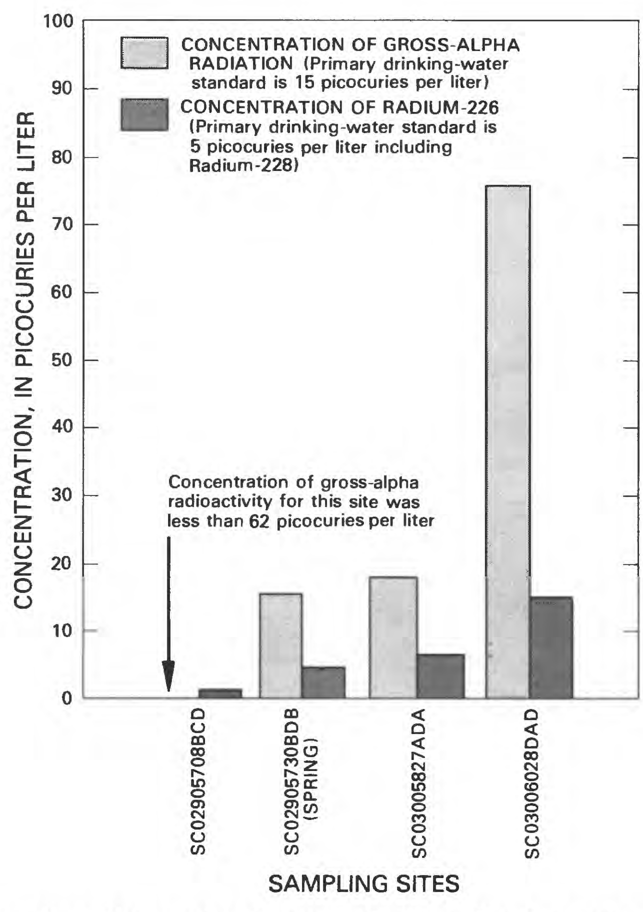


Figure 12.--Concentrations of dissolved gross alpha radiation and dissolved radium-226 for three wells and a spring used for domestic water supply.

There is no drinking-water standard established for dissolved gross beta radiation. However, State regulations (Colorado Department of Health, 1977) specify that when gross beta radiation exceeds 50 pCi/L, the water should be analyzed to identify the major radioactive constituents that are present. Dissolved gross beta radiation as Cesium-137 exceeded 50 pCi/L in 10 wells (table 23). The only spring sample had a concentration of 17 pCi/L.

Three wells and one spring that were used for domestic purposes were sampled for dissolved radium-226 and dissolved uranium. Concentrations of dissolved radium-226 at three domestic wells ranged from 1.2 to 15 pCi/L; the radium-226 concentration for the spring sampled was 4.4 pCi/L (fig. 12). The drinking-water standard for dissolved radium is based on radiation from radium-226 and radium-228. No analysis for dissolved concentrations of radium-228 was made. Therefore, direct comparison of concentrations of dissolved radium-226 to the drinking-water standard of 5 pCi/L could not be made. However, for these samples, the concentrations of dissolved radium-226 almost met or exceeded the combined drinking-water standard for radium 226 and 228. Because of these large concentrations of radium-226, it would be prudent to have a complete radiochemical analysis of the water before using it as a drinking-water supply.

Development Considerations

The Dakota-Purgatoire aquifer is the most dependable source of ground water at the Maneuver Site. Continued use of this source of water is possible for some purposes. The aquifer can continue to be a source of water for wildlife and for stock use during off-training periods. Water from the Dakota-Purgatoire aquifer has been and is being used for domestic purposes at homesteads on the site. However, chemical concentrations of constituents analyzed from wells that yield water from the Dakota-Purgatoire aquifer commonly exceeded drinking-water standards (table 9).

The natural presence of large concentrations of dissolved solids, sulfate, iron, manganese, and radiochemical constituents in most samples collected limits the usefulness of ground water from the Dakota-Purgatoire aquifer as a domestic water supply. Because of the large concentrations of naturally occurring radioactivity, it would be prudent to have a complete radiochemical analysis of the water before using it as a drinking-water supply. Large concentrations of nitrate, chloride, fluoride, and selenium may further exclude certain wells as sources of drinking water. Additional investigation is necessary to determine what treatment would be needed to bring the water within the limits of drinking-water standards.

SURFACE WATER

The following is a discussion of the surface-water resources of the Maneuver Site. Included in this section are data that pertain to the temporal and spatial characteristics of streamflow and rainfall runoff. The discussion of surface-water quality includes instream water-quality standards, summary statistics of water-quality data, and dissolved-solids and suspended-sediment loads.

Streamflow Characteristics

Streamflow data were collected at eleven streamflow-gaging stations in and near the Maneuver Site (table 1, pl. 1). Two of these stations are located on the Purgatoire River. The remainder of the streamflow-gaging stations are on ephemeral or intermittent streams, and with the exception of Chacuaco Creek and Van Bremer Arroyo, originate on the Maneuver Site.

Streamflow for the Purgatoire River sites for the 1984 and 1985 water years is shown on the monthly hydrographs in figure 13. Altitude differences in the Purgatoire River basin cause climatic variations which, in turn, affect the streamflow. During years with average and above-average snowpack, such as occurred in 1984, 30 to 50 percent of the annual streamflow of the Purgatoire River occurs during April and May. During the rainfall-runoff period, May through October, flash floods occur intermittently. Releases from Trinidad Reservoir, located about 53 mi upstream from the streamflow-gaging station Purgatoire River near Thatcher (site S4), affect streamflow on an intermittent basis.

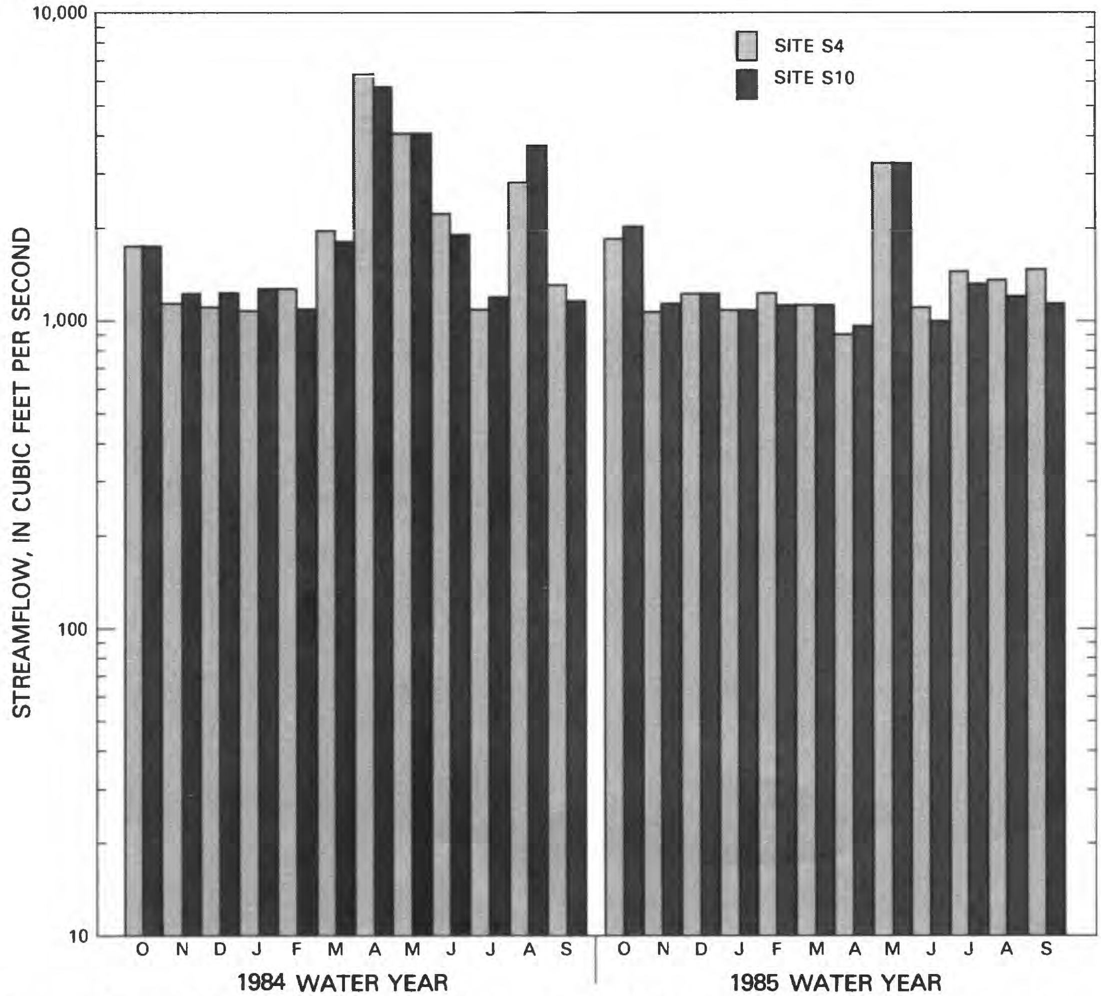


Figure 13.--Hydrograph of monthly streamflow for the streamflow-gaging stations Purgatoire River near Thatcher (site S4) and Purgatoire River at Rock Crossing near Timpas (site S10) for water years 1984 and 1985.

Hydrographs of monthly streamflow for the 1984 and 1985 water years at streamflow-gaging stations with ephemeral and intermittent streamflow are presented in figures 30-37 in the "Supplemental Information" section at the back of the report. Streamflow at ephemeral stations usually results from rainfall during May through October and is characterized by a quick rise to peak discharge and a rapid decline. Spatial and temporal distribution of runoff-producing storms is quite variable. Duration and magnitude of rainfall runoff is a function of antecedent moisture conditions and the location and duration of the storm in a drainage basin.

Streamflow at three streamflow-gaging stations, Van Bremer Arroyo near Tyrone (site S2A), Van Bremer Arroyo near Model (site S3), and Lockwood Canyon Creek near Thatcher (site S6) is characterized as intermittent. Rainfall runoff affects streamflow at these sites in the same manner as at ephemeral stream sites. However, the intermittent stream sites differ from ephemeral stream sites because streamflow occurs at times other than during storm runoff. *Base streamflow*, usually less than 0.50 ft^3/s, is maintained intermittently at these sites by ground-water recharge (sites S3 and S6) and by ground-water recharge and irrigation-return flow (site S2A and S3). A reservoir located immediately west of the Maneuver Site on Van Bremer Arroyo intercepts all streamflow that originates upstream from site S2 (pl. 1). Van Bremer Arroyo near Tyrone (site S2A) was established during the spring of 1985 downstream from Brown Sheep Camp in order to monitor irrigation-return flow entering the Maneuver Site from adjacent farmland.

Contributions of Tributary Streamflow to the Purgatoire River

During the 1984 and 1985 water years (table 10), Purgatoire River tributaries that drain the Maneuver Site (sites S3, S5, S6, S7, and S9) had streamflow of about 3,760 acre-ft, or about 4.4 percent of the streamflow at the Purgatoire River at Rock Crossing, near Timpas (site S10). About 64 percent of the tributary streamflow was discharged from Van Bremer Arroyo near Model (site S3) (table 10). The streamflow-duration curve (fig. 14) for Van Bremer Arroyo near Model (site S3) shows that mean daily streamflow is less than 0.70 ft^3/s approximately 90 percent of the time. However, during periods when irrigation-return flow is discharged into Van Bremer Arroyo from irrigated lands southwest of the Maneuver Site, mean daily streamflow ranges from 1 to 40 ft^3/s. During the 1984 and 1985 water years, approximately 2,100 acre-ft, or about 88 percent of the annual streamflow at Van Bremer Arroyo near Model (site S3) resulted from irrigation return flow. This return flow represents 56 percent of the streamflow that entered the Purgatoire River in or near the Maneuver Site. The remainder of the tributary streamflow results from rainfall runoff and from base streamflow sustained by ground-water recharge.

The main tributary inflow to the Purgatoire River between sites S4 and S10 that does not originate on the Maneuver Site is Chacuaco Creek at mouth, near Timpas (site S8). Chacuaco Creek has a drainage area of 424 mi^2, an area similar in size to the Maneuver Site. During the 1984 and 1985 water years, streamflow from Chacuaco Creek was 1,140 acre-ft, or about 1.3 percent of the streamflow at site S10 (table 10). All streamflow from Chacuaco Creek resulted from rainfall runoff.

Table 10.--*Streamflow at streamflow-gaging stations in and near the Pinon Canyon Maneuver Site, water years 1984 and 1985*

[--, no data]

Site number on plate 1	U.S. Geological Survey Station number	U.S. Geological Survey Station name	Streamflow, in acre feet, for indicated period: 1984 water year	Streamflow, in acre feet, for indicated period: 1985 water year	Streamflow, in acre feet, for indicated period: Total	Percent of streamflow at Purgatoire River at Rock Crossing, near Timpas for indicated period: 1984 water year	Percent ...: 1985 water year	Percent ...: Total
S1	07120620	Big Arroyo near Thatcher.	84	102	186	([1])	([1])	([1])
S2	07126130	Van Bremer Arroyo near Thatcher.	0	0	0	([1])	([1])	([1])
S2A	07126140	Van Bremer Arroyo near Tyrone.	--	[2]1,100	--	([1])	([1])	([1])
S3	07126200	Van Bremer Arroyo near Model.	605	1,790	2,400	1.1	5.4	2.8
S4	07126300	Purgatoire River near Thatcher.	52,000	34,100	86,100	98.1	103.6	100.2
S5	07126325	Taylor Arroyo below Rock Crossing, near Thatcher.	130	51	181	.24	.15	.21
S6	07126390	Lockwood Canyon Creek near Thatcher.	225	18	243	.42	.05	.28
S7	07126415	Red Rock Canyon Creek at mouth, near Thatcher.	275	7.9	283	0.52	0.02	0.33
S8	07126470	Chacuaco Creek at mouth, near Timpas.	532	606	1,140	1.0	1.8	1.3
S9	07126480	Bent Canyon Creek at mouth, near Timpas.	654	0	654	1.2	0	.76
S10	07126485	Purgatoire River at Rock Crossing, near Timpas.	53,000	32,900	85,900	([1])	([1])	([1])

[1]Not applicable.
[2]Figure is for partial year May 21 to September 30, 1985.

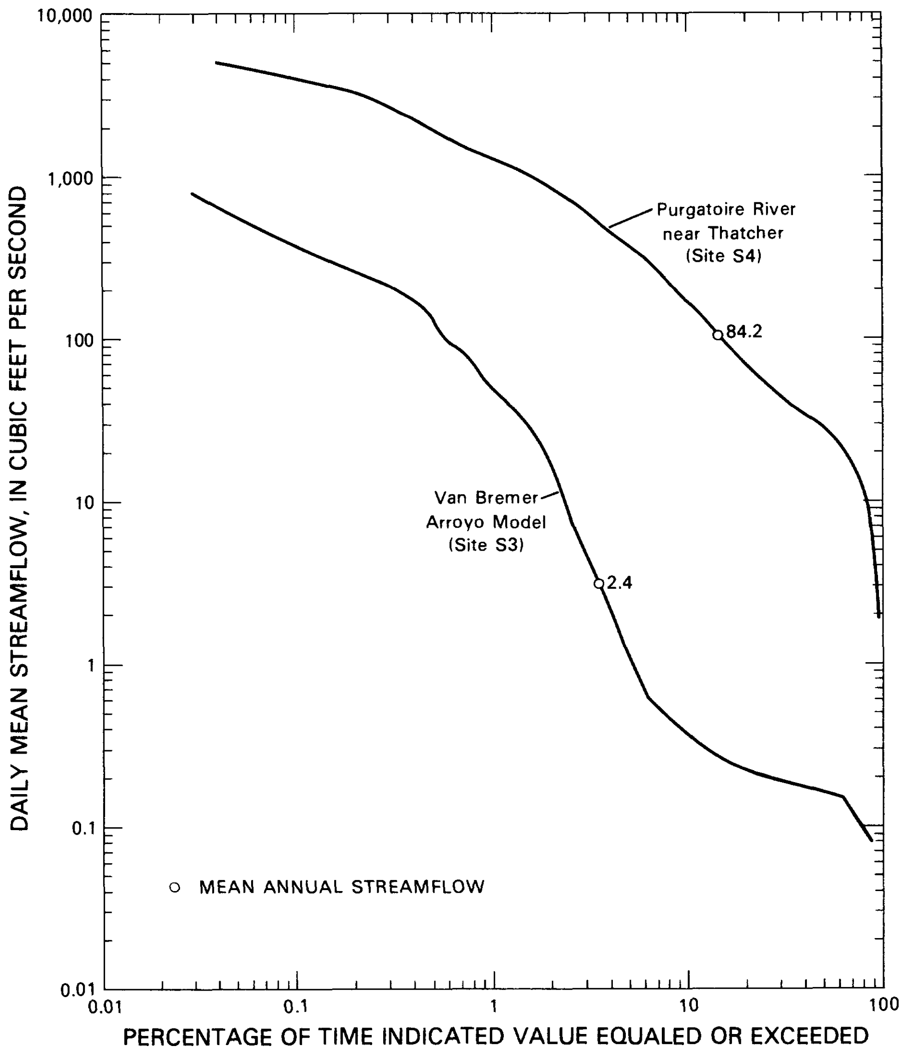


Figure 14.--Flow-duration curves for the streamflow-gaging stations, Van Bremer Arroyo near Model (site S3) and Purgatoire River near Thatcher (site S4).

Flow-Duration Analysis

A flow-duration curve is a cumulative frequency curve that indicates the percent of time a specified streamflow was equalled or exceeded. The flow-duration curve is an average curve for the period upon which it is based. The longer the period of streamflow record used to construct the flow-duration curve, the more representative is the curve of the range of streamflow at that site (Searcy, 1959). The flow-duration curve can be useful in estimating the probability of future streamflow if the curve is representative of long-term streamflow conditions. The general shape of the flow-duration curve indicates the physical and hydrologic characteristics of a drainage basin. A flow-duration curve with a steep slope indicates variable streamflow that is largely a result of direct runoff or where streamflow is affected by upstream diversions. A flatter slope, especially at the lower end of the flow-duration curve, indicates streamflow contributions from surface- or ground-water storage in the drainage basin (Searcy 1959; Livingston and others, 1976).

Flow-duration analysis of mean daily streamflow was done at two streamflow-gaging stations: Van Bremer Arroyo near Model (site S3) and Purgatoire River near Thatcher (site S4). These stations were selected because relatively long-term periods of record were available at both sites (table 1). At site S3, the flow-duration curve was computed using 19 years (1967-85) of streamflow data. The flow-duration curve for site S4 was computed using 9 years of record, the period of streamflow record available after the completion of Trinidad Dam (1977-85).

Flow-duration curves for the streamflow-gaging stations Van Bremer Arroyo near Model (site S3) and Purgatoire River near Thatcher (site S4) are shown in figure 14. The flow-duration curve for site S3 indicates that there is a steady source of flow between streamflows that range from 0.20 and 0.70 ft^3/s, probably as a result of ground-water discharge to the stream. Streamflows greater than 0.70 ft^3/s are very irregular and usually result from rainfall runoff. The flow-duration curve for site S4 indicates that there is a relatively constant source of streamflow at stream discharges that are greater than 20 ft^3/s. The lower end of the flow-duration curve steepens, indicating a limited source of streamflow from ground-water storage. The annual mean streamflow of 2.4 ft^3/s at site S3 is equaled or exceeded about 4 percent of the time, and the annual mean streamflow of 84 ft^3/s at site S4 is equaled or exceeded about 20 percent of the time.

Historical Floods

The Purgatoire River and its tributaries are subject to frequent flooding that, at times, reach extreme magnitudes. The September 19, 1875, issue of the Pueblo Star Journal-Chieftain reported high flows in the Van Bremer drainage basin; water was standing 3-ft deep in the stagecoach barn located on the western end of the Hogback. Today this area is known as Brown Sheep Camp (fig. 1).

Extreme flooding has occurred in the Purgatoire River basin during 1954, 1955, and 1965 (Snipes and others, 1974). The peak discharge of Chacuaco Creek near La Junta was 38,900 ft^3/s on June 17, 1965. This site is located about 1.5 mi upstream from the current streamflow-gaging station Chacuaco Creek at mouth, near Timpas (site S8) (pl. 1). Peak discharge on June 17, 1965, at streamflow-gaging station Purgatoire River near Thatcher (site S4) (pl. 1), was 47,700 ft^3/s.

Flood-Frequency Analysis

Mean streamflow is affected by extreme hydrologic events. In a semiarid environment, extended periods of small or no streamflow give way to short periods of flooding that can be extreme. The ability to predict the magnitude and frequency of floods where streamflow record is inadequate is useful for short term hydrologic records and design of culverts and other stream crossings. When streamflow record of adequate length is available, statistical estimates of flood frequencies can be made using log-Pearson III analysis (Dalrymple, 1960).

Flood-frequency curves were developed for the two streamflow-gaging stations that had long-term streamflow records. These stations were Van Bremer Arroyo near Model (site S3) and Purgatoire River near Thatcher (site S4). Estimates at site S4 were made using the period of streamflow record after the completion of Trinidad Dam. Application of the log-Pearson III analysis was made using U.S. Geological Survey computer programs in *WATSTORE* (Hutchison, 1975). This method analyzes the station record from a given site, estimates flood-frequency and magnitude, and extends the estimates for recurrence intervals beyond the length of the station record. Recurrence interval is the average number of years within which a given flood will be equaled or exceeded once. Results from the log-Pearson III analysis are presented in figures 15 and 16.

McCain and Jarrett (1976) developed a method for obtaining flood discharge for different recurrence intervals for natural-flow streams in Colorado that have drainage areas of 100 mi^2 or greater. The method predicts flood discharge based on the drainage-basin characteristics: effective drainage area in square miles that contribute to flood discharge and streambed slope in feet per mile measured from topographic maps or onsite surveys.

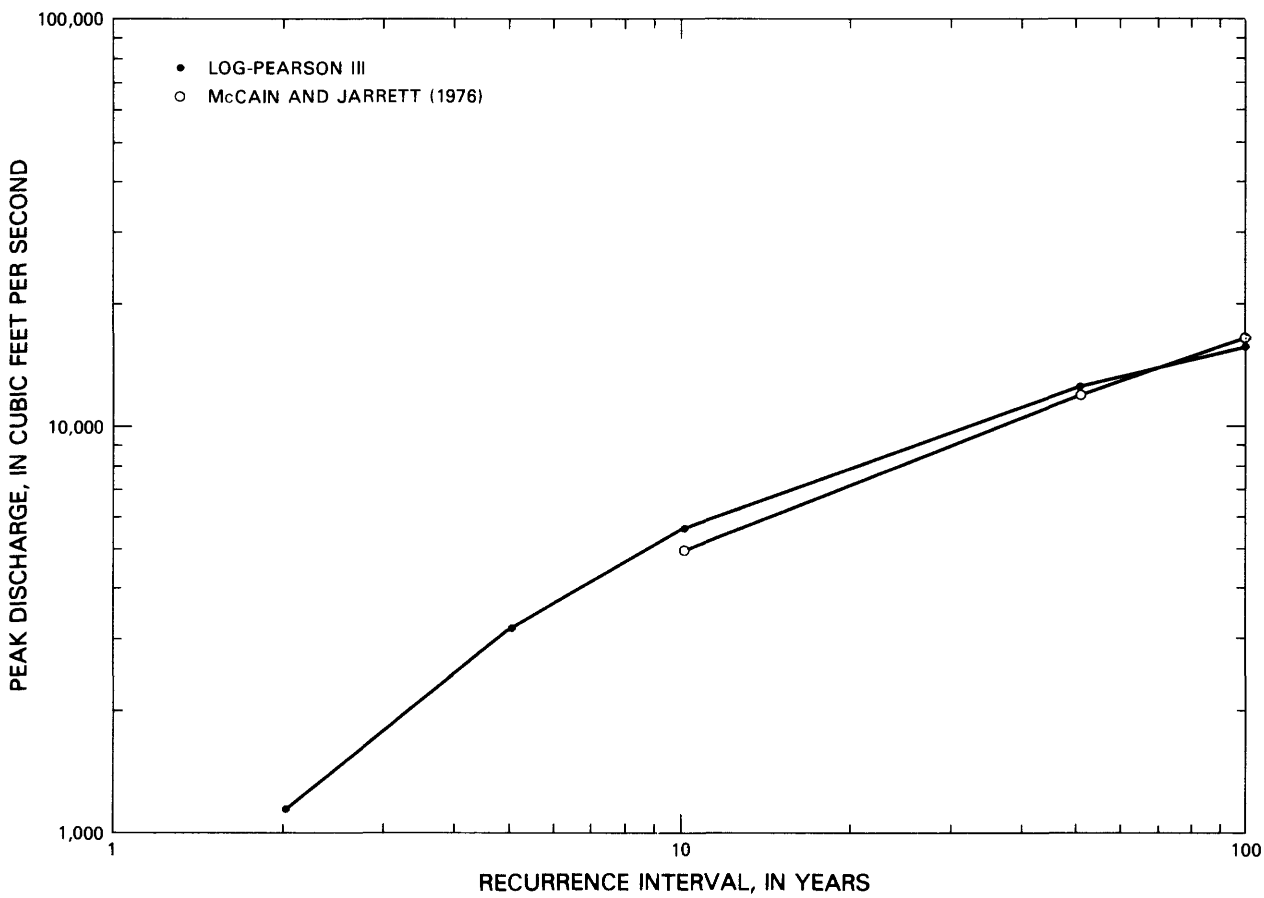


Figure 15.--Estimated flood magnitude and frequency for the streamflow-gaging station Van Bremer Arroyo near Model (site S3).

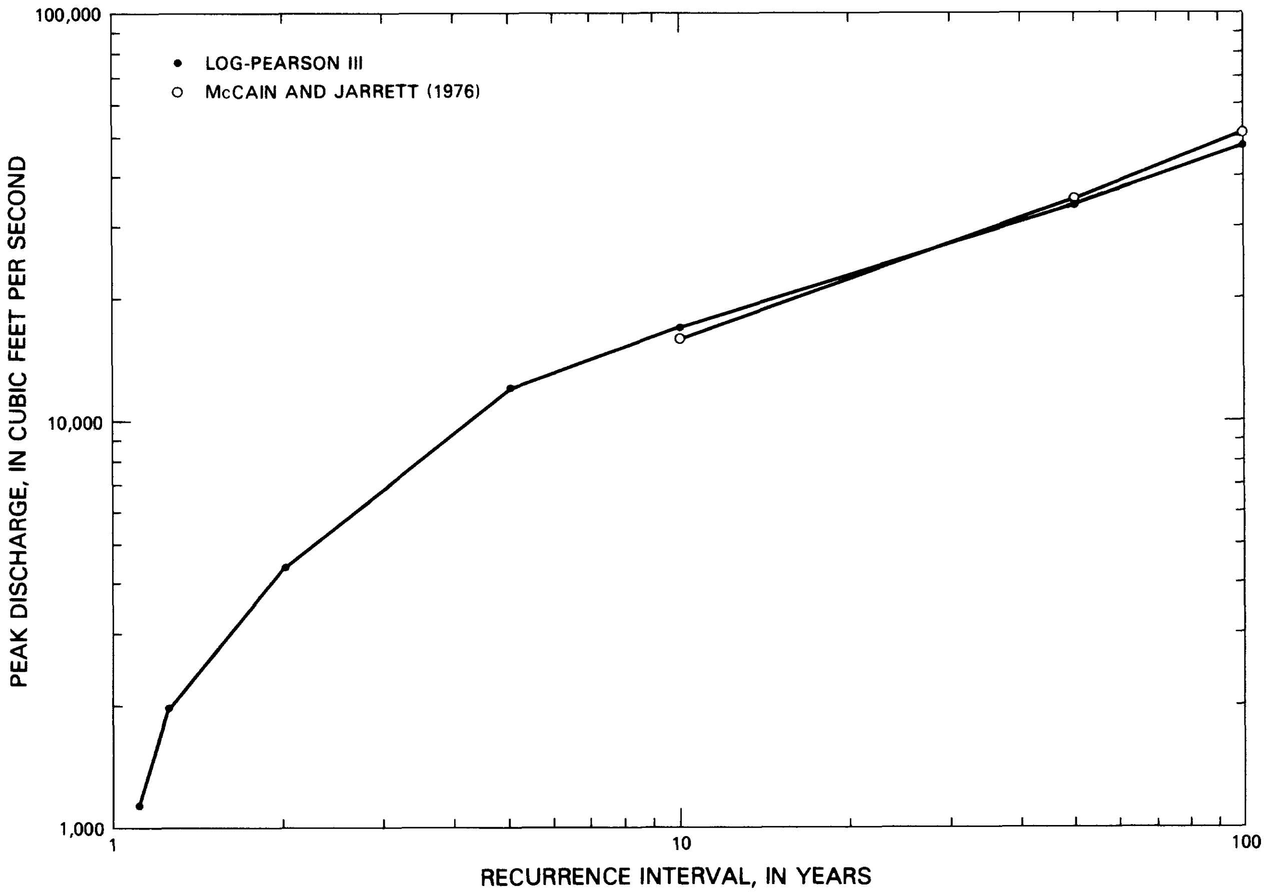


Figure 16.--Estimated flood magnitude and frequency for the streamflow-gaging station Purgatoire River near Thatcher (site S4).

Regression equations as defined by McCain and Jarrett (1976) were developed for the different physiographic regions that occur in Colorado. These regions are the plains, mountain, northern plateau and southern plateau. Regression equations for the plains region were used to estimate flood discharges at Van Bremer Arroyo near Model (site S3) and the Purgatoire River near Thatcher (site S4) for recurrence intervals of 10, 50 and 100 years (table 11). The effective drainage area for site S3 was adjusted for stock-watering and irrigation reservoirs in the drainage basin. Effective drainage area for site S4 was decreased by 816 mi^2, the drainage area upstream from Trinidad dam.

Flood discharges calculated using the McCain and Jarrett (1976) regional estimating techniques compared well with those derived using the log-Pearson III analysis (figs. 15 and 16). The fact that flood discharges calculated at site S3 compared well using the method developed by McCain and Jarrett and the log-Pearson III analysis indicates that the McCain and Jarrett estimation technique may be applicable to watersheds at the Pinon Canyon Maneuver Site that have effective drainage areas of less than 100 mi^2. This regional technique could be used for estimating flood discharges on streams in and near the Maneuver Site that have inadequate or no streamflow records.

Table 11.--*Regression equations and corresponding standard error of estimate used to estimate peak streamflows for selected recurrence-interval floods*

[Equations are from McCain and Jarrett, 1976, and Livingston and Minges, 1987; Q = water discharge, in cubic feet per second (the number in parenthesis is recurrence interval, in years); AE = effective drainage area, in square miles; Sb = streambed slope, in feet per mile; RF = relief factor, in feet; I24_100 = average rainfall intensity for a 24-hour period with a 100-year recurrence interval, in inches]

Equation	Standard error of prediction (percent)
McCain and Jarrett	
$Q(10) = 144AE^{0.528}Sb^{0.336}$	31
$Q(50) = 891AE^{0.482}Sb^{0.154}$	24
$Q(100) = 1{,}770AE^{0.463}Sb^{0.086}$	28
Livingston and Minges	
$\log Q(10) = 3.05 + 0.53(\log RF)(\log I24\_100) - 1.29AE^{-0.25}$	37
$\log Q(25) = 3.64 + 0.45(\log RF)(\log I24\_100) - 1.53AE^{-0.25}$	36
$\log Q(50) = 4.03 + 0.39(\log RF)(\log I24\_100) - 1.70AE^{-0.25}$	38
$\log Q(100) = 4.41 + 0.33(\log RF)(\log I24\_100) - 1.85AE^{-0.25}$	42

Another technique for estimating regional flood flows of small rural watersheds for natural flow streams in eastern Colorado has been developed by Livingston and Minges (1987). This technique is applicable to watersheds with drainage areas less than 30 mi^2. Flood-discharge estimates are based on the following drainage-basin characteristics: Effective drainage area, which is the area in square miles that contributes to flood discharge; a relief factor, which is the altitude difference between the highest point within the effective drainage area and the study site minus 18 ft; and the average 24-hr rainfall intensity with a 100-yr recurrence interval (Miller and others, 1973). Regression equations for estimating flood flows for recurrence intervals of 10, 25, 50, and 100 yrs using the technique of Livingston and Minges (1987) are listed in table 11.

Estimates of peak discharge for floods with recurrence intervals of 10, 50, and 100 yrs and peak streamflow of record through the 1985 water year at each streamflow-gaging station are listed in table 12. Except for sites S4, S8, and S10, the effective drainage-basin area for all sites was adjusted for stock-watering reservoirs in each watershed. For watersheds that had effective drainage areas of less than approximately 30 mi^2, peak-discharge estimates were calculated using regression equations developed by Livingston and Minges (1987). For watersheds that had effective drainage areas greater than 75 mi^2, the regression equations developed by McCain and Jarrett (1976) were used. Where effective drainage area ranged from 40 to 75 mi^2 (sites S7 and S9), both sets of regression equations were used to calculate the flood flows. The average of the two estimates is included in table 12.

Table 12.--*Selected drainage basin characteristics, estimates of flood magnitude for selected recurrence intervals and recorded peak discharges of periods of record for streamflow-gaging stations in and near the Pinon Canyon Maneuver Site*

[Peak discharges in cubic feet per second]

Site number on plate 1	U.S. Geological Survey		Drainage-basin characteristic				Estimated 10-year peak discharge	Estimated 50-year peak discharge	Estimated 100-year peak discharge	Peak recorded discharge for period of record
	Station number	Station name	Effective drainage area (square miles)	Relief factor (feet)	Average rainfall intensity for 24-hour period with 100-year recurrence interval (inches)	Streambed slope (feet per mile)				
S1	07120620	Big Arroyo near Thatcher.	7.7	562	5.0	NA	1,970	5,740	8,580	1,500
S3	07126200	Van Bremer Arroyo near Model.	77.7	NA	NA	19.3	3,880	11,500	17,100	6,240
S4	07126300	Purgatoire River near Thatcher.	1,119	NA	NA	23.0	16,800	42,600	59,800	[1]42,400
S5	07126325	Taylor Arroyo below Rock Crossing, near Thatcher.	28.9	907	5.0	NA	3,880	12,700	19,700	761
S6	07126390	Lockwood Canyon Creek near Thatcher.	31.7	537	5.0	NA	3,290	11,400	18,200	744
S7	07126415	Red Rock Canyon Creek at mouth, near Thatcher.	47.1	922	5.0	32.5	4,040	12,600	19,300	274
S8	07126470	Chacuaco Creek at mouth, near Timpas.	[2]424	NA	NA	10.5	7,740	23,600	35,700	[3]1,840
S9	07126480	Bent Canyon Creek at mouth, near Timpas.	51.1	1,013	5.0	35.1	4,300	13,300	20,400	2,640
S10	07126485	Purgatoire River at Rock Crossing, near Timpas.	1,819	NA	NA	19.0	20,400	52,200	73,700	3,290

[1]Peak flood discharge outside the period of record is 47,700 cubic feet per second.
[2]Effective drainage area not available; estimates of flood discharges are based on total drainage area.
[3]Peak flood discharge outside the period of record is 38,900 cubic feet per second.

Instream Transit Loss in Taylor Arroyo and Its Effects on Streamflow Reaching the Purgatoire River

For a given period of streamflow that results from rainfall, instream transit losses in ephemeral stream channels affect the volume of streamflow that reaches the outlet of a drainage basin. Transit losses are a result of channel storage and streambed infiltration. Therefore, the location of rainfall runoff in a drainage basin will, to a great extent, affect the quantity of streamflow that leaves a drainage basin (Gregory and Walling, 1973). The following example illustrates how the location of rainfall runoff in the Taylor Arroyo drainage basin affects the quantity of streamflow that reaches the Purgatoire River.

During August 1985, a thunderstorm caused intense local surface runoff in the upper part (21.4 stream mi upstream from the mouth of Taylor Arroyo) of the Taylor Arroyo drainage basin. The effective drainage area for the storm was 2.1 mi^2. A peak streamflow of 1,450 ft^3/s was measured using the slope-area method for indirect measurement of streamflow (Dalrymple and Benson, 1967). Onsite investigations after the storm indicated that minimal streamflow entered Taylor Arroyo downstream from the indirect measurement site. The following formula, which was developed for southeastern Colorado using 1,044 floods that ranged in peak discharge from 3 to 12,900 ft^3/s and flood volume from 0.98 to 1,884 acre-ft was used to approximate the volume--114 acre-ft--for this particular storm (Livingston, 1981):

$$V = 0.141\ (Qp)^{0.919},\ SE = 62 \qquad (1)$$

where: V = volume of storm event, in acre-feet,
Qp = peak streamflow, in cubic feet per second, and
SE = average standard error of estimate, in percent.

The streamflow-gaging station on Taylor Arroyo (site S5) is located about 13.2 stream miles downstream from the indirect measurement site. Peak streamflow at site S5 that resulted from rainfall runoff was 93 ft^3/s with a computed total runoff of 32 acre-ft. Streamflow losses to streambed infiltration and channel storage were 82 acre-ft (114 minus 32 acre-ft), or an average estimated transit loss of 6.2 acre-ft per mile of stream channel. Transit losses of 14 acre-ft per mile of stream channel were measured in the Big Sandy Creek drainage basin that is located in southeastern Colorado (Coffin, 1967). Assuming that instream transit losses are constant to the mouth of Taylor Arroyo, none of the streamflow from this rainstorm reached the Purgatoire River. However, had the streamflow of 114 acre-ft occurred at Rock Crossing, about 2 mi upstream from site S5 (10.8 stream mi upstream from the mouth of Taylor Arroyo), 50 acre-ft of streamflow would have reached the Purgatoire River, assuming a transit loss of 6.2 acre-ft per mile of stream. The proximity of runoff-producing storms to the outlet of the Taylor Arroyo drainage basin will affect the quantity of streamflow that reaches the Purgatoire River.

The peak discharge of August 1985 in the previous example had a recurrence interval of about 20 years for a watershed with an effective drainage area of 2.1 mi^2. Using the regression equations developed by Livingston and Minges (1987) (table 11), peak streamflows for a 25-year recurrence interval were calculated for certain points in the Taylor Arroyo watershed (table 13). Volumes for each estimated streamflow event were calculated using equation 1.

Table 13.--*Selected drainage-basin characteristics, estimates of flood magnitudes and volumes having a 25-year recurrence interval, and estimated volume of streamflow reaching the Purgatoire River at selected sites in the Taylor Arroyo drainage basin*

Location of peak discharge in the basin	Drainage-basin characteristic: Contributing drainage area (square miles)	Drainage-basin characteristic: Relief factor (feet)	Drainage-basin characteristic: Rainfall intensity for 24-hour period with a 100-year recurrence interval (inches)[1]	Streamflow with 25-year recurrence interval: Peak discharge (cubic feet per second)	Streamflow with 25-year recurrence interval: Volume (acre-feet)	Stream miles from basin mouth	Estimated transit loss (acre-feet)	Estimated volume of streamflow reaching the Purgatoire River (acre-feet)
Indirect measurement site.	2.1	497	5.0	1,650	128	21.4	128	0
Upstream at Rock Crossing.	12.2	707	5.0	5,220	368	17.0	105	263
At Rock Crossing.	26.5	857	5.0	7,730	528	10.3	64	464
Streamflow gage, Taylor Arroyo below Rock Crossing, near Thatcher (site S5).	28.9	907	5.0	8,140	553	8.2	51	502

[1]Miller and others, 1973.

Estimated volume of streamflow reaching the Purgatoire River was calculated assuming an estimated average instream transit loss of 6.2 acre-ft per stream mi (table 11). The closer the flood event occurs to the mouth of the basin, the larger the amount of streamflow that reaches the Purgatoire River. For example, at the site located above Rock Crossing (17.0 stream mi from the basin mouth, it was estimated that about 72 percent of the streamflow volume from the peak streamflow with a 25-year recurrence interval reached the Purgatoire River. At site S5, 8.8 mi downstream, it was estimated that about 90 percent of the streamflow, for a peak discharge with the same recurrence interval, reached the Purgatoire River.

Inflow to Stock-Watering Reservoirs

The storage capacities of 48 stock-watering reservoirs were measured during the 1984 and 1985 water years and inflow to 25 of these stock-watering reservoirs were measured (see table 24 in the "Supplemental Information" at the back of the report). Data from the 25 stock-watering reservoirs define the spatial and temporal variability of surface runoff on the Maneuver Site. These reservoirs have drainage basin areas ranging from 0.08 to 1.6 mi^2. Measurements of reservoir volumes generally were made biweekly, but were made more frequently after periods of intense rainfall in order to monitor inflow to the reservoirs. Techniques described by Culler (1961) were used to measure and compute reservoir inflow. Water-surface elevations before and after inflow, inflow stored, reservoir spill, and total inflow were computed for each stock-watering reservoir and are tabulated and presented in table 24.

During August 19-22, 1984, intense thunderstorms caused surface runoff over the entire Maneuver Site. The spatial variability of surface runoff for this period is shown in figure 17. Lines of equal surface runoff were drawn

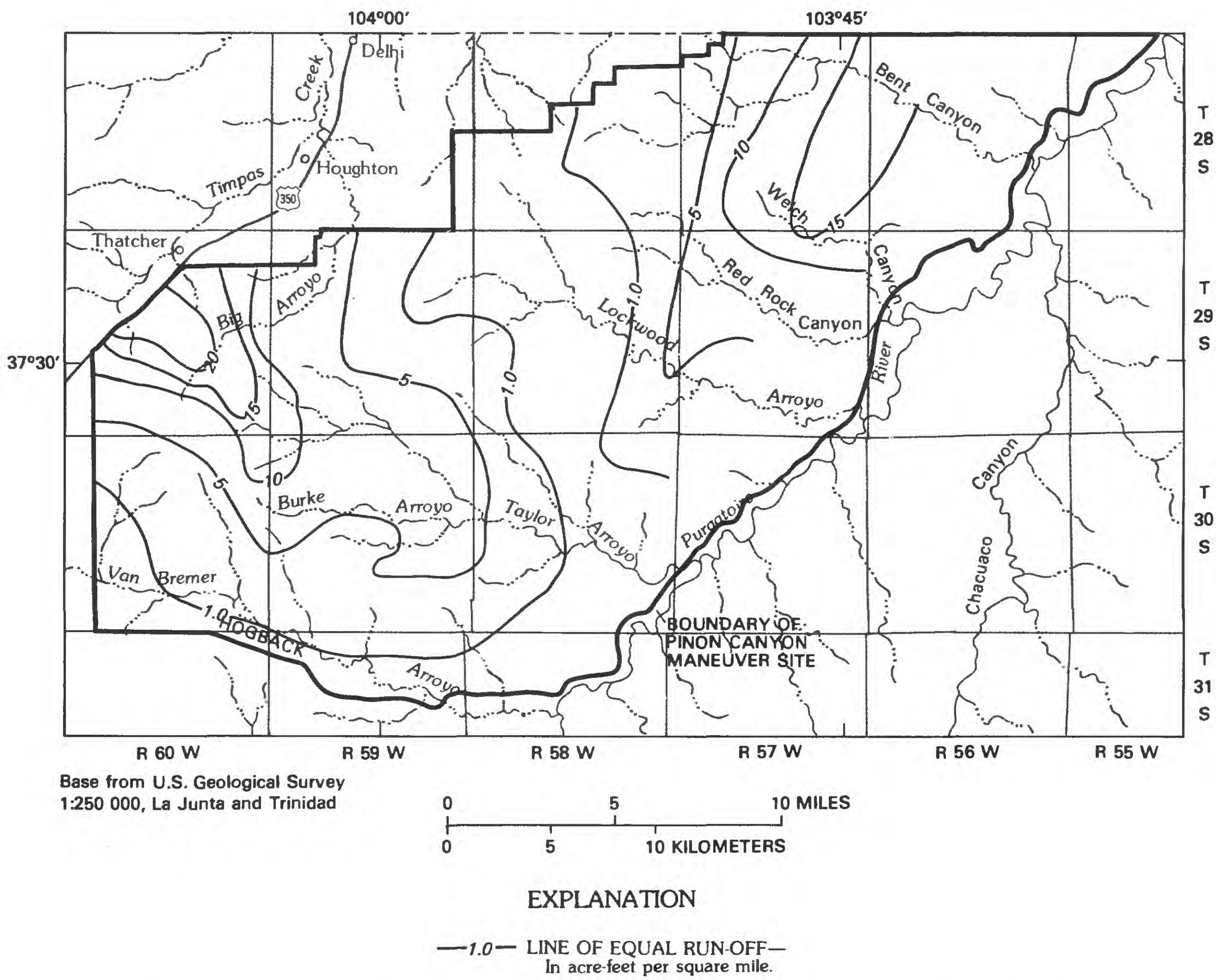


Figure 17.--Surface runoff for storm of August 19-22, 1984, at the Pinon Canyon Maneuver Site.

to conform with the measured surface runoff at each stock-watering reservoir. Surface runoff greater than 10 acre-ft/mi^2 was confined to the northeastern and western parts of the Maneuver Site, and the remainder of the area had surface runoff of 1 to 5 acre-ft/mi^2.

The temporal variability of surface runoff for the Maneuver Site is illustrated in figure 18. During April through November of the 1984 and 1985 water years, 60 periods of surface runoff were recorded at the network of 25 stock-watering reservoirs. The majority, about 62 percent of these surface-runoff events, occurred during July and August. August had the largest volume of surface runoff, about 41 acre-ft or about 60 percent of the surface runoff recorded flowing into the stock-watering reservoirs during the measurement period. Late spring snow storms can contribute considerable volumes of inflow to the stock-watering reservoirs. For example, eight surface-runoff events resulting from snowmelt during April 1984 contributed about 10 acre-ft, or about 15 percent of the surface runoff recorded during the measurement period. Although no surface-runoff data are collected at the network of stock-watering reservoirs during the winter months, years that have large quantities of snowfall and rapid snowmelt may contribute considerable quantities of surface runoff to stock-watering reservoirs.

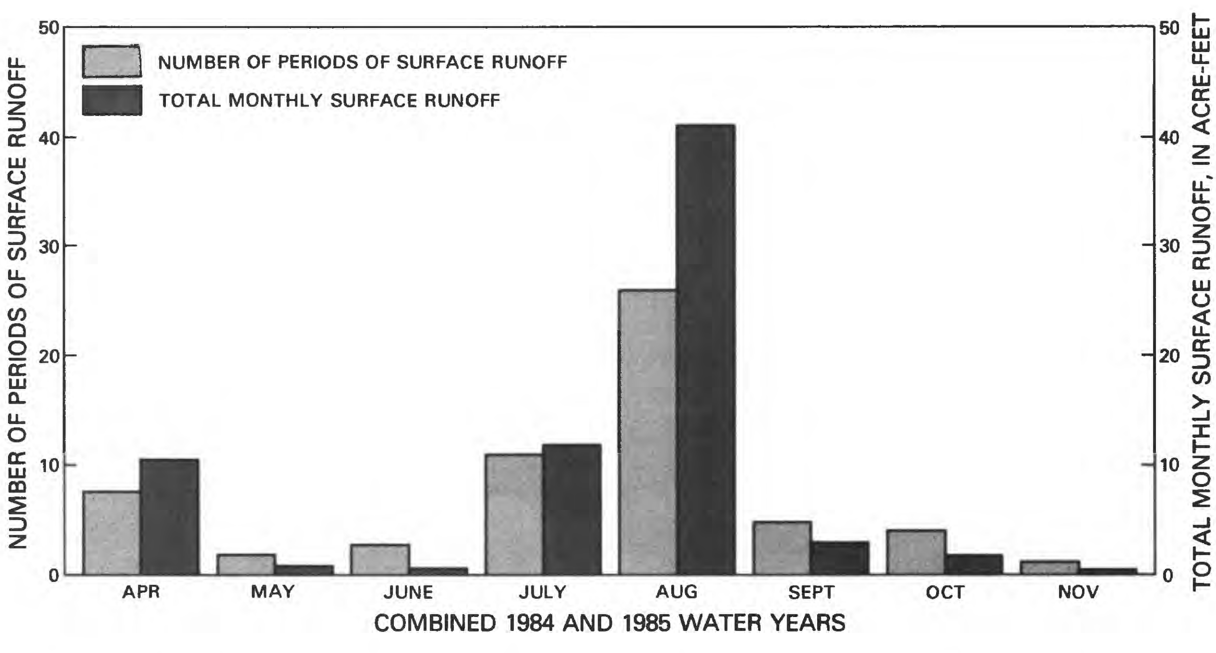


Figure 18.--Number of periods of surface runoff and total monthly surface runoff for the stock-watering reservoir network at the Pinon Canyon Maneuver Site for water years 1984 and 1985.

Surface-Water Rights

Prior to the U.S. Department of the Army's acquisition of the Maneuver Site, agricultural interests developed surface-water rights in the area. The July 1, 1984, tabulation of water rights in the Arkansas River basin issued by the Colorado State Engineer lists nine appropriated surface-water rights at the Maneuver Site that have been adjudicated. Information about these surface-water rights are listed in table 14 and plotted on plate 1.

Table 14.--*Decreed surface-water rights at the Pinon Canyon Maneuver Site*
[ft^3/s, cubic feet per second; acre-ft, acre-feet]

Name (See plate 1)	Location			Appropriation date	Adjudication date	Decreed quantity
	Township	Range	Section			
Brown number 3 ditch	30S.	60W.	27	11-11-09	01-12-25	3.9 ft^3/s
Brown number 3 ditch	30S.	60W.	28	11-11-09	01-12-25	3.9 ft^3/s
Brown number 3 ditch	30S.	60W.	28	09-01-14	01-12-25	3.9 ft^3/s
Brown number 4 ditch	30S.	60W.	29	11-19-14	01-12-25	6.5 ft^3/s
Brown number 3 reservoir	30S.	60W.	29	11-19-14	01-12-25	26.5 acre-ft
Mike Gagliardi ditch	30S.	60W.	14	06-22-17 [2]08-30-20	[1]01-07-22 01-12-25	10 ft^3/s 30 ft^3/s
Mike Gagliardi reservoir	30S.	60W.	23	05-01-19	01-12-25	186 acre-ft

[1]Prior adjudication.
[2]Ditch enlargement.

Surface-Water Quality

The change in land use at the Maneuver Site raised local concerns about the effects that military maneuvers might have on the hydrology of the area and, consequently, the effects on the water quality of the Purgatoire River. The Maneuver Site is located about 58 river miles upstream from the confluence of the Arkansas and Purgatoire Rivers. Changes in water quality, particularly an increase in salinity resulting from military maneuvers, could affect downstream agricultural water users. Baseline data were collected in order to describe the existing water-quality characteristics of the Purgatoire River and streams draining the Maneuver Site and Chacuaco Creek.

Instream Water-Quality Standards for the Purgatoire River

The Colorado Department of Health, Water Quality Control Commission has classified the Purgatoire River downstream from Trinidad to its confluence with the Arkansas River as a class 2 warm-water aquatic life, agricultural stream (Colorado Department of Health, 1982). This includes the reach of the Purgatoire River adjacent to the Maneuver Site. This water-quality classification is given to streams in which the variety of biological life forms primarily is limited by streamflow and streambed characteristics. Stream classifications are assigned to protect existing species and encourage the establishment of more sensitive species that are compatible with existing streamflow and streambed characteristics (Colorado Department of Health, 1982).

Water-quality data periodically collected at the Purgatoire River near Thatcher (site S4) and the Purgatoire River at Rock Crossing, near Timpas (site S10) include chemical properties and constituents that are included in the instream water-quality standards set by the Colorado Department of Health (table 15). These data are presented as time-series plots (figs. 38 and 39 in the "Supplemental Information" section at the back of the report). Each plot shows the instream standard indicated as the value of a property or as the maximum or ranges of concentration set by the Colorado Department of Health (1982). This enables easy identification of values that exceed the given standard.

Table 15.--*Instream standards for water-quality properties and constituents analyzed for the Purgatoire River in the vicinity of the Pinon Canyon Maneuver Site*

[Standards are from Colorado Department of Health, 1982; mg/L, milligrams per liter, μg/L, micrograms per liter]

Property or constituent	Units	Instream classification standard
Dissolved oxygen	mg/L	> 5.0
pH	standard units	6.5 - 9.0
Dissolved nitrite	mg/L	0.5
Total recoverable cadmium	μg/L	5
Dissolved chromium	μg/L	125
Total recoverable copper	μg/L	10
Total recoverable iron	μg/L	1,600
Total recoverable lead	μg/L	50
Total recoverable manganese	μg/L	1,000
Total recoverable zinc	μg/L	165
Total cyanide	mg/L	0.005

All dissolved-oxygen concentrations and pH values were within the instream standards. There is an instream water-quality standard for dissolved nitrite. Plots of dissolved nitrite plus nitrate indicate that the instream standard for nitrite may have been exceeded four times at sites S4 and S10 (figs. 38 and 39). However, dissolved nitrogen in surface water usually is not present as nitrite; therefore, it is reasonable to assume that most of the dissolved nitrite plus nitrate in surface water is present as nitrate. Probable sources of nitrate in the Purgatoire River basin are related to farming and ranching activities.

Time-series plots of data for seven total recoverable metals and suspended-sediment concentration indicate that instream standards were exceeded during periods of streamflow that had large concentrations of suspended sediment (figs. 38 and 39); these periods usually are associated with snowmelt and rainfall runoff. A water-quality standard may be exceeded because of natural conditions such as flood flows or drought (Colorado Department of Health, 1982). Otherwise, during periods of baseflow, metal concentrations met or were less than the instream standards. There is no instream standard for suspended sediment for streams classified as class 2 warm-water aquatic life. No plot of cyanide is included; the instream standard for cyanide is 0.005 mg/L. All samples analyzed for cyanide were less than 0.01 mg/L, which is the detection limit of the analytical method used for cyanide analysis.

Summary Statistics of Water-Quality Data

Summary statistics of selected water-quality data are presented in table 25 in the "Supplemental Information" at the back of the report. These data summarize water-quality properties and constituents collected at the Purgatoire River near Thatcher (site S4), the Purgatoire River at Rock Crossing, near Timpas (site S10) and at five intermittent and ephemeral streamflow-gaging stations (sites S1, S3, S5, S6, S8) for October 1982 through September 1985.

Data summarized include onsite measurements, and concentrations of dissolved cations and anions, dissolved nutrients, dissolved and total recoverable metals, radiochemical constituents, and suspended sediment. These data represent samples collected during base streamflow and during periods of snowmelt and rainfall runoff. Streamflows ranged from 14 to 1,090 ft^3/s at site S4, 12 to 861 ft^3/s at site S10, and 0.01 to 760 ft^3/s at the intermittent and ephemeral sites. The majority of the rainfall-runoff events sampled were at Big Arroyo near Thatcher (site S1), Taylor Arroyo below Rock Crossing, near Thatcher (site S5), and Chacuaco Creek at mouth, near Timpas (site S8). Samples collected at Lockwood Canyon Creek near Thatcher (site S6) represent intermittent base streamflows and samples at Van Bremer Arroyo near Model (site S3) represent base streamflow and irrigation-return flow.

As previously noted in the "Instream Water-Quality Standards for the Purgatoire River" section, large concentrations of total recoverable metals and suspended sediment are associated with periods of rainfall and snowmelt runoff. Conversely, concentrations of dissolved constituents are smaller during periods of runoff. For example, at the Purgatoire River near Thatcher (site S4), the median value for dissolved sulfate analyzed during periods of base flow was 1,500 mg/L and 670 mg/L during periods of runoff (table 16).

Table 16.--*Comparison of concentrations of major ions at streaflow-gaging station Purgatoire River near Thatcher (site S4), for period of base streamflow and rainfall and snowmelt runoff*

Runoff period	Number of samples	Minimum value	Percentiles 25th	Percentiles Median 50th	Percentiles 75th	Maximum
	Calcium, in milligrams per liter					
Base flow------------	16	150	220	230	280	350
Rainfall and snowmelt	7	49	65	123	180	270
	Sulfate, in milligrams per liter					
Base flow------------	16	800	1,200	1,500	1,900	2,000
Rainfall and snowmelt	8	160	250	670	930	1,600

Dissolved Solids

Dissolved solids is a measure of the quantity of dissolved minerals in water and is used as a measure of inorganic water quality. Large concentrations of dissolved solids can adversely affect water quality for irrigation and municipal use. The soils at the Maneuver Site have developed from sedimentary limestone, shale, and sandstone and have naturally large concentrations of soluble salts. The development of soils has occurred under semiarid conditions where insufficient moisture is available to leach soluble salts. The chemistry of most surface and ground water is the result of interaction between precipitation and geologic materials near the surface of the earth; much of this interaction occurs in the soil zone (Drever, 1982).

Calcium, magnesium, and sulfate are the main constituents that constitute the dissolved solids in the surface water of the area (fig. 19). Bicarbonate concentrations were obtained by multiplying alkalinity values by the constant 1.2192 (Hem, 1985). Composition of dissolved solids is similar at the Purgatoire River near Thatcher (site S4) and the Purgatoire River at Rock Crossing, near Timpas (site S10).

Dissolved solids at Taylor Arroyo below Rock Crossing, near Timpas (site S5) primarily are composed of calcium and sulfate. These data represent streamflows that result from storm runoff from the Taylor Arroyo drainage basin. Soils in the basin are developed from sedimentary rocks that contain gypsum (calcium sulfate), which is very soluble in water. The dissolved solids for Van Bremer Arroyo near Model (site S3) are composed of a larger percentage of bicarbonate than at the other sites. There is no apparent reason for the large percentage of bicarbonate; however, these data represent base flow and irrigation return flow that enter Van Bremer Arroyo from farmland adjacent to the Maneuver Site. Irrigation water may contain large concentrations of carbon dioxide, and interaction of this water with calcareous soils may be causing the larger percentage of bicarbonate (Hem, 1985).

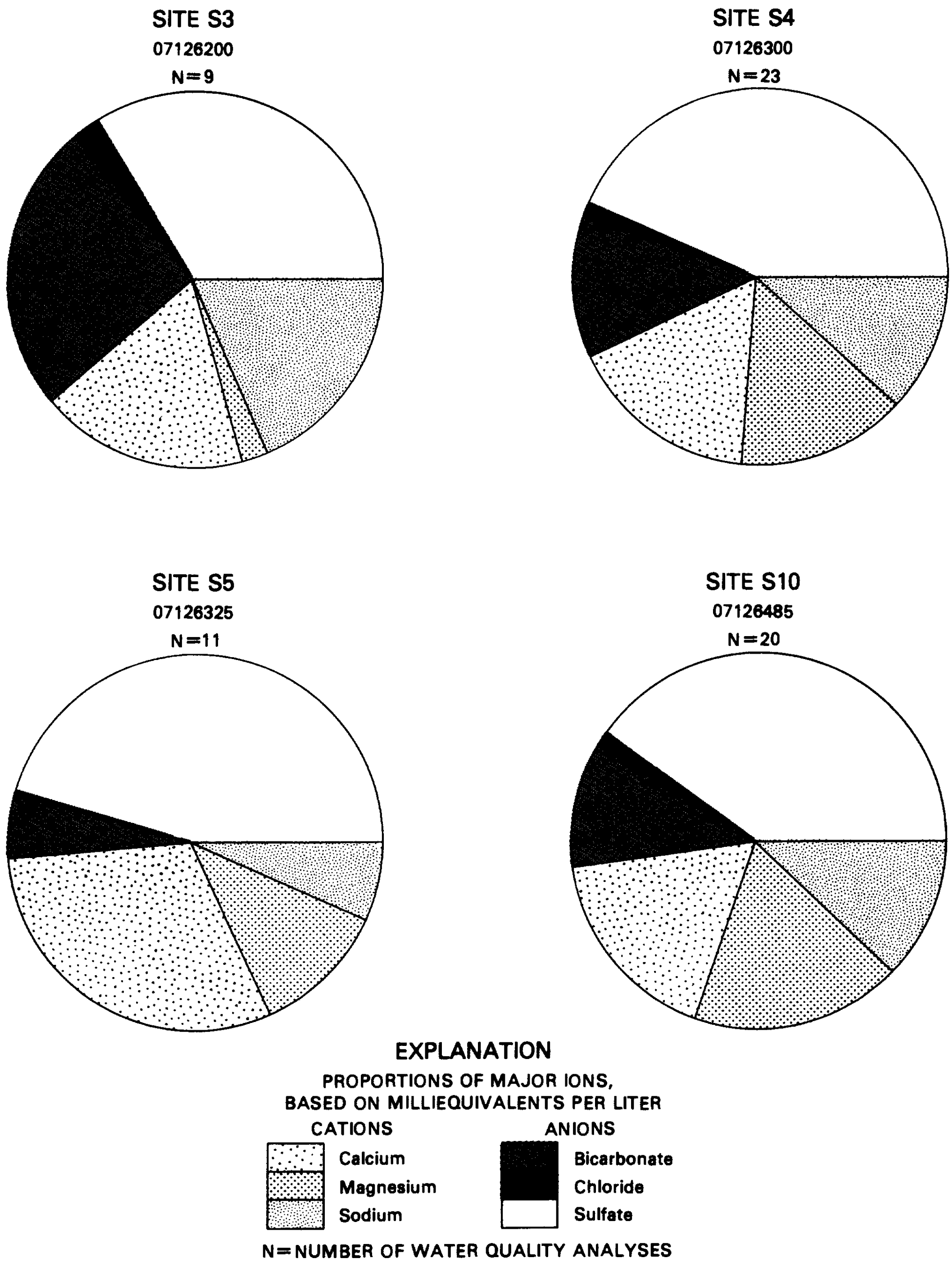


Fig. 19.--Comparison of proportions of major ions for the streamflow-gaging stations Van Bremer Arroyo near Model (site S3); Purgatoire River near Thatcher (site S4); Taylor Arroyo below Rock Crossing, near Thatcher (site S5); and Purgatoire River at Rock Crossing, near Timpas (site S10).

Streamflow from areas of disturbed lands on the Maneuver Site may cause deterioration of water quality in the Purgatoire River. Lands disturbed by military land use may produce larger quantities of suspended sediment and thus larger quantities of dissolved solids than were produced previously. The example of instream transit loss of flood streamflows in the "Instream transit loss in Taylor Arroyo and its effects on streamflow reaching the Purgatoire River" section would apply to dissolved-solids and suspended-sediment loads, because loads of water-quality constituents are dependent on streamflow. The closer land disturbance is located to the outlet of a drainage basin, the larger the quantities of suspended sediment and dissolved solids that result from that disturbance will be transported out of the drainage basin.

Relations of dissolved solids and major ions to specific conductance

Regression relations of dissolved solids and major ions to specific conductance were determined using an ordinary least-squares technique for estimating linear regression models (Statistical Analysis System Institute, 1985).[1] Relations were determined for the Purgatoire River at sites S4 and S10, and the tributary streams Big Arroyo near Thatcher (site S1), Van Bremer Arroyo near Model (site S3), and Taylor Arroyo below Rock Crossing, near Thatcher (site S5). The regression procedure computes slope (a) and y-intercept (b) for the equation

$$C_i = a K + b \quad (2)$$

where C_i = the constituent concentration, in milligrams per liter;
K = the specific conductance, in microsiemens per centimeter at 25 °C; and
a and b = the regression coefficients.

In addition to the slope and intercept of the equations, the following regression parameters are listed in table 26 in the "Supplemental Information" section at the back of the report.

(1) N is the number of observation pairs used to compute the regression;
(2) The coefficient of determination (R^2) is the square of the correlation coefficient (R). The coefficient of determination explains what proportion of the variation of the dependent variable (the major ion) can be attributed to the linear relation with specific conductance; and
(3) The standard error of estimate, which is the standard deviation of the sample points from the least squares lines in the same units as the dependent variable.

Specific-conductance values for the Purgatoire River near Thatcher (site S4) were plotted compared to corresponding concentrations of calcium and sulfate (fig. 20). These plots indicate that at the Purgatoire River near Thatcher (site S4) a good relation exists between concentrations of the major cations and anions and specific conductance. Similar relations exist downstream at the Purgatoire River at Rock Crossing, near Timpas (site S10).

---

[1]The use of trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Specific conductance was a good predictor of all cations except potassium. Potassium seldom occurs in large concentrations in natural water partly because of the considerable degree of stability of potassium-bearing aluminosilicate minerals (Hem, 1985). The lack of definable relations of specific conductance to potassium probably is because of the lack of potassium available for transport.

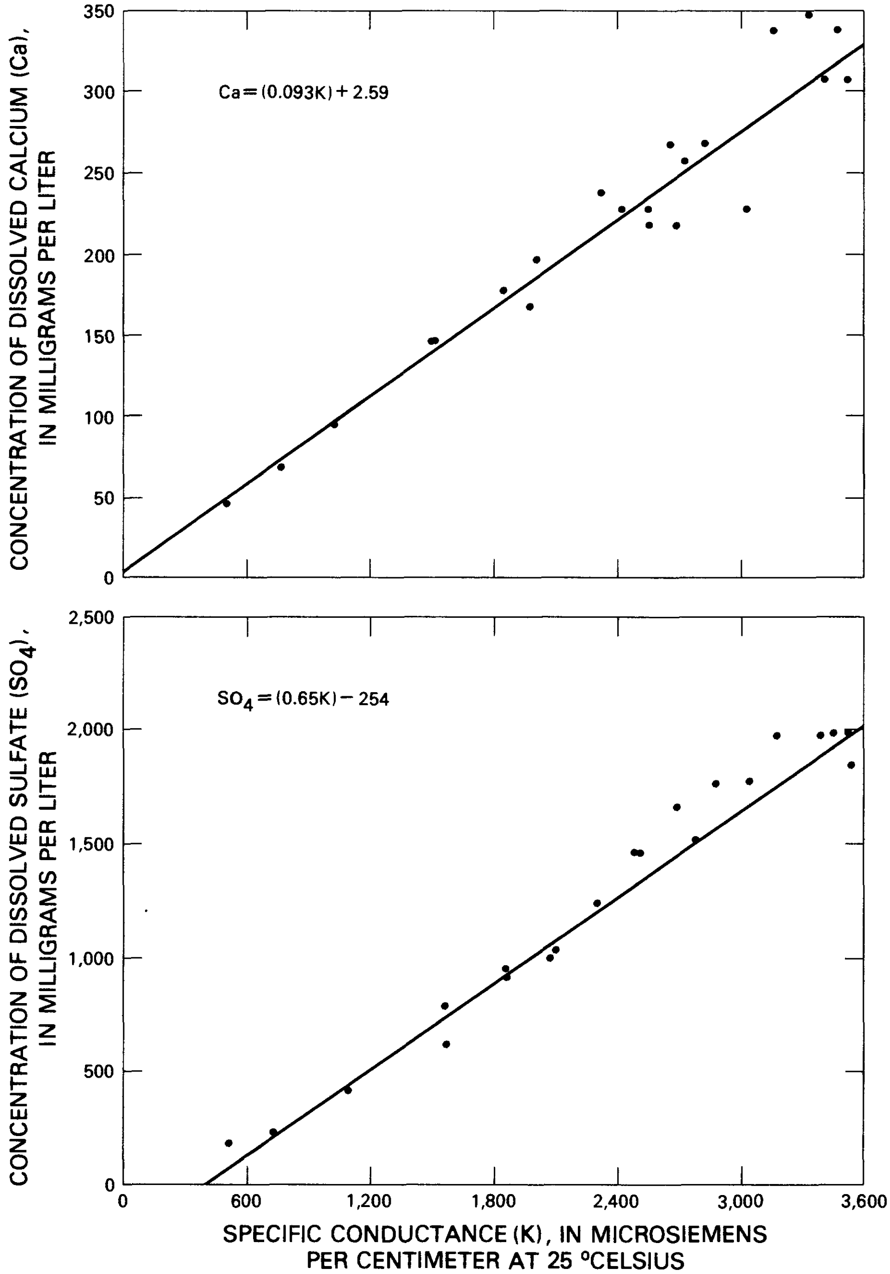


Figure 20.--Correlations and regressions of concentrations of calcium and sulfate to specific conductance at streamflow-gaging station 07126300, Purgatoire River near Thatcher (site S4).

At sites S4 and S10, specific conductance correlated well with sulfate and chloride but correlated poorly with fluoride and bicarbonate. At the intermittent and ephemeral sites, S1, S3, and S5, specific conductance was a good predictor of sulfate at all sites and was a good predictor of fluoride only at site S5. Good relations between specific conductance and fluoride are unusual and unexplainable because minerals that contain fluoride generally have a low solubility that results in small quantities of fluoride in solution. Bicarbonate concentration is affected by chemical controls, which include the availability of carbonate minerals, such as calcite, for solution. When streamflow is small, specific-conductance values are larger, and bicarbonate reaches saturation with respect to calcite.

Daily mean specific conductance for the Purgatoire River

Continuous records of specific-conductance measurements were collected at the Purgatoire River near Thatcher (site S4) and the Purgatoire River at Rock Crossing, near Timpas (site S10). These data are used to compute daily mean specific conductance for each site. Daily mean specific conductance ranged from 530 to 3,810 μS/cm at site S4 and 534 to 4,030 μS/cm at site S10.

Hydrologic data usually do not have a normal probability distribution. They often are skewed and serially correlated. Therefore, when doing statistical analyses, it is necessary either to transform the data to follow a normal distribution or to use nonparametric statistical techniques that are less sensitive to the skewed distribution.

During the 1984 and 1985 water years, when daily mean specific-conductance data are available at both sites (S4 and S10), the mean value for daily specific conductance was computed. The average of the daily mean specific-conductance values at site S4 was 2,550 μS/cm, and the average of the daily mean values at site S10 was 2,540 μS/cm. The hypothesis that the average values of daily mean specific conductance at sites S4 and S10 were equal ($\mu_1=\mu_2$) was tested using the nonparametric Wilcoxon rank sum test (SAS Institute, 1985). The average values of the daily mean specific conductance from both sites are equal at the 0.01 percent level of significance. This test indicated that for periods when specific-conductance data are available, streamflow and ground-water discharge that enter the Purgatoire River between sites S4 and S10 do not significantly affect dissolved-solids concentrations.

Dissolved-Solids and Suspended-Sediment Loads

Dissolved-solids and suspended-sediment loads can be characterized best in terms of magnitude, duration, and frequency. Dissolved-solids and suspended-sediment loads are the summation of the mean daily dissolved-solids and suspended-sediment discharges for one water year. Daily mean specific-conductance data were available for calculating dissolved-solids discharge, and daily suspended-sediment data were available to calculate the suspended-sediment discharge. Dissolved-solids and suspended-sediment discharge were computed using the following equations (Porterfield, 1972):

$$Qds = Qw \times ds \times 0.0027 \quad (3)$$

$$Qs = Qw \times c \times 0.0027 \quad (4)$$

where Qds is dissolved-solids discharge, in tons per day;
Qw is streamflow, in cubic feet per second;
ds is dissolved-solids concentration, in milligrams per liter;
Qs is suspended-sediment discharge, in tons per day;
c is suspended-sediment concentration, in milligrams per liter; and
0.0027 is a unit conversion constant.

Regression relations between dissolved-solids concentration and specific conductance (table 26 in the "Supplemental Information" section at the back of the report) were used in conjunction with daily mean specific-conductance data to compute daily dissolved-solids concentrations for the 1985 water year at Van Bremer Arroyo near Model (site S3), the Purgatoire River near Thatcher (site S4), and the Purgatoire River at Rock Crossing, near Timpas (site S10). Daily mean dissolved-solids discharge at all three sites was calculated using equation 3 and then summed to obtain annual dissolved-solids load.

Dissolved solids

During the 1985 water year, dissolved-solids load was 107,000 tons at the Purgatoire River near Thatcher (site S4), and was 106,000 tons at the Purgatoire River at Rock Crossing, near Timpas (site S10) (table 17). Monthly

Table 17.--*Calculated and estimated dissolved-solids load for the 1985 water year at streamflow-gaging stations in and near the Pinon Canyon Maneuver Site*

[E, estimated; C, calculated]

Site number on plate 1	U.S. Geological Survey station number and station name	Streamflow (acre-feet)	Dissolved-solids load (tons)	Ratio of dissolved-solids load to streamflow (tons per acre-feet)
S1	07120620 Big Arroyo near Thatcher	102	[E]64	0.63
S3	07126200 Van Bremer Arroyo near Model.	1,790	[C]2,140	1.20
S4	07126300 Purgatoire River near Thatcher.	34,100	[C]107,000	1.58
S5	07126325 Taylor Arroyo below Rock Crossing, near Thatcher.	51	[E]32	.63
S6	07126390 Lockwood Canyon Creek near Thatcher.	18	[E]11	.61
S7	07126415 Red Rock Canyon Creek at mouth, near Thatcher.	7.9	[E]5.0	.63
S8	07126470 Chacauco Creek at mouth, near Timpas.	606	[E]380	.63
S9	07126480 Bent Canyon Creek at mouth, near Timpas.	0	0	0
S10	07126485 Purgatoire River at Rock Crossing, near Timpas.	32,900	[C]106,000	1.70

dissolved-solids load at sites S4 and S10 was smallest during April and largest during May and October (fig. 21). Sources of dissolved solids are: inflow of ground water, surface runoff, and irrigation-return flows from farmland in the upper Purgatoire River basin.

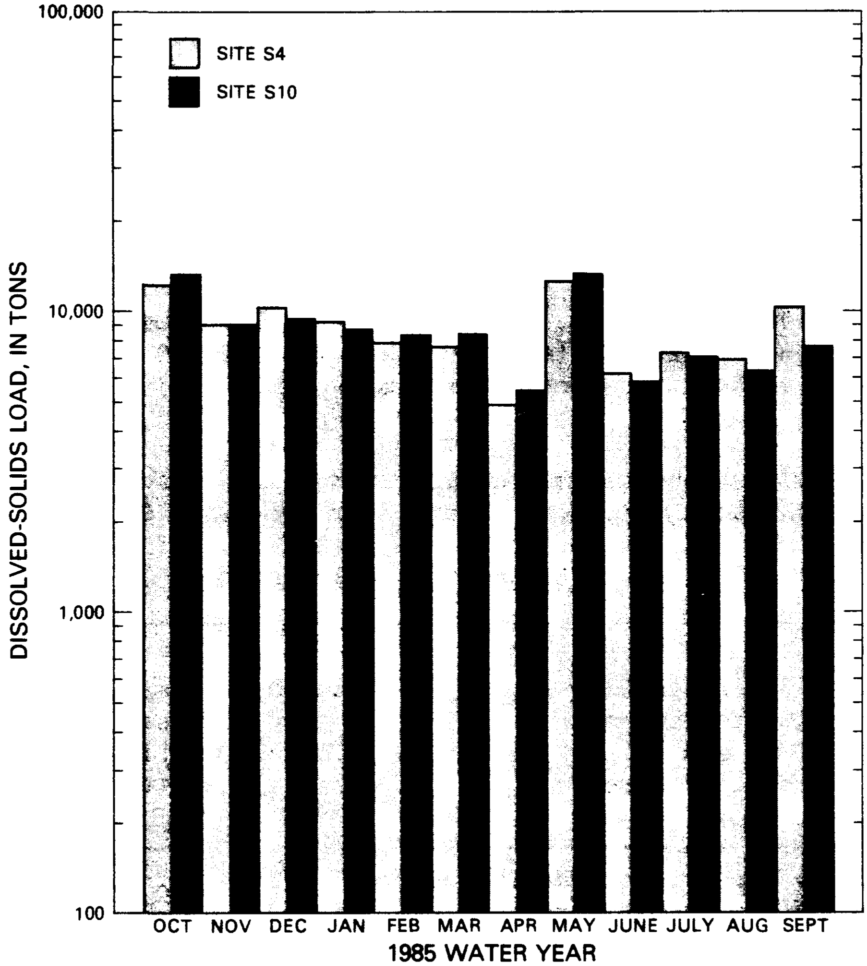


Figure 21.--Monthly dissolved-solids load for the 1985 water year at the streamflow-gaging stations Purgatoire River near Thatcher (site S4) and Purgatoire River at Rock Crossing, near Timpas (site S10).

During periods of low streamflow, dissolved-solids concentrations are largest. The steady supply of dissolved solids at low streamflows results in low streamflows transporting most of the annual dissolved-solids load. During the 1985 water year at sites S4 and S10, about 80 percent of the dissolved-solids load was transported by daily mean streamflows that were less than 80 ft^3/s (fig. 22).

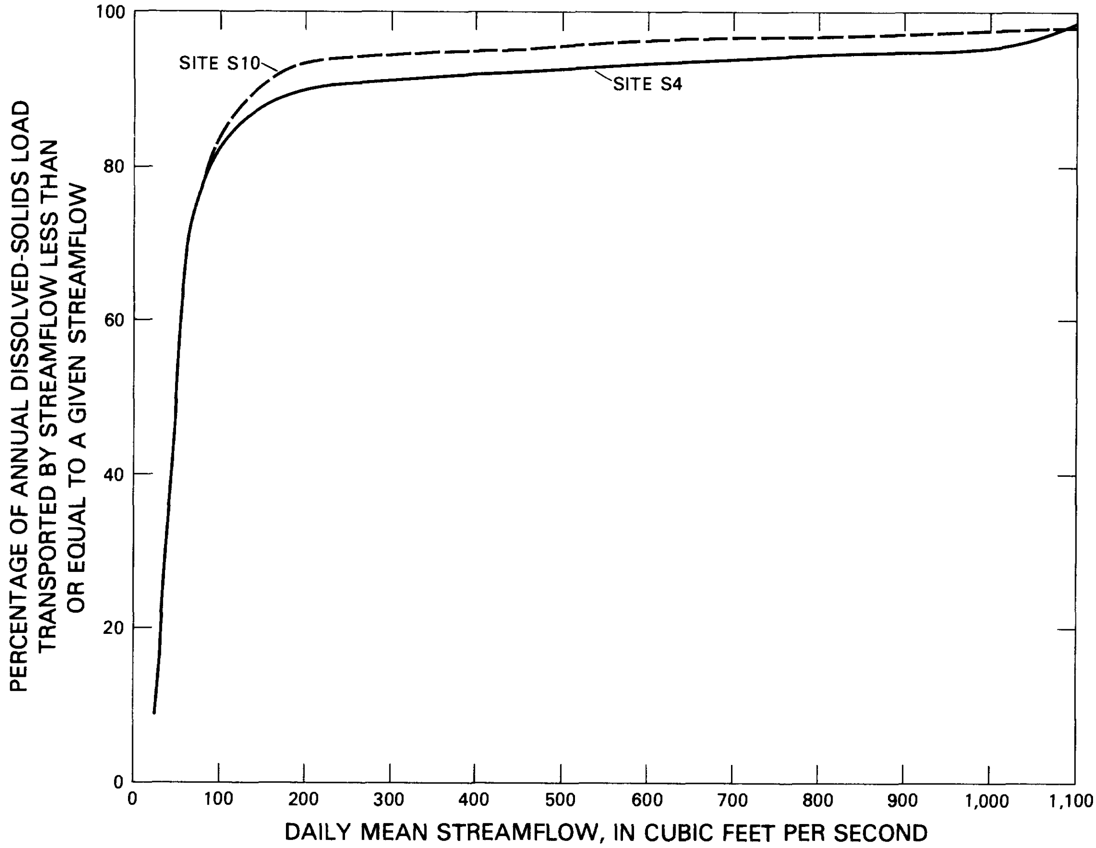


Figure 22.--Relation between cumulative dissolved-solids load and daily mean streamflow for the streamflow-gaging stations Purgatoire River near Thatcher (site S4) and Purgatoire River at Rock Crossing, near Timpas (site S10).

During the 1985 water year, dissolved-solids load transported at Van Bremer Arroyo near Model (site S3) was 2,140 tons or only about 2 percent of the dissolved-solids load at the Purgatoire River near Thatcher (site S4) (table 17). Dissolved-solids loads were largest during May through October, except for August, when loads were smallest, due to minimal irrigation-return flow (fig. 23). During this period, about 2,000 tons, or approximately 93 percent of the dissolved-solids load transported, is associated with irrigation-return flows that enter Van Bremer Arroyo from farmland southwest of the Maneuver Site.

During the 1985 water year, the total volume of streamflow contributed to the Purgatoire River from Taylor Arroyo (site S5), Lockwood Canyon Creek (site S6), Red Rock Canyon Creek (site S7), Chacuaco Creek (site S8), and Bent Canyon Creek (site S9) was about 682 acre-ft. Most of the streamflow from sites S5, S6, S7, S8, and S9 results from rainfall runoff; concentrations of dissolved solids analyzed from these sites had a mean of 462 mg/L. Samples for dissolved solids analyzed periodically from Van Bremer Arroyo near Model (site S3) had a mean concentration of 1,160 mg/L, 60 percent greater than the mean dissolved-solids concentration for sites S5, S6, S7, S8, and S9.

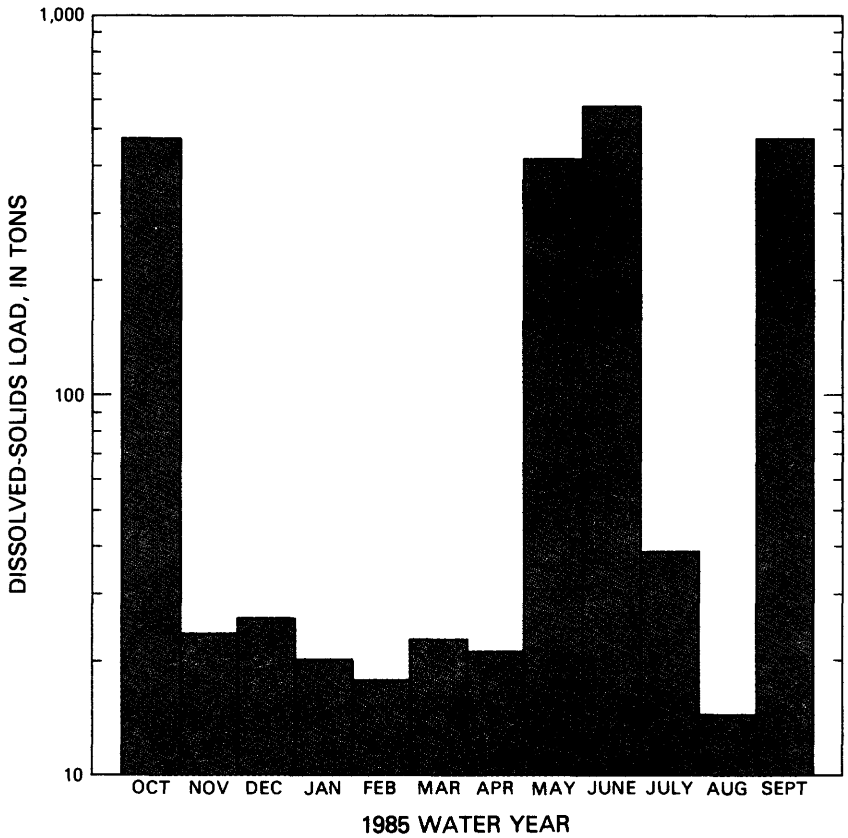


Figure 23.--Monthly dissolved-solids load for the streamflow-gaging station Van Bremer Arroyo near Model (site S3) for water year 1985.

Dissolved-solids loads for sites S5, S6, S7, S8, and S9 can be estimated, assuming that the mean dissolved-solids concentration of 462 mg/L represents streamflow that results from rainfall runoff. The average concentration for dissolved-solids concentration of 462 mg/L was applied, using equation 3, to the daily mean streamflow in cubic feet per second from sites S5, S6, S7, S8, and S9 and then summed to estimate annual dissolved-solids load in tons for each site (table 17). Estimated dissolved-solids load for the 1985 water year at sites S5, S6, S7 and S9 was about 48 tons, or about 0.05 percent of the dissolved-solids load transported at the Purgatoire River at Rock Crossing, near Timpas (site S10). Estimated dissolved-solids load at Chacuaco Creek at mouth, near Timpas (site S8) was 380 tons, or about 0.36 percent of the dissolved-solids load transported at site S10.

Annual dissolved-solids loads for the 1985 water year were related to streamflow by computing a ratio of dissolved-solids load to streamflow. Streamflow-gaging stations on the Purgatoire River had the largest quantity of dissolved solids transported per acre-feet of streamflow (1.58 ton/acre-ft at site S4 and 1.70 tons/acre-ft at site S10). Dissolved-solids load transported by tributary streams ranged from 0 at site S9 to 1.20 ton/acre-ft at site S3 (table 17).

Suspended Sediment

Daily mean suspended-sediment discharges were computed for the 1984 and 1985 water years at the Purgatoire River near Thatcher (site S4) and for the Purgatoire River at Rock Crossing, near Timpas (site S10). Calculated total suspended-sediment loads at these sites were 414,000 tons and 402,000 tons (table 18). Suspended-sediment loads for the Purgatoire River are largest during late spring and during periods of summer thunderstorms (figs. 24 and 25). Floods transport the larger part of the annual suspended-sediment load. For example, during the 1984 and 1985 water years, about 80 percent of the suspended-sediment load at site S4 was transported on days when daily mean streamflow exceeded 200 ft^3/s (fig. 26). However, the daily mean streamflow of 200 ft^3/s was equaled or exceeded only about 8 percent of the time (fig. 14). The effect of floods is further illustrated by suspended-sediment data for May 22-24, 1985. During this 3-day period, 193,000 tons, or 45.6 percent of the suspended-sediment load for the 1985 water year was transported at site S4.

Daily mean suspended-sediment loads were computed for the 1984 and 1985 water years at streamflow-gaging stations Big Arroyo near Thatcher (site S1), Taylor Arroyo below Rock Crossing, near Thatcher (site S5), Chacuaco Creek at mouth, near Timpas (site S8) and Bent Canyon Creek at mouth, near Timpas (site S9). Suspended-sediment load from ephemeral tributaries is limited to streamflow that results from storm runoff during May through October (figs. 40 through 43 in the "Supplemental Information" section at the back of the report).

Table 18.--*Suspended-sediment load transported during the 1984 and 1985 water years for streamflow-gaging stations in and near the Pinon Canyon Maneuver Site*

Site number on plate 1	U.S. Geological Survey station number and station name	Suspended-sediment load: Water year 1984 (tons)	Suspended-sediment load: Water year 1985 (tons)	Suspended-sediment load: Total (tons)	Suspended-sediment load: Ratio of suspended-sediment load to streamflow (tons per acre-feet)
S1	07120620 Big Arroyo near Thatcher.	3,410	2,570	5,980	32.1
S4	07126300 Purgatoire River near Thatcher.	134,000	280,000	414,000	4.8
S5	07126325 Taylor Arroyo below Rock Crossing, near Thatcher.	4,020	388	4,410	24.3
S8	07126470 Chacuaco Creek at mouth, near Timpas.	10,200	6,020	16,200	14.2
S9	07126480 Bent Canyon Creek at mouth, near Timpas.	20,000	0	20,000	30.6
S10	07126485 Purgatoire River at Rock Crossing, near Timpas.	158,000	244,000	402,000	4.7

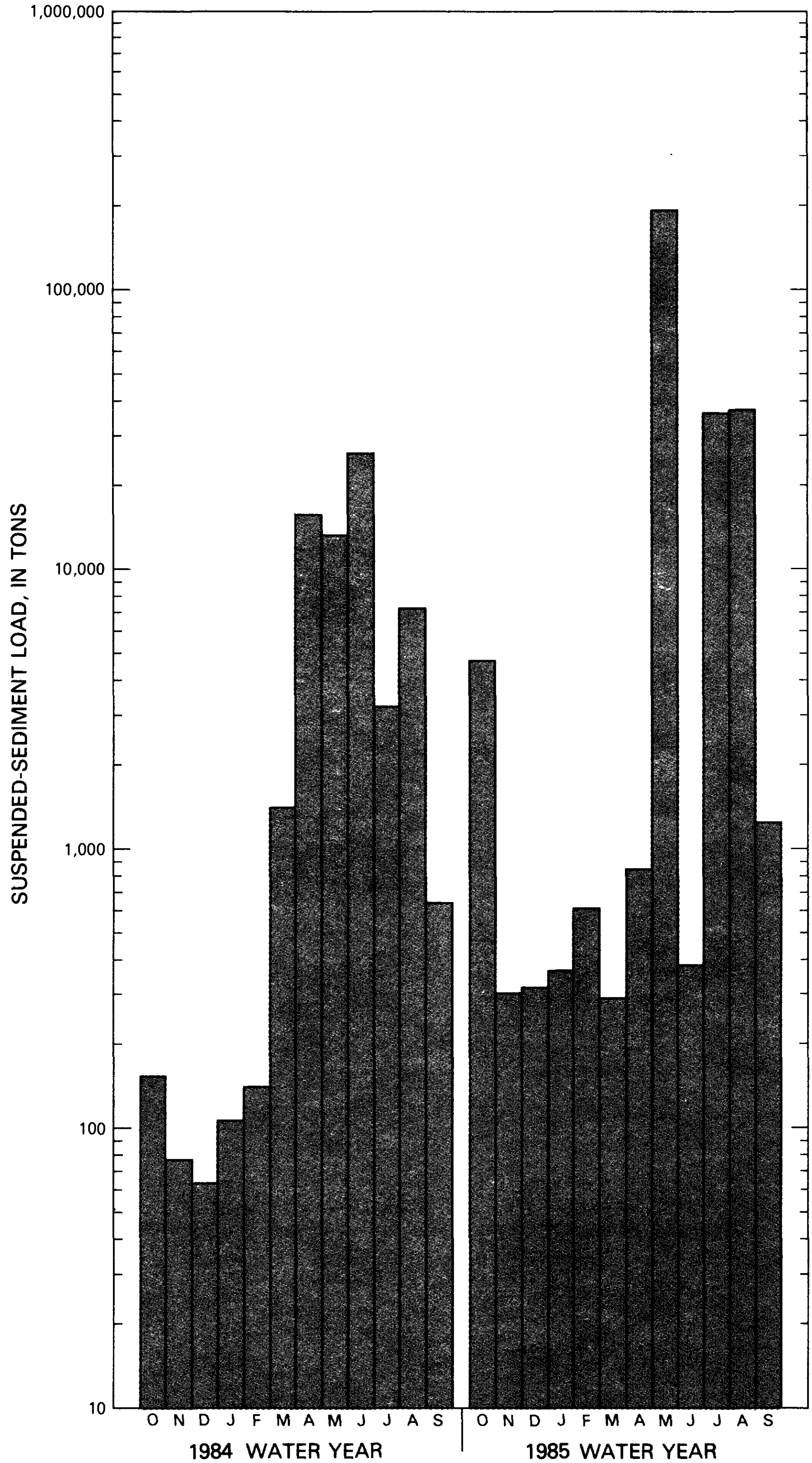


Figure 24.--Monthly suspended-sediment load for the streamflow-gaging station Purgatoire River near Thatcher (site S4) for water years 1984 and 1985.

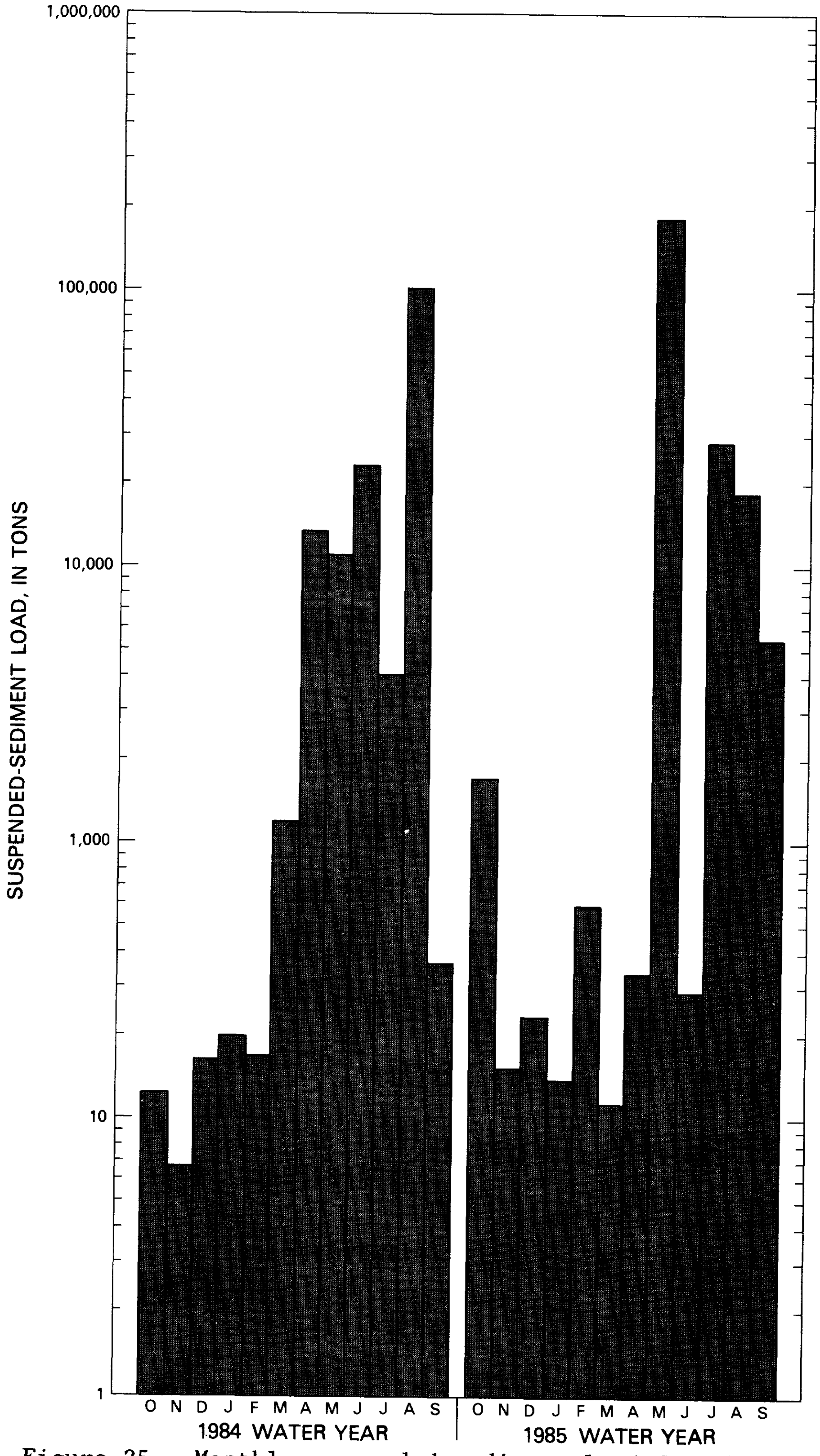


Figure 25.--Monthly suspended-sediment load for the streamflow-gaging station Purgatoire River at Rock Crossing, near Timpas (site S10) for water years 1984 and 1985.

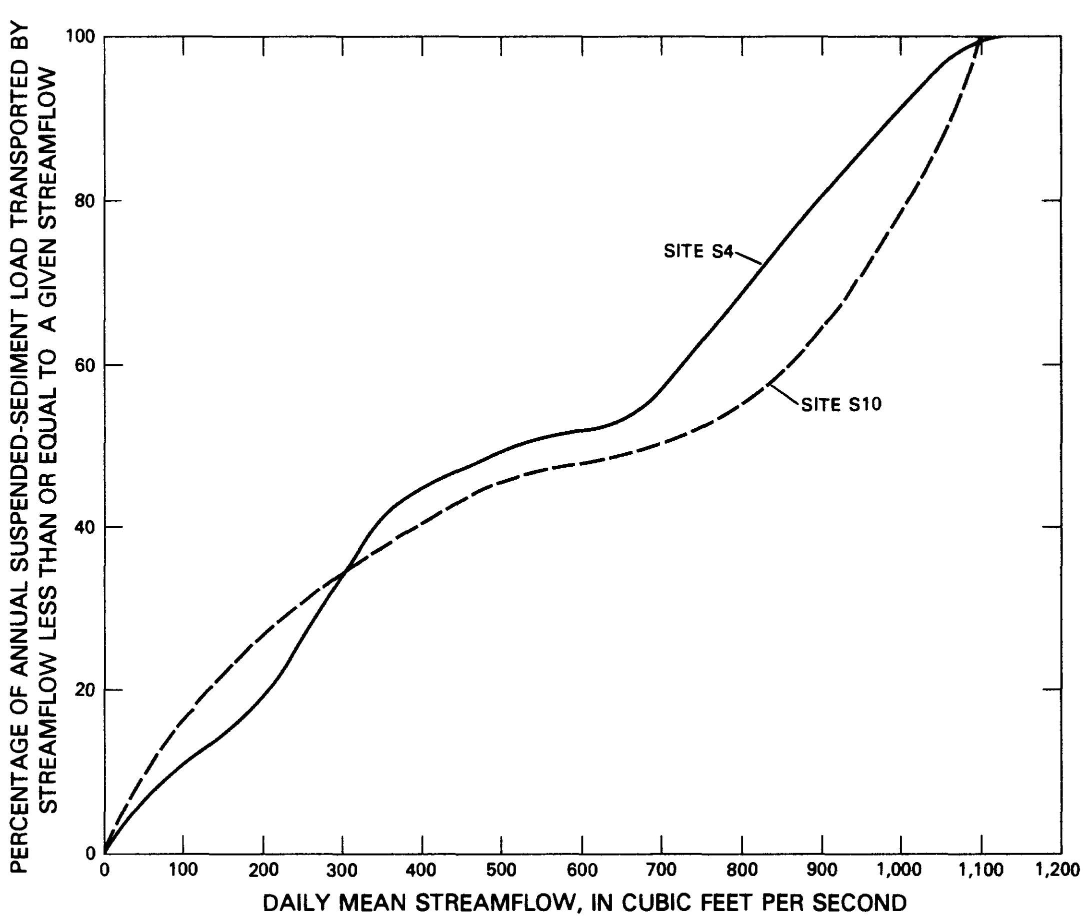


Figure 26.--Relation between cumulative suspended-sediment load and daily mean streamflow for the streamflow-gaging stations Purgatoire River near Thatcher (site S4) and Purgatoire River at Rock Crossing, near Timpas (site S10).

Suspended-sediment load transported at sites S5 and S9 for the 1984 and 1985 water years was about 1.1 and about 5 percent of the suspended-sediment load transported at the Purgatoire River at Rock Crossing, near Timpas (site S10) (table 18). Annual suspended-sediment load from ephemeral streams is extremely variable. This variability is indicated by suspended-sediment load at Bent Canyon Creek at mouth, near Timpas (site S9), which during the 1984 water year was 20,000 tons or about 13 percent of the annual suspended-sediment load transported at site S10. During the 1985 water year, there was no flow and therefore, no suspended-sediment load transported at site S9. Annual suspended-sediment loads during the 1984 and 1985 water years at Chacuaco Creek at mouth, near Timpas (site S8) were 10,200 and 6,020 tons or about 6 and about 2 percent of the annual suspended-sediment load transported at site S10.

Total suspended-sediment loads for the 1984 and 1985 water years were related to streamflow by computing the ratio of suspended-sediment load to streamflow. Streamflow-gaging stations on the Purgatoire River had the smallest quantity of suspended-sediment load transported per acre-foot of streamflow--4.8 tons/acre-ft at site S4 and 4.7 tons/acre-ft at site S10. Suspended-sediment load transported per acre-feet at tributary streams ranged from 14.2 tons/acre-ft at site S8 to 32.1 tons/acre-ft at site S1 (table 18).

SEDIMENT YIELDS

Effects of the semiarid climate and sedimentary geology at the Maneuver Site produce the potential for large sediment yields. Sediment yields are greatest when the effective annual precipitation is about 10 to 14 in. (fig. 27). Long-term mean annual precipitation at the Maneuver Site is 12 in. Variation in sediment yield with precipitation can be explained by the interaction of precipitation and vegetation on runoff and erosion. When annual precipitation increases from zero to about 12 in., sediment yields increase as more runoff is available to move sediment. Mitigating this process is vegetation, which becomes more abundant as precipitation increases. When annual precipitation is greater than 12 in., sediment yields decrease as vegetation cover becomes more effective in decreasing sediment movement (Schumm, 1977).

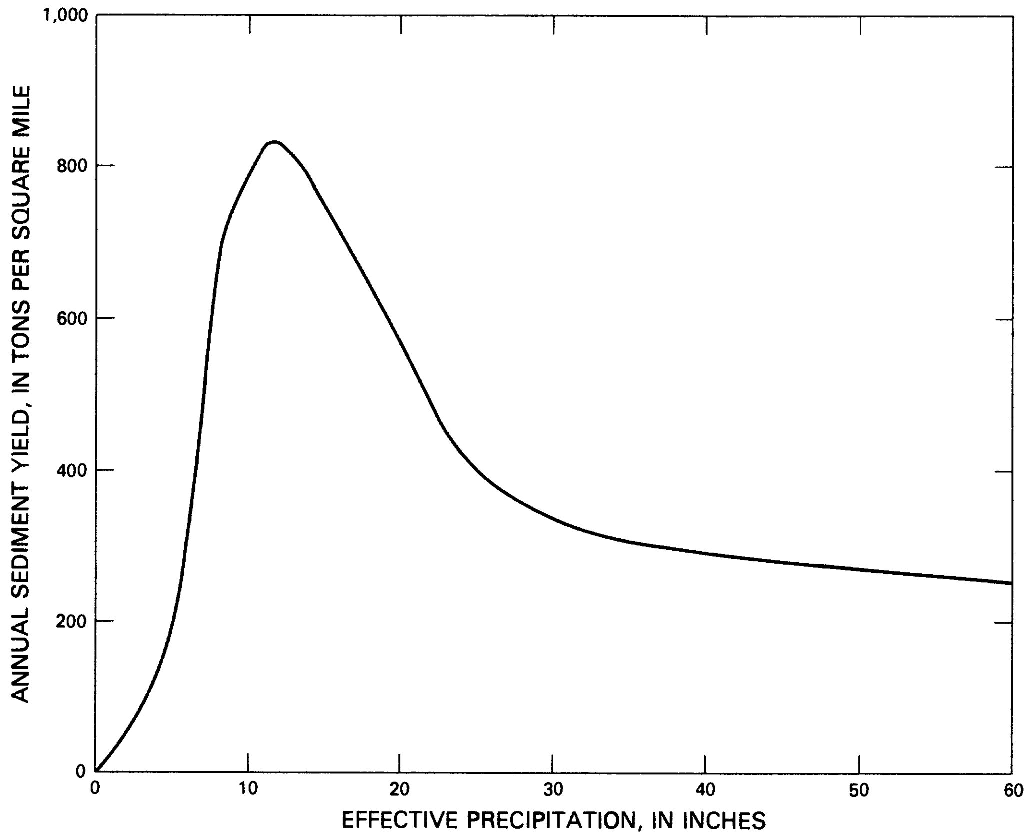


Figure 27.--Variation of sediment yield with precipitation (from Langbien and Schumm, 1958).

Sediment yield is the quantity of net eroded sediment that is transported at the mouth of a drainage basin. Sediment yields are usually much smaller than the gross quantity of sediment eroded in a drainage basin. In general, the rate at which sediment is discharged from a drainage basin is less than one-fourth the actual rate of soil erosion from the land surface (Vanoni, 1975).

Sediment Yields Measured from Stock-Watering Reservoirs

In order to determine the effects of military land use on sediment yields at the Maneuver Site, it was necessary to determine sediment yields in the area prior to any change in land use. Sediment yields were measured for the drainage basins upstream from 29 of 49 stock-watering reservoirs (table 19) (pl. 1). Twenty-two of these reservoirs are located within the boundary of the Maneuver Site and the remaining seven reservoirs are located offsite on adjacent rangeland. Stock-watering reservoirs where sediment yields were measured had drainage-basin areas that ranged from 0.06 to 1.2 mi^2 and storage capacities that ranged from 0.41 to 16.0 acre-ft.

Contour maps of deposited sediment were developed from a transit survey and the probing of sediment depths. Volume of deposited sediment was calculated using the modified prismodial formula (Heinemann and Dvorak, 1963). Bulk density samples were collected to determine the weight per unit volume of deposited sediments. In order to measure actual sediment yields, trap efficiencies were needed for each reservoir. These trap efficiencies were estimated based on the condition of the spillway and on the comparison of capacity-inflow ratios with the trap efficiency curve described by Heinemann (1981). Ages of stock-watering reservoirs were determined from interviews with previous landowners and inspection of aerial photographs available at the U.S. Soil Conservation office in Trinidad.

Annual mean sediment yield, in tons per square mile, was calculated by converting sediment volume in acre-feet to tons by applying the bulk density for each stock-watering reservoir, then dividing the total volume of sediment in tons by the size of the drainage-basin area in square miles and then dividing by the age of the reservoir in years. Calculated mean annual sediment yields were adjusted by dividing by the estimated trap efficiency for each reservoir (table 19).

Annual mean sediment yields determined at the 22 stock-watering reservoirs located on the Maneuver Site ranged from 9.5 to 1,700 tons/mi^2. Stock-watering reservoirs that have drainage basins underlain by shale had the largest measured sediment yields and an annual mean sediment yield of 588 tons/mi^2. Stock-watering reservoirs that have drainage basins underlain by sandstone and limestone had annual mean sediment yields of 186 and 68 tons/mi^2. One stock-watering reservoir has a drainage basin underlain by basalt and had an annual mean sediment yield of 302 tons/mi^2. Mean annual sediment yields determined for seven stock-watering reservoirs located adjacent to the Maneuver Site ranged from 22 to 325 tons/mi^2.

Table 19.--*Characteristics of selected stock-watering reservoirs in and near the Pinon Canyon Maneuver Site*

[--, no data]

Stock-watering reservoir number on plate 1	Drainage area (square miles)	Age (years)	Year surveyed	Inflow measured during the 1984 and 1985 water years	Capacity (acre-feet)	Year probed	Sediment volume (tons)	Estimated trap efficiency (percent)	Annual mean sediment yield	
									Tons per square mile	Acre-feet per square mile
1	0.15	31	1983	Yes	1.8	1983	152	90	36	0.02
2	.23	22	1983	Yes	5.6	1983	1,970	90	432	.14
3	.10	1	--	No	--	1985	155	100	1,550	.80
4	.23	26	1984	Yes	3.7	1984	7,880	85	1,550	.79
5	.58	33	1983	Yes	12.0	1983	4,110	90	238	.14
6	.19	28	1983	Yes	5.2	1983	3,040	80	714	.44
7	.10	18	1983	No	1.4	1985	2,760	90	1,700	.78
8	.18	--	1984	Yes	7.2	--	--	--	--	--
9	.34	--	1983	Yes	1.6	--	--	--	--	--
10	.62	31	1983	No	5.1	1983	182	100	9.5	.01
[1]11	.17	12	1984	No	4.1	1985	629	95	325	.19
[1]12	.30	17	1984	No	4.4	1985	1,120	95	231	.13
[1]13	.25	23	1984	No	4.9	1985	1,270	95	232	.13
[1]14	.37	17	1984	No	7.2	1985	1,670	85	312	.16
[1]15	.12	26	1984	No	4.5	1985	928	95	313	.16
[1]16	.65	50	1984	No	3.2	1985	685	95	22	.01
[1]17	.03	--	1983	No	3.8	--	--	--	--	--
[1]18	.31	--	1984	No	4.2	--	--	--	--	--
[1]19	.17	33	1983	Yes	4.6	1983	1,080	95	203	.14
[1]20	.71	--	1984	No	7.3	--	--	--	--	--
21	.21	--	1983	No	7.7	--	--	--	--	--
22	1.6	--	1984	Yes	.92	--	--	--	--	--
23	.36	9	1983	Yes	16	1983	1,530	100	472	.38
24	1.2	33	1983	Yes	8.5	1983	413	100	10	0.01
25	.19	16	1983	No	.79	1983	1,880	95	651	.31
26	.20	22	1983	No	4.0	1983	2,800	95	670	.41
27	.11	22	1983	Yes	3.1	1983	1,680	95	731	.47
28	.19	22	1983	Yes	1.6	1983	1,200	95	302	.17
29	.18	22	1983	Yes	.41	1983	628	95	167	.08
30	.17	--	1983	No	2.9	--	--	--	--	--
31	.11	--	1983	No	.25	--	--	--	--	--
32	.03	--	1983	No	.37	--	--	--	--	--
33	.67	--	1983	No	23.7	--	--	--	--	--
34	.29	11	1983	Yes	2.5	1983	775	95	256	.13
35	1.1	33	1983	Yes	4.9	1983	771	95	22	.02
36	.66	29	1983	Yes	1.2	1984	859	85	53	.03
37	.98	30	1983	No	.77	1985	757	95	27	.02
38	.10	13	1983	No	4.1	1983	364	100	280	.17
39	.20	--	1983	No	3.5	--	--	--	--	--
40	.38	--	1984	Yes	11.4	--	--	--	--	--
41	.51	--	1983	Yes	2.9	--	--	--	--	--
42	.08	--	1983	Yes	3.9	--	--	--	--	--
43	.14	--	1985	Yes	2.1	--	--	--	--	--
44	.13	--	1983	Yes	2.8	--	--	--	--	--
45	.13	25	1983	No	1.4	1983	2,290	90	783	.38
46	.08	--	1983	Yes	5.8	--	--	--	--	--
47	.25	33	1983	Yes	15.5	1983	3,220	100	390	.20
48	.20	--	1985	Yes	1.5	--	--	--	--	--
49	.20	--	1985	No	3.0	--	--	--	--	--

[1]Stock-watering reservoir located off the Pinon Canyon Maneuver Site.

Estimating Sediment Yields

Measuring sediment yields in the semiarid environment is difficult because of temporal and spatial variability of surface runoff. Where changes in land use portend changes in sediment yields, the ability to predict these changes is essential to land-use managers. Two methods for estimating sediment yields are discussed in the following sections. The first technique is quantitative, and annual mean sediment yields are estimated using drainage-basin characteristics. The second technique is qualitative, and sediment yields are estimated using a rating system in which numeric values are assigned to certain geologic, topographic, land-use, and hydrologic characteristics of a drainage basin.

Estimating Sediment Yields Using Drainage-Basin Characteristics

The physical characteristics of a drainage basin affect sediment yields from that drainage basin. Sediment yields have been expressed as a function of drainage-basin characteristics using multivariate techniques. It is necessary to use several variables in the analysis because drainage-basin characteristics are interrelated, and no single variable will account for a large percentage of the variation in sediment yield (Gregory and Walling, 1973).

A multiple-regression model was developed using a forward selection stepwise regression procedure (Statistical Analysis System Institute, 1985). Data were log transformed (natural logarithm, base e) and entered in the model at a 5-percent significance level. The multiple-regression model estimates the mean response of the dependent variable (annual mean sediment yield) given known values of the independent variables. The form of the multiple-regression models is a linear function of logarithmic-transformed variables:

$$l_n\, Y = l_n\, B_0 + B_1\, l_n\, X_1 + B_2\, l_n\, X_2 + \ldots + B_p\, l_n\, X_p . \qquad (5)$$

Taking the antilogs, the form of the multiple-regression models becomes multiplicative:

$$Y = B_0\, X_1^{B_1}\, X_2^{B_2} \ldots X_p^{B_p} , \qquad (6)$$

where Y = mean annual sediment yield,
B = regression coefficients,
X = geomorphic or hydrologic variables, and
p = number of independent variables in the model.

A transformation bias occurs when the logarithm of the estimated mean response (ln of annual mean sediment yield) is detransformed (eq. 6). This transformation bias usually results in underestimation of the detransformed mean response (annual mean sediment yield). For estimates of the detransformed mean response, transformation bias is multiplicative and increases exponentially with variance. It is possible, however, to eliminate the major part of this transformation bias by multiplying the estimated annual mean sediment yield by a correction factor:

$$C_b = e^{0.5\ MSE} \tag{7}$$

where C_b = transformation bias correction factor;
e = base of the natural logarithm; and,
MSE = mean squared error of the regression model (Miller, 1984).

Basin characteristics that were considered as independent variables and that were used to predict mean annual sediment yields were:

1. Drainage area: The area of a stream or river basin in square miles measured in a horizontal plane that is enclosed by a topographic divide. Planimetered from U.S. Geological Survey topographic quadrangle maps, scale 1:24,000.
2. Basin slope: Average land slope from length of contours, computed by multiplying the total length of all contours in the basin by the contour interval and then dividing by the drainage area. Contours were measured from U.S. Geological Survey topographic quadrangle maps, scale 1:24,000. Reported in dimensionless units.
3. Basin width: Average width of the basin in miles, determined by dividing the drainage area by the drainage length.
4. Surface geology: Predominant surface rocks that occur in the basin. Determined by an onsite inspection.
5. Gully length: The length of the channel in stream miles upstream from the basin outlet, including tributaries, combining discontinuous and continuous gullies. Measured during onsite surveys.
6. Percent total cover: Total cover in the basin including vegetation, bedrock, and large rock fragments. Determined using transects that contained from 100 to 300 points depending upon the size of the drainage basin.
7. Channel slope: The slope of the main channel computed from the difference in streambed elevation at points 10 percent and 85 percent of the distance along the main channel from the outlet to the basin divide. Determined from U.S. Geological Survey topographic quadrangle maps, scale 1:24,000. Reported in dimensionless units.
8. Drainage-form factor: Drainage area divided by basin length squared. Reported in dimensionless units.
9. Relief ratio: Basin relief divided by basin length. Reported in dimensionless units.

Drainage area, gully length, and drainage-form factor provided the best estimate of mean annual sediment yield. Linear regression of log-transformed data resulted in the equation:

$$YT = [(227\ (D+1)^{-4.92}(G+1)^{3.07}(FF+1)^{1.72})]\ C_b, \tag{8}$$

$$N = 28,\ R^2 = 0.81,\ SE = 73,\ C_b = 1.24$$

where: YT = mean annual sediment yield, in tons per square mile;
D = drainage area, in square miles;
G = gully length, in miles;
FF = drainage-form factor, in dimensionless units;
C_b = log transformation bias correction factor (Miller, 1984);
N = number of observations;
R^2 = coefficient of determination; and
SE = standard error of estimate, in average percent.

The R^2 value indicates that 81 percent of the variation in sediment yields can be explained by the basin characteristics of drainage area, gully length, and drainage-form factor.

Sediment yields decrease with an increase in drainage area because the opportunity for deposition of sediments increases within the basin. The negative exponent associated with drainage area in the equation indicates this inverse relation. Sediment yield also is dependent on the transport efficiency of the channel network (Hadley and Shown, 1976). As gully length increases, there is greater opportunity for conveyance of sediment from a basin. Existing gullies also provide additional sediment sources through exposed erosional surfaces on headcuts and gully walls. Drainage-form factor is an expression of basin shape (Gregory and Walling, 1973). Basin shape can affect the proximity of eroded sediment to conveyance channels and subsequently the basin outlet. Drainage-form factors ranged from 0.11 to 0.96. Small values represent greater watershed length relative to drainage area. Drainage-form factor has a positive correlation with sediment yield indicating that with a decrease in drainage length relative to drainage area, sediment yields increase.

Estimating Sediment Yields Using the Pacific Southwest Inter-Agency Committee Method

A qualitative method for estimating sediment yields in the semiarid southwest was developed by the Pacific Southwest Inter-Agency Committee (1968) or PSIAC. The PSIAC method considers nine factors that affect sediment yields; these are: (1) Surface geology, (2) soils, (3) climate, (4) runoff, (5) topography, (6) ground cover, (7) land use, (8) upland erosion, and (9) channel erosion and sediment transport. Each factor is given a numerical rating based on those listed in table 20. The sum of these numerical ratings then is compared with the rating column in table 21, which corresponds to a range of annual sediment yields in acre feet per square mile. Numerical values assigned to each drainage-basin condition, and the estimated annual mean sediment yield, in acre-feet per square mile, are listed in table 22.

The PSIAC guidelines recommend this method be used for drainage basins that are no smaller than 10 mi^2. However, Shown (1970) reported that sediment-yield estimates compared favorably with measured sediment yields in basins ranging in size from 0.02 to 7.1 mi^2. Sediment-yield data obtained from 28 stock-watering reservoirs (stock-watering-reservoir number 3 was excluded from this analysis) that have drainage-basin areas that range from 0.10 to 1.20 mi^2 were compared with PSIAC estimates for their respective basins (fig. 28). Estimated annual mean sediment yields generally were larger

Table 20.--*Factors for estimating annual mean sediment yield*

[Method based on Pacific Southwest Inter-Agency Committee (1968)]

Sediment yield levels	Surface geology	Soils	Climate	Runoff	Topography	Ground cover	Land use	Upland erosion	Channel erosion and sediment transport
High	[1](10) a. Marine shales and related mudstones and siltstones. b. Single grain silts and fine sands.	(10) a. Fine textured; easily dispersed; saline-alkaline; high shrinkswell characteristics. b. Frequent intense convective storms. c. Freeze-thaw occurrence.	(10) a. Storms of several days of duration with short periods of intense rainfall.	(10) a. High peak flows per unit area. b. Large volume of flow per unit area.	(20) a. Steep upland slopes (in excess of 30 percent), high relief; little or no floodplain development.	(10) Ground cover does not exceed 20 percent. a. Vegetation sparse; little or no litter. b. No rock in surface soil.	(10) a. More than 50 percent cultivated. b. Almost all of area intensively grazed. c. All of area recently burned.	(25) a. More than 50 percent of the area characterized by rill and gully or landslide erosion.	(25) a. Eroding banks continuously or at frequent intervals with large depths and long flow duration. b. Active headcuts and degradation in tributary channels.
Moderate[2]	(5) a. Rocks of medium hardness. b. Moderately weathered. c. Moderately fractured.	(5) a. Medium textured soil. b. Occasional rock fragments. c. Caliche layers.	(5) a. Storms of moderate duration and intensity. b. Infrequent convective storms.	(5) a. Moderate peak flows. b. Moderate volume of flow per unit area.	(10) a. Moderate upland slopes (less than 20 percent). b. Moderate fan or floodplain development.	(0) Cover not exceeding 40 percent. a. Noticeable litter. b. If trees present, understory not well developed.	(0) a. Less than 25 percent cultivated. b. Fifty percent or less recently logged. c. Less than 50 percent intensively grazed. d. Ordinary road and other construction.	(10) a. About 25 percent of the area characterized by rill and gully or landslide erosion. b. Wind erosion with deposition in stream channels.	(10) a. Moderate flow depths, medium flow with occasionally eroding banks or beds.
Low[2]	(0) a. Massive, hard formations.	(0) a. High percentage of rock fragments. b. Aggregated clays. c. High in organic matter.	(0) a. Humid climate with rainfall of low intensity. b. Precipitation in form of snow. c. Arid climate; low intensity storms. d. Arid climate; rare convective storms.	(0) a. Low peak flows per unit area. b. Low volume of runoff per unit acre. c. Rare runoff events.	(0) a. Gentle upland slopes (less than 5 percent). b. Extensive alluvial plains.	(-10) a. Area completely protected by vegetation; rock fragments, litter; little opportunity for rainfall to reach erodible	(-10) a. No cultivation. b. No recent logging. c. Low intensity grazing.	(0) a. No apparent signs of erosion.	(0) a. Wide shallow channels with flat gradients, short flow duration. b. Channels in massive rock; large boulders or well vegetated. c. Artificially controlled channels.

[1]The numbers in specific boxes indicate values to be assigned appropriate characteristics. The small letters a, b, and c, refer to independent characteristics to which full value may be assigned.

[2]If experience so indicates, interpolation between the three sediment-yield levels may be made.

Table 21.--*Rating conversions used for estimating annual mean sediment yield*

[Rating conversions based on Pacific Southwest Inter-Agency Committee method (1968)]

Rating	Sediment yield (acre-feet per square mile)
100	3.0
75-100	1.0-3.0
50-75	0.5-1.0
25-50	0.2-0.5
0-25	0.2

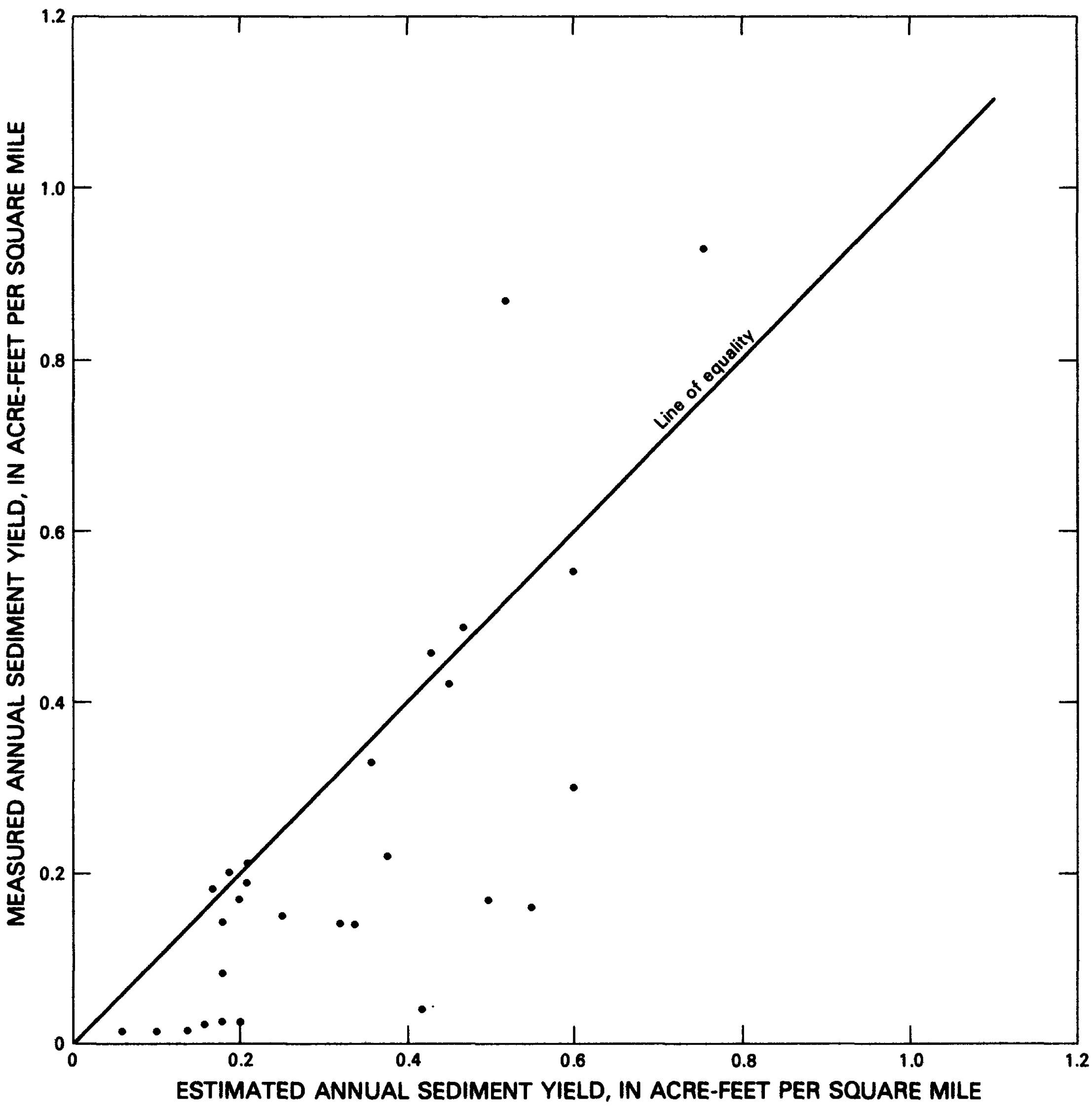


Figure 28.--Relation between measured annual mean sediment yields and estimated annual mean sediment yields using the Pacific Southwest Inter-Agency Committee (PSIAC) method.

Table 22.--*Values used for estimating annual mean sediment yields using the Pacific Southwest Inter-Agency Committee method in small drainage basins in and near the Pinon Canyon Maneuver Site*

Stock-watering reservoir number on plate 1 and in table 21	Geology	Soils	Climate	Runoff	Topography	Ground cover	Land use	Upland erosion	Channel erosion and sediment transport	Total	Estimated mean annual sediment yield (acre-feet per square mile)
1	5	5	5	0	0	-2	5	2	10	30	.26
2	5	4	5	3	4	5	10	9	8	53	.56
4	10	7	5	2	8	3	9	9	5	58	.66
5	5	6	5	3	12	2	0	13	7	53	.56
6	3	4	5	5	15	-2	0	10	12	52	.54
7	8	7	5	4	8	1	3	15	3	54	.58
10	3	5	5	0	0	-5	0	3	0	11	.09
11	3	3	5	3	0	0	5	5	0	24	.19
12	3	3	5	1	5	0	6	10	2	35	.32
13	5	2	5	3	3	-4	2	2	2	20	.16
14	5	2	5	5	3	-2	0	3	3	24	.19
15	0	4	5	5	2	0	0	5	5	26	.20
16	0	2	5	0	0	-2	0	2	0	7	.06
19	5	4	5	4	3	0	-5	3	7	26	.21
23	3	3	5	3	0	0	0	5	8	27	.22
24	5	5	5	2	0	-5	2	3	0	17	.14
25	3	5	5	2	3	5	8	5	2	38	.36
26	4	4	5	3	4	1	10	6	6	43	.42
27	5	6	5	2	6	5	10	6	3	48	.48
28	1	1	5	2	8	-4	-4	5	5	19	.17
29	3	3	5	3	3	-2	-5	5	8	23	.18
34	4	5	5	5	9	-3	0	6	5	36	.33
35	5	3	5	0	2	0	5	3	1	24	.19
36	5	8	5	3	0	5	7	6	5	44	.43
37	0	7	5	0	0	3	3	5	0	23	.18
38	5	7	5	2	0	6	10	8	7	50	.50
45	5	4	5	6	6	1	2	9	8	46	.45
47	5	5	5	3	1	-1	3	5	2	28	.24

than the measured annual mean sediment yields determined from stock-watering reservoirs. The overestimates may be explained by estimator bias that affects the subjectivity of the technique. Also, PSIAC estimates represent the effects of the current basin conditions on sediment yields. Measured sediment yields from the stock-watering reservoirs integrate conditions for a period of years, during which time the physical characteristics of each basin have not been static but have been evolving into their present condition.

SUMMARY

The U.S. Department of the Army has acquired 381 mi^2 of semiarid rangeland in southeastern Colorado for mechanized military maneuvers. The U.S. Geological Survey was directed by the U.S. Congress to collect background hydrologic information at the U.S. Army Pinon Canyon Maneuver Site. A multi-disciplined hydrologic investigation began in October 1982. As part of the ground-water investigation, 114 wells and springs were inventoried and water-quality samples were collected at 24 wells and 1 spring. Streamflow and water-quality data were collected at 11 streamflow-gaging stations in and near the Maneuver Site. Suspended-sediment data were collected at six streamflow-gaging stations. Storage capacities of 48 stock-watering reservoirs were surveyed, and sediment volumes and sediment yields were determined at 29 of these reservoirs.

The primary aquifer at the Maneuver Site is the Dakota-Purgatoire aquifer. The Dakota-Purgatoire aquifer has been a source of water for a few domestic wells and many stock-watering wells. On the Maneuver Site, recharge to the aquifer is primarily from precipitation and subsurface inflow from adjoining areas. Where outcrop areas are traversed by ephemeral streams, occasional flood flows provide some local recharge of very limited extent. Discharge from the aquifer is by well pumpage, spring flow, evapotranspiration, and ground-water flow. On the basis of 16 aquifer tests, values of transmissivity ranged from 14 to 882 ft^3/d, and values of storage coefficient ranged from 0.0001 to 0.10.

Wells in the Dakota-Purgatoire aquifer have yields that generally range from 10 to 500 gal/min. On the basis of periodic measurements made at eight wells during the 1985 water year, water levels in the aquifer are not fluctuating to a great extent. Only two of the wells had water-level changes greater than 1 ft.

Water-quality samples from the Dakota-Purgatoire aquifer have large concentrations of dissolved solids and extremely large dissolved-iron concentrations at certain wells. Primary and secondary drinking-water standards for dissolved solids were exceeded at 84 percent of the ground-water sites sampled. Secondary drinking-water standards for dissolved iron were exceeded at 64 percent of the ground-water sites sampled. Ground-water-quality samples indicated that ground water in the area of the Maneuver Site has naturally large concentrations of radiochemicals. Samples collected from two wells used for domestic purposes exceeded the primary drinking-water standard of 15 pCi/L for gross alpha radiation and the primary drinking-water standard of 5 pCi/L for radium-226.

Existing streamflow-gaging stations 07126200, Van Bremer Arroyo near Model (site S3) and 07126300, Purgatoire River near Thatcher (site S4) were incorporated into a network of 11 streamflow-gaging stations to monitor streamflow in and around the Maneuver Site. Streamflow in the Purgatoire River is perennial. Snowmelt runoff, intense rainfall, and reservoir releases affect increases in streamflow in the Purgatoire River. The majority of the streamflow from the Maneuver Site results from rainfall runoff during May through October. Tributary streams to the Purgatoire River that drain the Maneuver Site are intermittent or ephemeral. Base streamflow, usually less than 0.50 ft^3/s, is sustained by ground-water seepage and is typical of the intermittent streams located near the canyon rim of the Purgatoire River. During the 1984 and 1985 water years, streamflow in tributaries was about 3,760 acre-ft, or about 4.4 percent of the streamflow at the Purgatoire River at Rock Crossing, near Timpas (site S10). About 64 percent of the tributary streamflow was derived from Van Bremer Arroyo near Model (site S3) of which 88 percent resulted from irrigation-return flow. The remainder of the tributary streamflow resulted from rainfall runoff and base streamflow sustained by ground-water storage.

Flow-duration analysis of daily mean streamflow was done at Van Bremer Arroyo near Model (site S3) and at Purgatoire River near Thatcher (site S4). On the basis of long-term periods of record, the annual mean streamflow of 2.4 ft^3/s at site S3 is equaled or exceeded about 4 percent of the time, but daily mean streamflows greater than 0.70 ft^3/s are quite variable and usually result from rainfall runoff; the annual mean streamflow of 84 ft^3/s at site S4 is equaled or exceeded about 20 percent of the time, but daily mean streamflows less than 20 ft^3/s are quite variable and indicate a limited source of flow from ground-water storage.

Flood estimates for recurrence intervals of 10, 50, and 100 years were made for the two streamflow-gaging stations that have long-term periods of record--Van Bremer Arroyo near Model (site S3) and Purgatoire River near Thatcher (site S4). Estimates of flood frequency derived from long-term station records using the log-Pearson III analysis compared well with those obtained using a regional estimating techniques developed by McCain and Jarrett (1976). The regional estimating technique is considered fairly reliable for estimating flood discharges in streams in and near the Maneuver Site that have effective drainage areas greater than 75 mi^2.

Inflow was measured at 25 stock-watering reservoirs that represent small watersheds that have drainage-basin areas ranging from 0.08 to 1.6 mi^2. Data collected include inflow, inflow stored, and reservoir spill.

Water-quality data were presented for 7 of the 11 streamflow-gaging stations. Samples collected were analyzed for water-quality properties and constituents used by the Colorado Department of Health to classify the Purgatoire River. Time-series plots indicated that nitrate and metal concentrations exceeded instream water-quality standards. Dissolved solids present in the surface water predominantly are composed of calcium, magnesium, and sulfate ions. Dissolved-solids loads were computed for Van Bremer Arroyo near Model (site S3), the Purgatoire River near Thatcher (site S4), and the Purgatoire River at Rock Crossing, near Timpas (site S10). Dissolved-solids load for the 1985 water year at Van Bremer Arroyo near Model (site S3) was 2,140 tons, or about 2 percent of the dissolved-solids load transported at the Purgatoire River near Thatcher (site S4). Dissolved-solids load for the 1985 water year was 107,000 tons at site S4 and was 106,000 tons at the Purgatoire River at Rock Crossing, near Timpas (site S10). Dissolved-solids load estimated for four ephemeral streams during the 1985 water year was about 48 tons, or about 0.05 percent of the dissolved-solids load transported at the Purgatoire River at Rock Crossing, near Timpas (site S10).

Annual suspended-sediment load was computed at six sites in and near the Maneuver Site. Floods originating from rainfall runoff transport the majority of suspended sediment. During the 1984 and 1985 water years, suspended-sediment loads at tributaries were about 22 and about 3 percent of the suspended-sediment load transported at the Purgatoire River at Rock Crossing, near Timpas (site S10).

Sediment-yield data were collected for 29 small stock-watering reservoirs. The drainage-basin areas of these reservoirs ranged from 0.06 to 1.2 mi^2 and had annual mean sediment yields that ranged from 9.5 to 1,700 $tons/mi^2$. Sediment yields were largest from drainage basins that are underlain by shale. A multiple-regression model was developed that predicts sediment yields using physical drainage-basin characteristics. Drainage area, gully length, and drainge-form factor were the drainage-basin characteristics that best predicted annual mean sediment yields.

Sediment yields also were estimated by using the Pacific Southwest Inter-Agency Committee (1968) method in all but one drainage basin where sediment yields were measured. Estimated annual mean sediment yields tended to be larger than measured annual mean sediment yields; this is attributed to the subjectivity of the estimate and the assumption of static, long-term, land-use and climatic conditions within the drainage basin.

REFERENCES CITED

Bass, N.W., 1947, Structure-contour map of the surface rocks of the Model anticline, Las Animas County, Colorado: U.S. Geological Survey Oil and Gas Investigations Preliminary Map 68, scale 1:84,500, 1 sheet.

Coffin, D.L., 1967, Geology and ground-water resources of the Big Sandy Creek Valley, Lincoln, Cheyenne, and Kiowa Counties, Colorado: U.S. Geological Survey Water-Supply Paper 1843, 49 p.

Colorado Climate Center, 1984, Colorado average precipitation map 1951-1980: scale 1:500,000.

Colorado Department of Health, 1977, Primary drinking water regulations for the State of Colorado: Denver, Colorado, 56 p.

_____1982, Classifications and numeric standards, Arkansas River Basin: Colorado Department of Health, Water Quality Control Commission, 59 p.

Crouch, T.M., Cain, Doug, Abbott, P.O., Penley, R.D., and Hurr, R.T., 1984, Water-resources appraisal of the upper Arkansas River basin from Leadville to Pueblo, Colorado: U.S. Geological Survey Water-Resources Investigations Report 82-4114, 123 p.

Culler, R.C., 1961, Hydrology of the upper Cheyenne River basin: U.S. Geological Survey Water-Supply Paper 1531-A, 136 p.

Dalrymple, Tate, 1960, Flood frequency analysis: Manual of hydrology, part 3, flood flow techniques: U.S. Geological Survey Water-Supply Paper 1543-A, 77 p.

Dalrymple, Tate, and Benson, M.A., 1967, Measurement of peak discharge by the slope-area method: U.S. Geological Survey Techniques of Water-Resources Investigations, bk. 3, chap. A2, 12 p.

Drever, J.I., 1982, The geochemistry of natural waters: Englewood Cliffs, New Jersey, Prentice-Hall, 388 p.

Femlee, J.K., and Cadigan, R.A., 1979, Radium and uranium concentrations and associated hydrogeochemistry in groundwater in southwestern Pueblo County, Colorado: U.S. Geological Survey Open-File Report 79-974, 59 p.

Fenneman, N.M., 1931, Physiography of western United States: New York, McGraw-Hill, 534 p.

Gregory, K.T., and Walling, D.E., 1973, Drainage basin form and process: New York, John Wiley and Sons, 458 p.

Hadley, R.F., and Shown, L.M., 1976, Relation of erosion to sediment yield: Third Inter-Agency Sedimentation Conference, Denver, 1976, Proceedings, Water Resources Council Sedimentation Committee, p. 1-131-1-139.

Heinemann, H.G., 1981, A new sediment trap efficiency curve for small reservoirs: Water Resources Bulletin, v. 17, no. 5, p. 825-830.

Heinemann, H.G., and Dvorak, V.I., 1963, Improved volumetric survey and computation procedures for small reservoirs: Federal Inter-Agency Sedimentation Conference, Denver, 1963, Proceedings, U.S. Department of Agriculture Miscellaneous Publication no. 970, p. 845-856.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water (3d ed.): U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Hutchison, N.E., Compiler, 1975 WATSTORE users guide, volume 1: U.S. Geological Survey Open-File Report 75-426, 708 p.

Johnson, R.B., 1969, Geologic map of the Trinidad quadrangle, south-central Colorado: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-558, scale 1:250,000, 1 sheet.

Langbien, W.B., and Schumm, S.A., 1958, Yield of sediment in relation to mean annual precipitation: American Geophysical Union Transactions, v. 39, p. 1076-1084.

Leonard, G.J., 1984, Assessment of water resources at Fort Carson Military Reservation near Colorado Springs, Colorado: U.S. Geological Survey Water-Resources Investigations Report 83-4270, 78 p.

Livingston, R.K., 1981, Rainfall runoff modeling and preliminary regional flood characteristics of small rural watersheds in the Arkansas River basin in Colorado: U.S. Geological Survey Water-Resources Investigations Report 80-112, 40 p.

Livingston, R.K., Klein, J.M., and Bingham, D.L., 1976, Appraisals of water resources of southeastern El Paso County, Colorado: Denver, Colorado, Water Conservation Board, Colorado Water Resources Circular No. 33, 66 p.

Livingston, R.K., and Minges, D.R., 1987, Techniques for estimating regional flood characteristics of small rural watersheds in the plains region of eastern Colorado: U.S. Geological Survey Water-Resources Investigations Report 87-4904, 72 p.

Lusby, G.C., 1970, Hydrologic and biotic effects of grazing versus nongrazing near Grand Junction, Colorado: U.S. Geological Survey Research 1970, p. B232-B236.

Mark, Anson, and Requist, Norris, 1969, First day's road log--Trinidad to Walsenburg and return to Trinidad--Mesozoic and Tertiary of the east flank of the Raton Basin, *in* the Mountain Geologist: Denver, Rocky Mountain Association of Geologists, v. 6, no. 3, p. 149-164.
McCain, J.F., and Jarrett, R.D., 1976, Manual for estimating flood characteristics of natural-flow streams in Colorado: Colorado Water Conservation Board Technical Manual No. 1, 68 p.
McLaughlin, T.G., 1954, Geology and ground-water resources of Baca County, Colorado: U.S. Geological Survey Water-Supply Paper 1256, 232 p.
_____1966, Ground water in Huerfano County, Colorado: U.S. Geological Survey Water-Supply Paper 180S, 91 p.
Miller, D.M., 1984, Reducing transformation bias in curve fitting: The American Statistician, v. 38, no. 2, p. 124-126.
Miller, J.F., Frederick, R.H., and Tracey, R.J., 1973, Precipitation-frequency atlas of the western United States, v. III, Colorado: National Oceanic and atmospheric Administration, 67 p.
National Academy of Sciences, National Academy of Engineering, 1972 (1973), Water quality criteria, 1972: Washington, D.C., U.S. Government Printing Office, 594 p.
Pacific Southwest Inter-Agency Committee, 1968, Report on factors affecting sediment yield in the Pacific Southwest area: Water Management Subcommittee, Sedimentation Task Force, 10 p.
Porterfield, George, 1972, Computation of fluvial sediment discharge: U.S. Geological Survey Techniques of Water-Resources Investigations, bk. 3, chap. C3, 66 p.
Robson, S.G. and Banta, E.R., 1987, Geology and hydrology of the deep bedrock aquifers in eastern Colorado: U.S. Geological Survey Water-Resources Investigations Report 85-4240, scale 1:500,000, 6 sheets.
Schumm, S.A., 1977, The fluvial system: New York, John Wiley and Sons, 335 p.
Scott, G.R., 1968, Geologic and structure contour map of the La Junta quadrangle, Colorado and Kansas: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-560, scale 1:250,000, 1 sheet.
Searcy, J.K., 1959, Flow-duration curves: U.S. Geological Survey Water-Supply Paper 1542-A, 33 p.
Shown, L.M., 1970, Evaluation of a method for estimating sediment yield *in* Geological Survey Research 1970: U.S. Geological Survey Professional Paper 700-B, p. B245-B249.
Snipes, R.J., and others, 1974, Floods of June 1965 in Arkansas River basin, Colorado, Kansas, and New Mexico: U.S. Geological Survey Water-Supply Paper 1850-D, 94 p.
Statistical Analysis System Institute, 1985, SAS users guide--Statistics (5th ed.): Cary, North Carolina, SAS Institute, Inc., 956 p.
Thatcher, L.L., Janzer, V.J., and Edwards, K.W., 1977, Methods for determination of radioactive substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, bk. 5, chap. A5, 95 p.
U.S. Army Corps of Engineers, 1981, Final environmental impact statement for training land acquisition, Fort Carson, Colorado: Omaha, Nebraska, 280 p.
U.S. Department of the Interior, 1970, The national atlas of the United States of America: U.S. Geological Survey, 417 p.

U.S. Environmental Protection Agency, 1976, Quality criteria for water: Washington, D.C., U.S. Government Printing Office, 256 p.

_____1986a, Maximum contaminant levels (subpart B of part 141, national interim primary drinking-water regulations): U.S. Code of Federal Regulations, Title 40, Parts 100 to 149, revised as of July 1, 1986, p. 524-528.

_____1986b, Secondary maximum contaminant levels (section 143.3 of part 143, national secondary drinking-water regulations): U.S. Code of Federal Regulations, Title 40, Parts 100 to 149, revised as of July 1, 1986, p. 587-590.

U.S. Soil Conservation Service, 1983, Soils manuscript for the Pinon Canyon Maneuver Site: Trinidad, Colo., U.S. Department of Agriculture, unpublished, 157 p.

Vanoni, V.A., 1975, Sedimentation Engineering: New York, American Society of Civil Engineers, 745 p.

Voegeli, P.T., Sr., and Hershey, L.A., 1965, Geology and ground-water resources of Prowers County, Colorado: U.S. Geological Survey Water-Supply Paper 1772, 101 p.

Weist, W.G., Jr., and others, 1965, Geology and occurrence of ground water in Otero County and the southern part of Crowley County, Colorado: U.S. Geological Survey Water-Supply Paper 1799, 90 p.

Wilson, W.W., 1965, Pumping tests in Colorado: Denver, Colorado Water Conservation Board, Colorado Water Resources Circular No. 11, 361 p.

Wood, W.W., 1976, Guidelines for collection and field analysis of ground-water samples for selected unstable constituents: U.S. Geological Survey Techniques of Water-Resources Investigations, bk. 1, chap. D2, 24 p.

page 77 follows

SUPPLEMENTAL INFORMATION

System of Numbering Streamflow-Gaging Stations

Streamflow-gaging-station numbers are assigned in downstream order. Station numbers on tributaries are assigned between station numbers on the mainstream and in the order in which those tributaries enter the mainstream. The station number is the file-identification number used in storage and retrieval of station information and streamflow data from the U.S. Geological Survey.

System of Numbering Well Locations

Well locations given in this report (identified as the local identifier or local number in tables) are assigned numbers based on the U.S. Bureau of Land Management system of land subdivision and show the well locations by quadrant, township, range, section, and position in the section (fig. 29).

The first letter of the location number indicates which principal meridian governs the area in which the well is located; S indicates the sixth principal meridian and N indicates the New Mexico principal meridian. The second letter indicates the quadrant in which the well is located. Four quadrants are formed by the intersection of the base line and the principal meridian; A indicates the northeast quadrant, B the northwest, C the southwest, and D the southeast. The first number indicates the township; the second, the range; and the third, the section in which the well is located. The letters following the section number indicate the location of the well within the seciton. The first letter denotes the quarter section; the second, the quarter-quarter section; and the third, the quarter-quarter-quarter section. The letters are assigned within the section in a counterclockwise direction, beginning with A in the northeast quarter. Letters are assigned within each quarter section and within each quarter-quarter section in the same manner. Where two or more locations are within the smallest subdivision, consecutive numbers, beginning with 1, are added in the order in which the wells are inventoried. For example, SC18-66-20CCC indicates a well in the SW¼SW¼SW¼ sec. 20, T. 18 S., R. 66 W. (fig. 29).

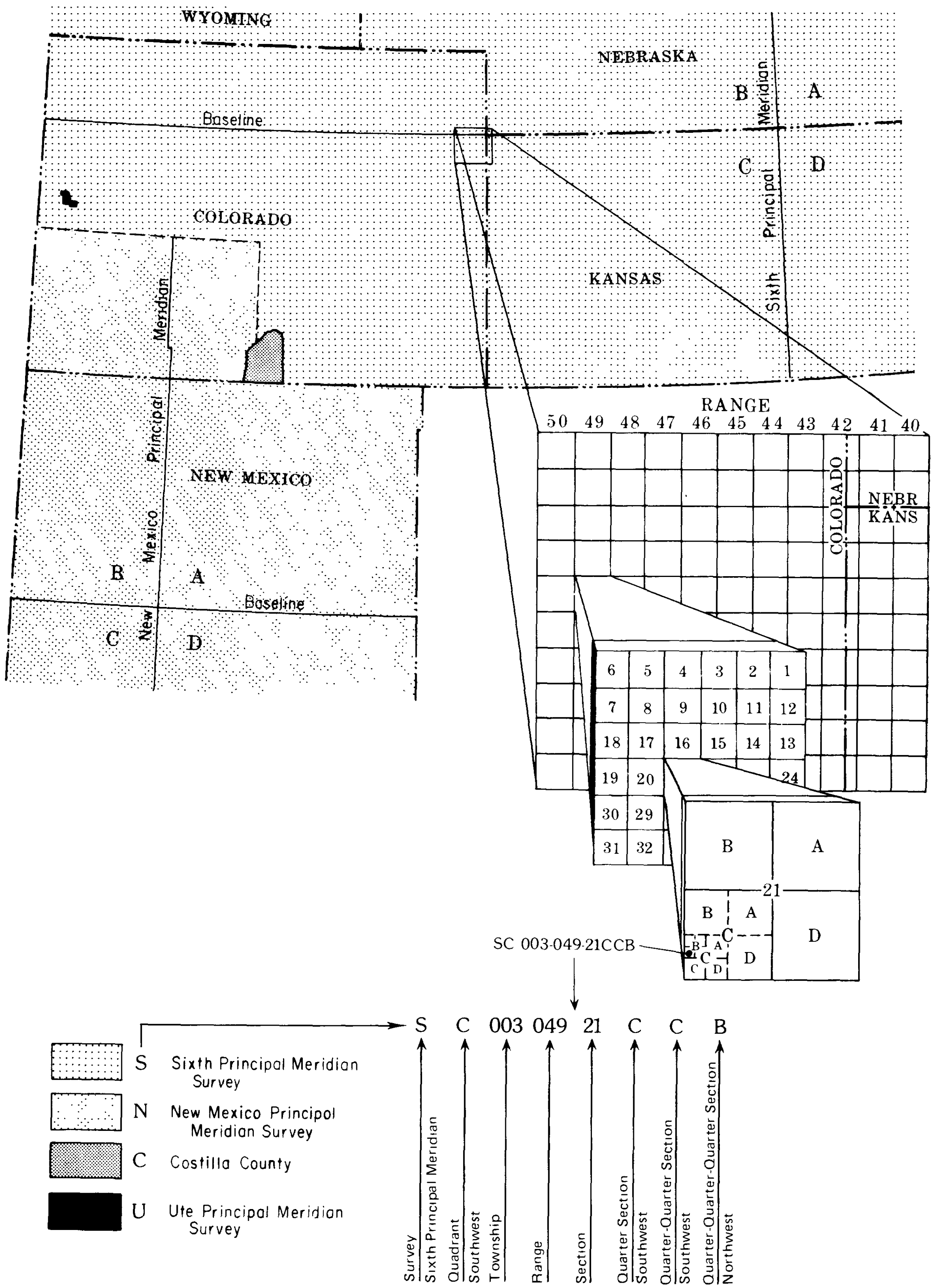


Figure 29.--System of numbering wells, using township, range, and section.

Table 23.--*Results of chemical analysis of ground-water*

[°C, degrees Celsius; μS/cm, microsiemens per centimeter at 25 °Celsius; mg/L, milligrams per liter;

Station number (as shown on plate 2)	Sample number[1]	Date of sample	Time	Temperature (°C)	Specific conductance (μS/cm)	pH, field (units)	Dissolved oxygen (mg/L)	Alkalinity, laboratory (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Chloride, dissolved (mg/L)	Sulfate, dissolved (mg/L)	Fluoride, dissolved (mg/L)
SC02805835DAA	1	02-06-86	1400	14.2	5,640	6.2	--	100	360	490	420	35	28	3,600	.1
[2]SC02905708BCD	2	11-21-84	1030	14.0	3,800	7.5	--	220	450	360	310	21	56	2,800	.8
SC02905710ABA	3	11-06-85	1255	14.5	1,560	7.5	--	260	150	68	110	5.5	60	540	1.0
SC02905728ADB2	4	11-05-85	1636	14.5	1,490	5.4	--	5	160	55	78	8.1	59	710	1.3
[3]SC02905730BDB	5	11-20-84	1630	11.5	890	6.4	--	12	86	35	54	5.3	27	410	1.0
SC02905807ABC	6	12-18-85	1620	16.0	2,030	6.2	0.0	120	150	85	170	5.8	31	1,000	<1.0
SC02905815BCA	7	08-09-84	1415	16.0	1,120	7.1	--	120	170	23	55	6.6	23	400	.5
SC02905826DCA	8	11-19-85	1440	13.0	3,240	5.5	--	52	300	190	220	1.6	36	1,900	1.4
SC03005704BBC	9	12-11-85	1250	14.5	6,250	5.6	--	30	490	430	630	15	470	3,700	9.0
SC03005707DBD	10	12-19-85	1200	15.0	5,600	6.2	7.8	86	460	230	770	2.8	330	3,100	6.2
SC03005810CCA	11	11-19-85	1125	13.0	410	7.4	--	160	42	13	88	2.0	5.2.	26	.5
SC03005826CCC	12	11-07-85	1335	15.0	4,010	3.4	--	--	120	110	200	9.2	76	2,600	--
[2]SC03005827ADA	13	11-20-84	1430	15.0	690	6.2	--	66	50	26	50	3.8	13	270	1.2
SC03005924BBC	14	12-13-85	1350	15.0	3,000	4.6	--	3	160	220	230	16	94	1,800	2.5
SC03005931DBA	15	08-14-84	1845	18.0	1,640	6.0	--	--	--	--	--	--	--	--	.4
SC03005931DBA	16	12-12-85	1520	15.0	1,980	6.4	--	230	160	96	160	14	21	940	.9
SC03005932ABC	17	08-07-84	1315	16.0	1,700	6.9	--	220	130	75	140	16	14	740	1.0
SC03005934DBD2	18	12-26-85	1445	15.8	1,720	6.9	--	220	120	75	150	13	12	720	1.0
SC03006023DAD	19	06-14-85	1530	14.5	1,990	7.1	--	240	--	--	190	14	14	960	1.1
SC03006026DBD	20	11-18-85	1430	15.0	3,830	6.7	--	240	210	350	300	11	110	2,300	1.0
[2]SC03006028DAD	21	11-20-84	1100	14.5	1,950	6.6	--	300	130	81	290	13	49	920	.7
SC03105802BBD	22	12-09-85	1450	14.0	730	6.9	--	270	95	24	28	2.1	17	79	1.0
SC03105803CBB	23	12-27-85	1245	15.0	1,700	7.1	--	250	84	57	190	20	12	620	1.4
SC03105901ABA	24	01-08-86	1250	14.7	1,690	7.1	1.4	250	93	60	200	11	14	670	1.2
SC03105904CBC	25	09-24-85	1200	15.0	1,970	7.6	--	230	130	78	200	15	14	800	1.7
SC03105908DCD	26	02-05-86	1120	16.3	1,849	7.0	2.5	330	87	58	240	15	17	680	2.0

[1]Arbitrary reference number for locations shown in figure 9.
[2]Domestic well.
[3]Spring used for domestic water supply.

from wells and a spring at the Pinon Canyon Maneuver Site

µg/L, micrograms per liter; pCi/L, picocuries per liter; susp., suspended; --, no data]

Silica, dissolved (mg/L)	Solids residue at 180 °C, dissolved (mg/L)	Nitrogen, nitrite plus nitrate, dissolved (mg/L)	Phosphorus, dissolved (mg/L as P)	Iron dissolved (µg/L)	Manganese, dissolved (µg/L)	Arsenic, dissolved (µg/L)	Selenium, dissolved (µg/L)	Gross alpha, dissolved (µg/L as U-nat)	Gross alpha, susp., total (µg/L as U-nat)	Gross beta, dissolved (pCi/L as Cs-137)	Gross beta, susp., total (pCi/L as (Cs-137)	Gross beta, dissolved (pCi/L as Sr/Yt-90)	Gross beta, susp., total (pCi/L as Sr/Yt-90)	Radium-226, dissolved, planchet count (pCi/L)	Uranium, natural, dissolved (µg/L as U)
5.6	5,870	0.10	0.01	67,000	1,200	3	1	140	--	130	--	87	--	--	--
15	4,490	9.4	<.01	70	10	--	--	<92	<0.4	<45	<0.4	<39	<0.4	1.2	6.0
11	1,130	7.1	<.01	90	35	<1	6	94	--	--	--	40	--	--	--
9.3	--	1.9	<.01	40	150	--	3	91	--	75	--	51	--	--	--
12	655	.42	.03	30	110	--	--	20	<.4	17	<.4	15	<.4	4.4	.5
7.8	--	<.10	<.01	13,000	280	<1	<1	--	--	--	--	--	--	--	--
12	--	8.1	<.01	800	22	<1	15	<23	--	14	--	12	--	--	--
15	2,890	12	<.01	10,000	440	<1	2	71	--	--	--	45	--	--	--
33	6,150	32	<.01	2,400	1,300	<1	67	290	--	140	--	90	--	--	--
14	--	37	--	6,600	60	--	--	290	--	150	--	95	--	--	--
4.7	195	<.10	<.01	320	110	4	<1	9.4	--	--	--	10	--	--	--
--	--	.10	.01	420,000	3,400	10	1	--	--	--	--	--	--	--	--
11	472	.78	.02	30	4	--	--	25	<.4	14	<.4	12	<.4	6.3	.5
8.8	2,900	.43	.01	28,000	1,200	<1	<1	92	--	59	--	34	--	--	--
--	--	<.10	<.01	--	--	<1	4	110	--	76	--	66	--	--	--
8.0	1,640	<.10	.02	1,600	96	1	<1	170	--	--	--	77	--	--	--
7.6	--	<.10	<.01	4	84	<1	<1	69	--	55	--	48	--	--	--
7.8	1,280	<.10	<.01	3,100	89	<1	<1	--	--	--	--	--	--	--	--
9.5	1,740	<.10	<.01	4,400	140	1	<1	--	--	--	--	--	--	--	--
7.8	3,540	4.4	<.01	60	200	<1	56	110	--	--	--	52	--	--	--
9.9	1,750	<.10	<.01	180	70	--	--	110	<.4	75	<.4	65	<.4	15	1.0
12	440	7.0	<.01	8	<1	<1	7	28	--	18	--	13	--	--	--
7.6	1,140	<.10	<.01	1,600	480	<1	<1	--	--	--	--	--	--	--	--
7.6	1,210	<.10	<.01	2,600	75	<1	<1	110	--	110	--	68	--	--	--
7.7	1,510	<.10	.01	12,000	150	<1	<1	--	--	--	--	--	--	--	--
7.4	1,340	.32	.01	3,800	82	2	1	150	--	93	--	61	--	--	--

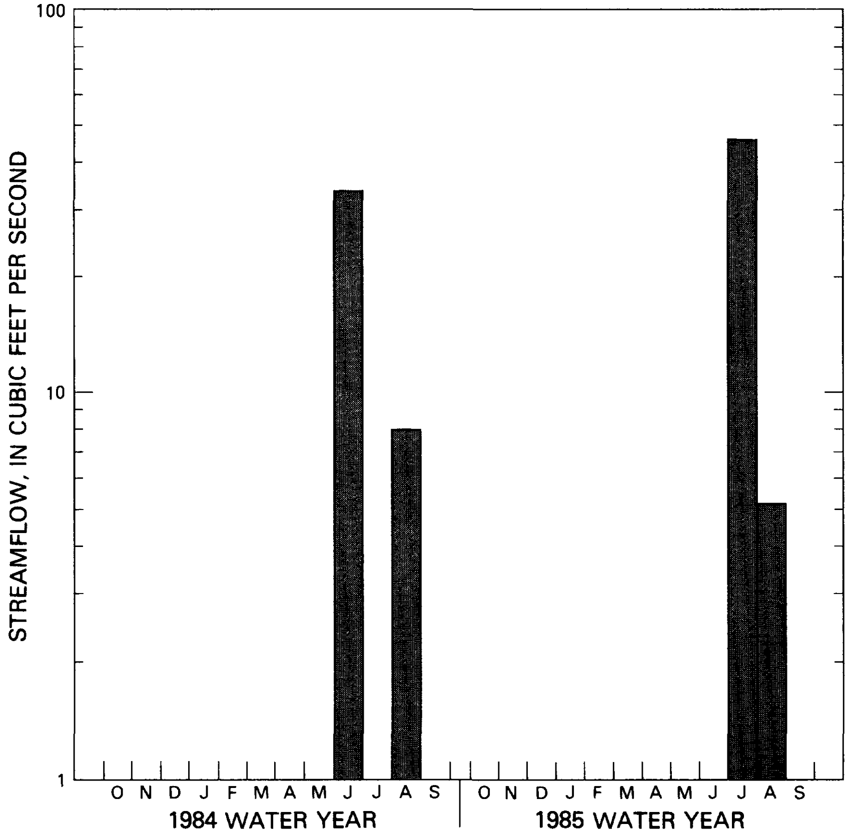


Figure 30.--Monthly streamflow for the streamflow-gaging station Big Arroyo near Thatcher (site S1), for water years 1984-85.

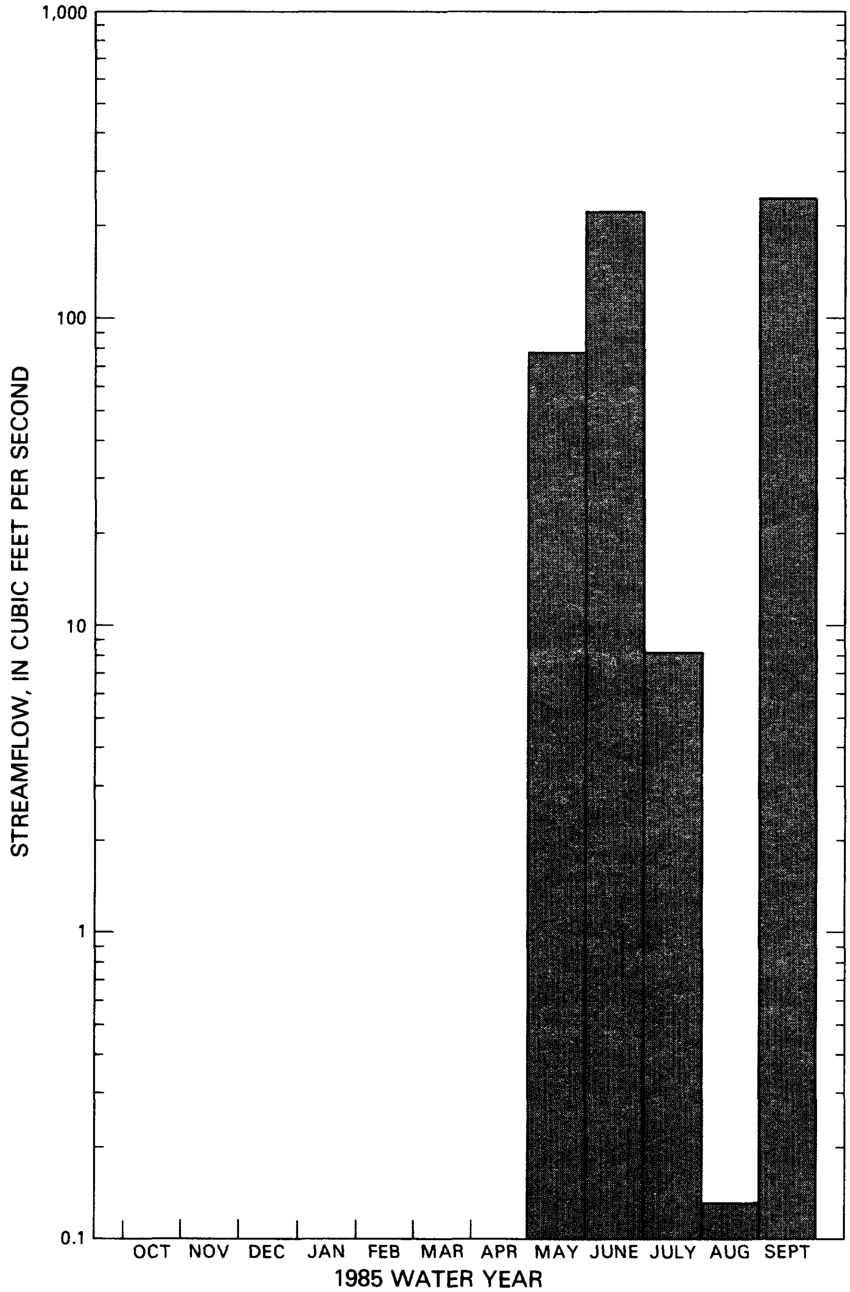


Figure 31.--Monthly streamflow for the streamflow-gaging station Van Bremer Arroyo near Tyrone (site S2A), for water year 1985.

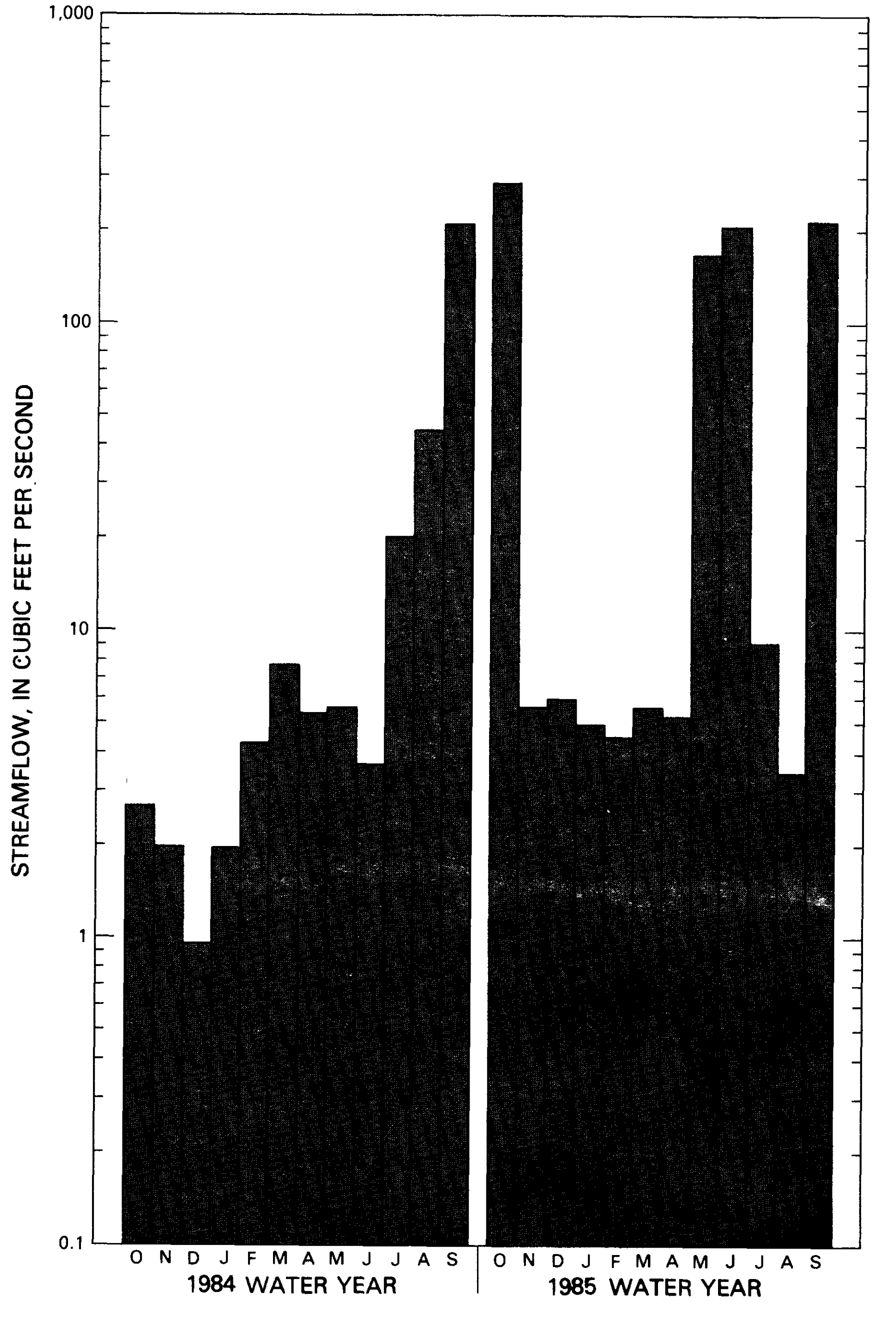


Figure 32.--Monthly streamflow for the streamflow-gaging station Van Bremer Arroyo near Model (site S3), for water years-1984-85.

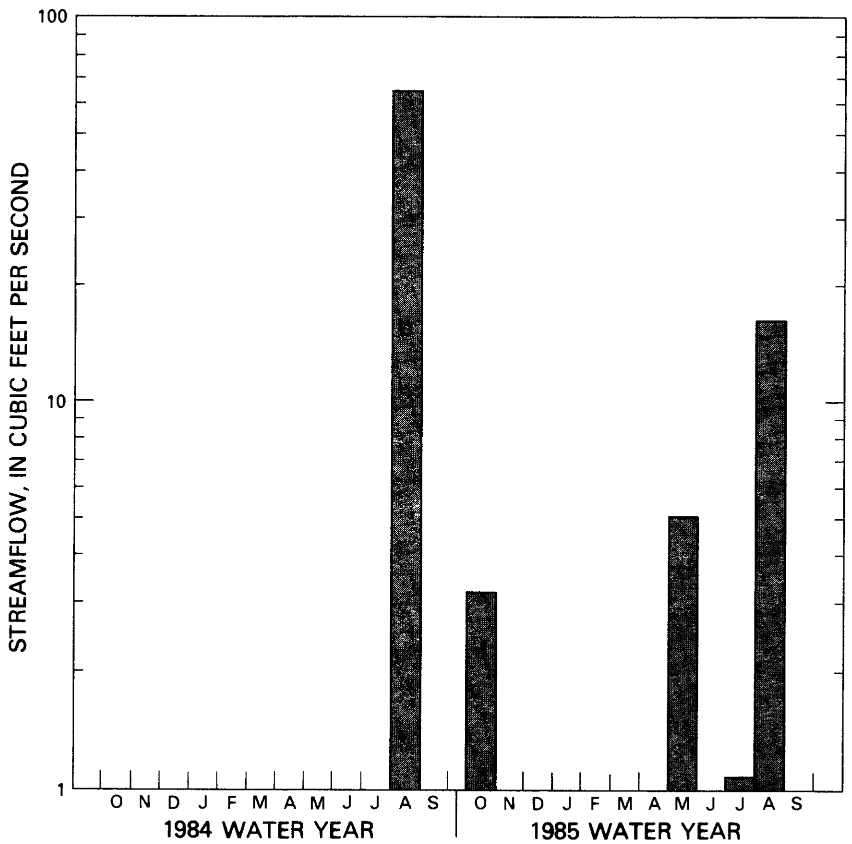


Figure 33.--Monthly streamflow for the streamflow-gaging station Taylor Arroyo below Rock Crossing, near Thatcher (site S5), for water years 1984-85.

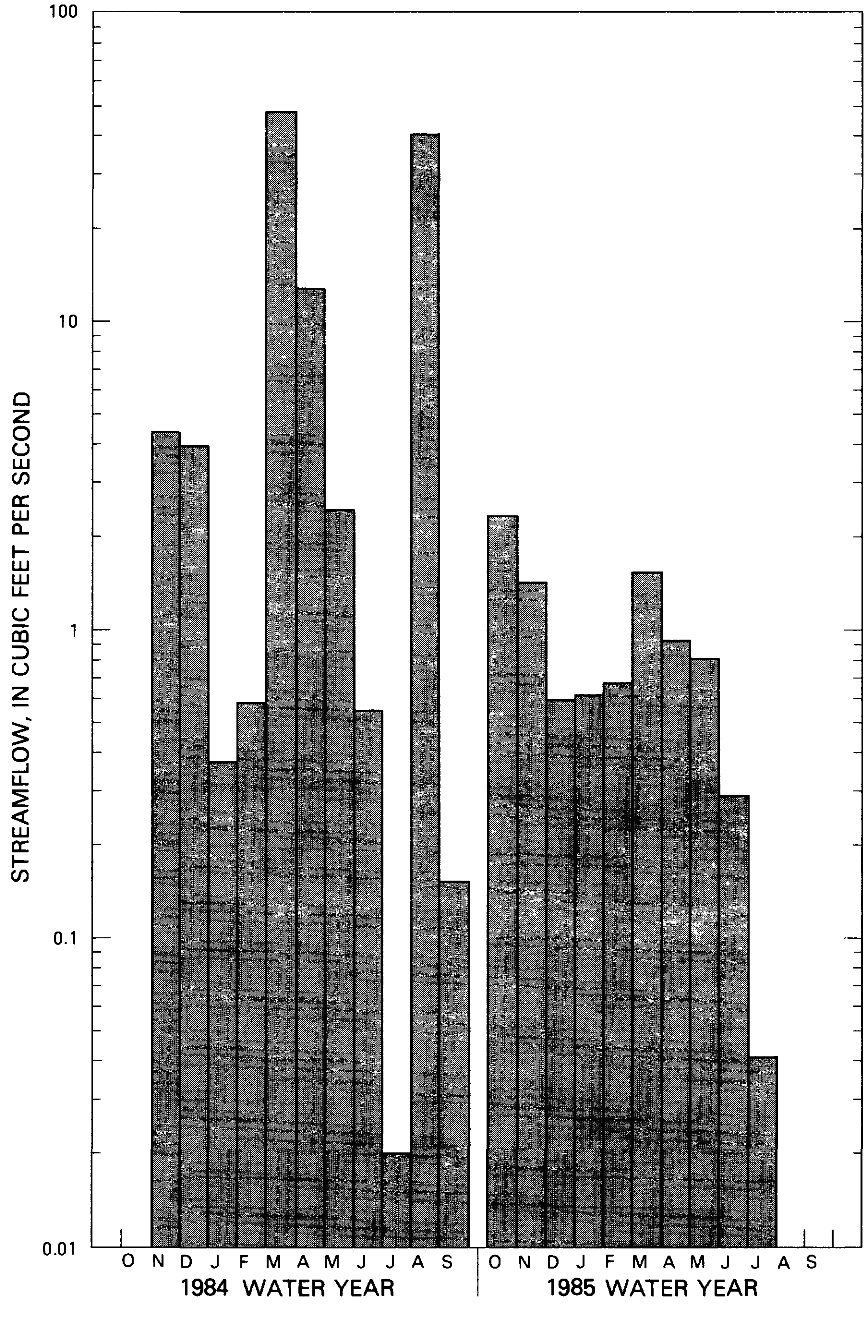


Figure 34.--Monthly streamflow for the streamflow-gaging station Lockwood Canyon Creek near Thatcher (site S6), for water years 1984-85.

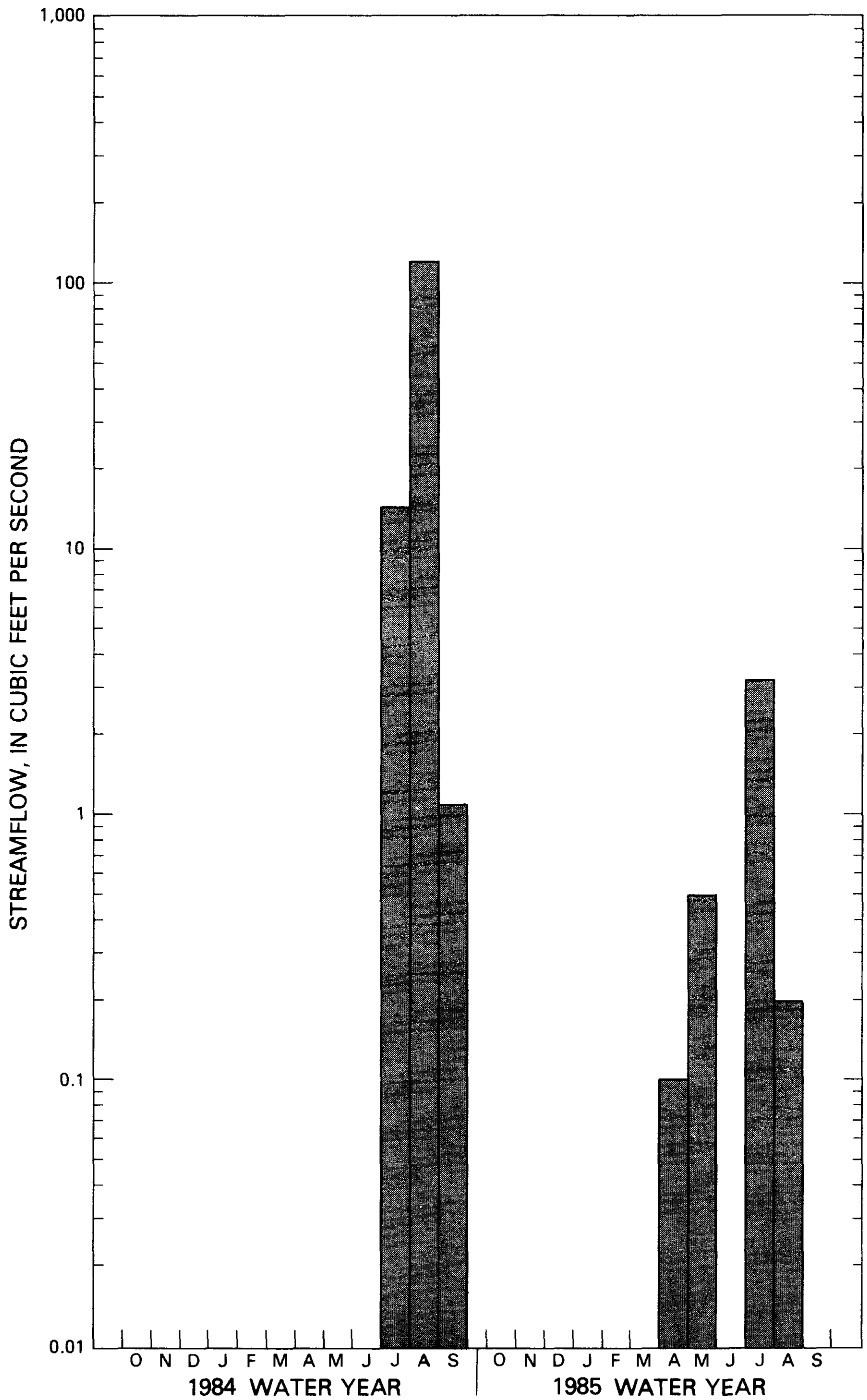


Figure 35.--Monthly streamflow for the streamflow-gaging station Red Rock Canyon Creek at mouth, near Thatcher (site S7), for water years 1984-85.

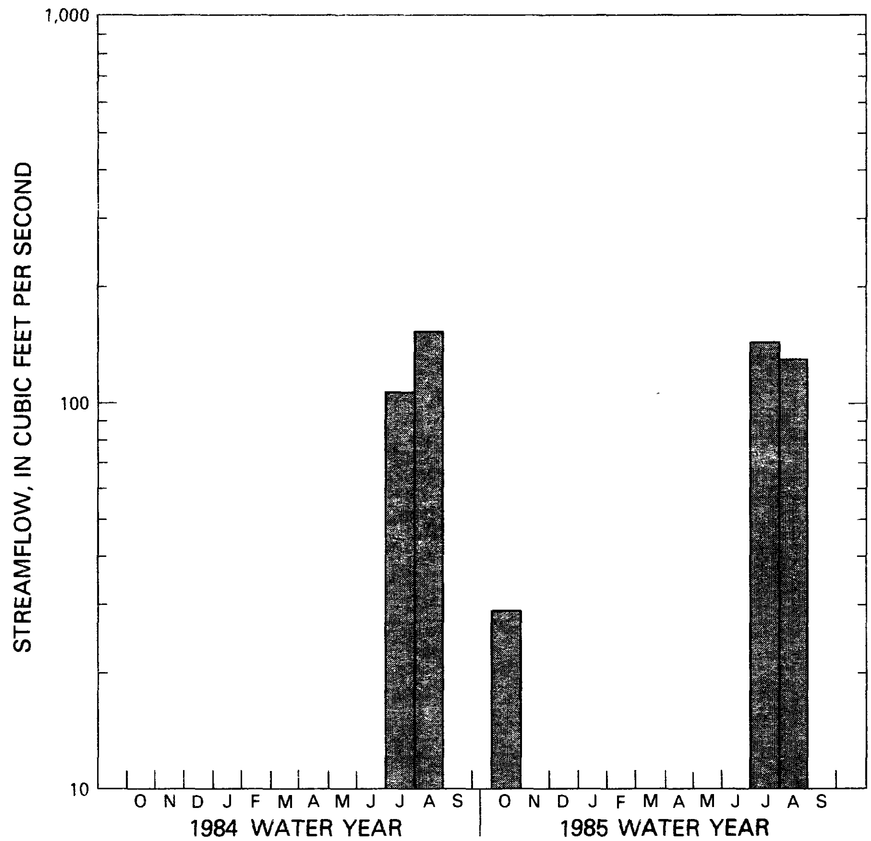


Figure 36.--Monthly streamflow for the streamflow-gaging station Chacuaco Creek at mouth, near Timpas (site S8), for water years 1984-85.

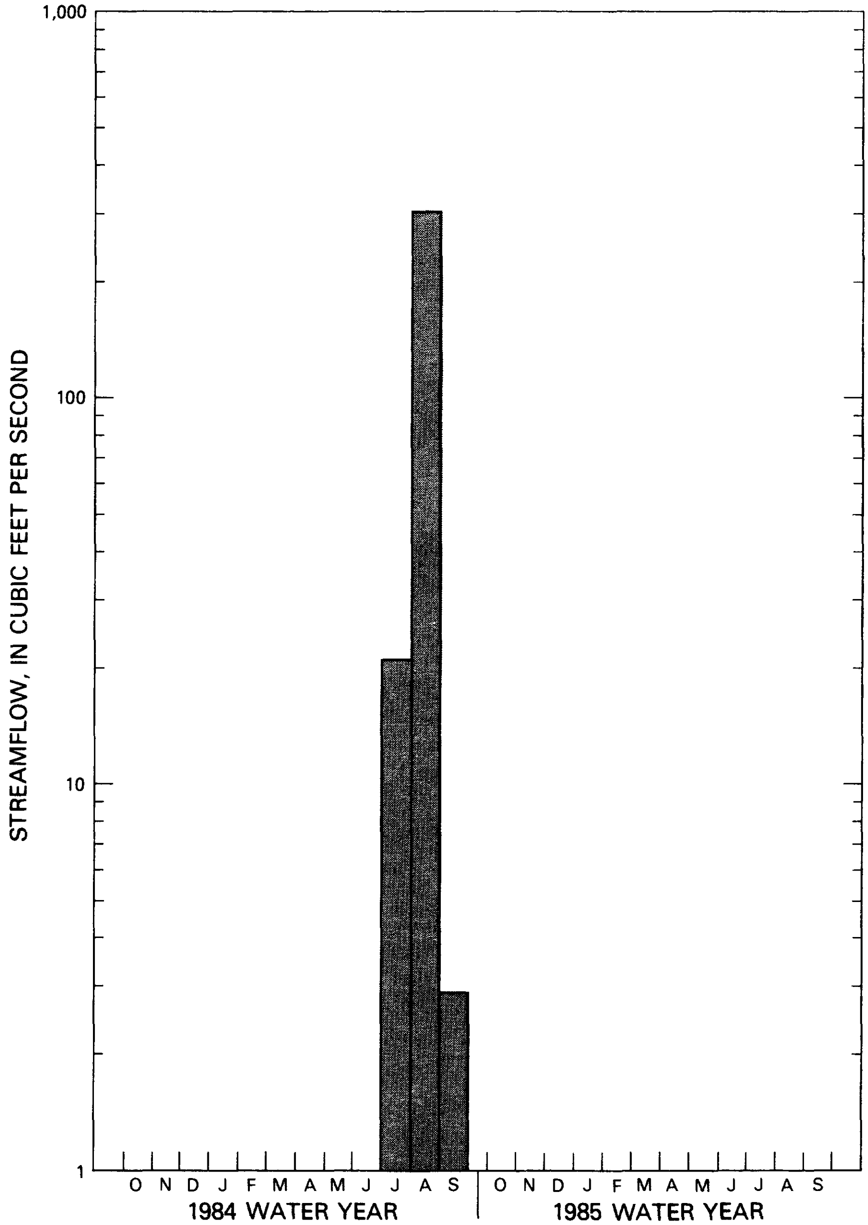


Figure 37.--Monthly streamflow for the streamflow-gaging station Bent Canyon Creek at mouth, near Timpas (site S9), for water years 1984-85.

Table 24.--*Stock-watering reservoirs and inflow record for water years 1984 and 1985*

[Reservoir locations are shown on plate 1, and reservoir characteristics are listed in table 19]

RESERVOIR 1

Location--Latitude 37°28'06", longitude 104°07'42", sec. 4, T. 30 S., R. 60 W., located in Las Animas County, Colorado, on a tributary of Van Bremer Arroyo. Elevation is 5,830 feet.
Drainage area--0.15 square mile.
Records available--October 1983 to 1985 (late spring and summer months only).
Gage--Reference mark, set to arbitrary datum. Gage read biweekly.
Remarks--Reservoir capacity is 1.8 acre-feet; spillway elevation is 99.39 feet.

Date and water year	Water-surface elevation (feet)		Inflow stored (acre-feet)	Spill (acre-feet)	Total inflow (acre-feet)	Inflow (acre-feet per square mile)
	Before inflow	After inflow				
July 24, 1984	94.26	95.53	0.2	0.0	0.2	1.3
Total			0.2	0.0	0.2	1.3
1985 -- No inflow this year			0.0	0.0	0.0	0.0
Total			0.0	0.0	0.0	0.0

RESERVOIR 2

Location--Latitude 37°29'59", longitude 104°07'35", sec. 21, T. 29 S, R. 60 W, located in Las Animas County, Colorado, on a tributary of Timpas Creek. Elevation is 5,820 feet.
Drainage area--0.23 square mile.
Records-available--October 1983 to 1985 (late spring and summer months only).
Gage--Reference mark, set to arbitrary datum. Gage read biweekly.
Remarks--Reservoir capacity is 5.6 acre-feet; spillway elevation is 99.47 feet.

Date and water year	Water-surface elevation (feet)		Inflow stored (acre-feet)	Spill (acre-feet)	Total inflow (acre-feet)	Inflow (acre-feet per square mile)
	Before inflow	After inflow				
August 24, 1984	88.26	98.79	5.6	0.0	5.6	24.3
Total			5.6	0.0	5.6	24.3
July 19, 1985	88.26	96.60	3.5	0.0	3.5	15.2
29	96.54	97.70	1.9	0.0	1.9	8.3
August 3, 1985	97.47	99.40	2.2	1.2	3.4	14.8
Total			7.6	1.2	8.8	38.3

Table 24.--*Stock-watering reservoirs with inflow record for water years 1984 and 1985*--Continued

RESERVOIR 4

Location--Latitude 37°27'39", longitude 104°04'31", sec. 01, T. 30 S, R. 60 W, located in Las Animas County, Colorado, on a tributary of Taylor drainage. Elevation is 5,640 feet.
Drainage-area--0.23 square mile.
Records-available--June 1984 to 1985 (late spring and summer months only).
Gage--Reference mark, set to arbitrary datum. Read biweekly.
Remarks--Reservoir capacity is 3.7 acre-feet; spillway elevation is 94.04 feet.

Date and water year	Water-surface elevation (feet) Before inflow	After inflow	Inflow stored (acre-feet)	Spill (acre-feet)	Total inflow (acre-feet)	Inflow (acre-feet per square mile)
August 24, 1984	94.90	98.53	3.1	0.0	3.1	13.5
Total (Partial year)			3.1	0.0	3.1	13.5
October 10, 1984	97.26	97.55	0.5	0.0	0.5	2.2
June 1, 1985	94.04	95.57	0.6	0.0	0.6	2.6
July 25, 1985	94.04	98.11	2.8	0.0	2.8	12.2
July 29, 1985	98.11	98.25	0.2	0.0	0.2	0.9
August 3, 1985	98.20	98.77	0.8	0.8	1.6	7.0
Total			4.9	0.8	5.7	24.9

RESERVOIR 5

Location--Latitude 37°30'11", longitude 104°00'53" sec. 21, T. 29 , R. 59 W, located in Las Animas County, Colorado, on a tributary of Taylor Arroyo. Elevation is 5,570 feet.
Drainage area--0.58 square mile.
Records available--October 1983 to 1985 (late spring and summer months only).
Gage--Reference mark, set to arbitrary datum, read biweekly.
Remarks--Reservoir capacity is 12.0 acre-feet; spillway elevation is 99.77 feet.

Date and water year	Water-surface elevation (feet) Before inflow	After inflow	Inflow stored (acre-feet)	Spill (acre-feet)	Total inflow (acre-feet)	Inflow (acre-feet per square mile)
April 17, 1984	92.02	95.54	3.2	0.0	3.2	5.5
July 24, 1984	92.97	94.87	1.9	0.0	1.9	3.3
August 24, 1984	92.02	92.91	0.4	0.0	0.4	0.7
Total			5.5	0.0	5.5	9.5
1985 -- No inflow this year			0.0	0.0	0.0	0.0
Total			0.0	0.0	0.0	0.0

Table 24.--*Stock-watering reservoirs with inflow record for water years 1984 and 1985*--Continued

RESERVOIR 6

Location--Latitude 37°22'54", longitude 104°06'30", sec. 34, T. 30 S, R. 60 W, located in Las Animas County, Colorado, on a tributary of Van Bremer Arroyo. Elevation is 5,635 feet.
Drainage area--0.19 square mile.
Records available--October 1983 to 1985 (late spring and summer months only).
Gage--Water stage recorder. Read from March to October.
Remarks--Reservoir capacity is 5.2 acre-feet; spillway elevation is 98.17 feet.

Date and water year	Water-surface elevation (feet)		Inflow stored (acre-feet)	Spill (acre-feet)	Total inflow (acre-feet)	Inflow (acre-feet per square mile)
	Before inflow	After inflow				
May 4, 1984	39.76	41.44	0.3	0.0	0.3	1.6
August 19, 1984	39.76	39.87	0.01	0.0	0.01	0.1
Total			0.31	0.0	0.31	1.7
1985 -- No inflow this year			0.0	0.0	0.0	0.0
Total			0.0	0.0	0.0	0.0

RESERVOIR 8

Location--Latitude 37°29'11", longitude 104°40'05", sec. 25, T. 29 S, R. 60 W, located in Las Animas County, Colorado, on a tributary of Taylor Arroyo. Elevation is 5,720 feet.
Drainage area--0.18 square mile.
Records available--June 1985 to 1985 (late spring and summer months only).
Gage--Reference mark, set to arbitrary datum. Read biweekly.
Remarks--Reservoir capacity is 7.2 acre-feet; spillway elevation is 99.49 feet.

Date and water year	Water-surface elevation (feet)		Inflow stored (acre-feet)	Spill (acre-feet)	Total inflow (acre-feet)	Inflow (acre-feet per square mile)
	Before inflow	After inflow				
July 25, 1985	86.00	86.36	0.01	0.0	0.01	0.06
July 29, 1985	86.36	87.18	0.03	0.0	0.03	0.17
August 1, 1985	87.10	96.10	3.8	0.0	3.8	21.1
Total (Partial year)			3.84	0.0	3.84	21.33

Table 24.--*Stock-watering reservoirs with inflow record for water years 1984 and 1985*--Continued

RESERVOIR 9

Location--Latitude 37°24'56", longitude 104°08'05", sec. 21, T. 30 S, R. 60 W, located in Las Animas County, Colorado, on a tributary of Van Bremer Arroyo. Elevation is 5,540 feet.
Drainage area--0.34 square mile.
Records available--October 1983 to 1985 (late spring and summer months only).
Gage--Reference mark, set to arbitrary datum. Read biweekly.
Remarks--Reservoir capacity is 1.6 acre-feet; spillway elevation is 98.22 feet.

Date and water year	Water-surface elevation (feet)		Inflow stored (acre-feet)	Spill (acre-feet)	Total inflow (acre-feet)	Inflow (acre-feet per square mile)
	Before inflow	After inflow				
April 1, 1984	42.10	44.21	0.2	0.0	0.2	0.6
Total			0.2	0.0	0.2	0.6
1985 -- No inflow this year			0.0	0.0	0.0	0.0
Total			0.0	0.0	0.0	0.0

RESERVOIR 19

Location--Latitude 37°38'35", longitude 103°42'57", sec. 31, T. 27S, R. 56W, located in Las Animas County, Colorado on a tributary of Bent Canyon Creek. Elevation is 5,000 feet.
Drainage area--0.17 square mile.
Records available--October 1983 to 1985 (late spring and summer months only).
Gage - Reference mark, set to arbitrary datum. Read biweekly.
Remarks--Reservoir capactiy is 4.6 acre-feet; spillway elevation is 98.56 feet.

Date and water year	Water-surface elevation (feet)		Inflow stored (acre-feet)	Spill (acre-feet)	Total inflow (acre-feet)	Inflow (acre-feet per square mile)
	Before inflow	After inflow				
July 15, 1984	88.92	90.22	0.1	0.0	0.1	0.6
August 4, 1984	89.65	90.90	0.2	0.0	0.2	1.2
August 8, 1984	90.90	91.14	0.1	0.0	0.1	0.6
August 24, 1984	90.62	97.60	3.4	0.0	3.4	20.0
September 10, 1984	97.00	97.65	0.6	0.0	0.6	3.5
September 16, 1984	97.65	98.43	0.8	0.8	1.6	9.4
Total			5.2	0.0	5.2	35.3
May 16, 1985	94.56	95.50	0.5	0.0	0.5	2.9
Total			0.5	0.0	0.5	2.9

Table 24.--*Stock-watering reservoirs with inflow record for water years 1984 and 1985*--Continued

RESERVOIR 22

Location--Latitude 37°25'10", longitude 104°00'11", sec. 22, T. 30 S, R. 59 W, located in Las Animas County, Colorado, on a tributary of Burke Arroyo. Elevation is 5,400 feet.
Drainage area--1.6 square miles.
Records available--August 1984 to 1985 (late spring and summer months only).
Gage--Reference mark, set to arbitrary datum. Read biweekly.
Remarks--Reservoir capacity is 0.92 acre-feet; spillway elevation is 46.7 feet.

Date and water year	Water-surface elevation (feet)		Inflow stored (acre-feet)	Spill (acre-feet)	Total inflow (acre-feet)	Inflow (acre-feet per square mile)
	Before inflow	After inflow				
August 23, 1984	42.55	46.80	0.9	10.2	11.2	7.2
Total (Partial year)			0.9	10.2	11.2	7.2
1985 -- No inflow this year			0.0	0.0	0.0	0.0
Total			0.0	0.0	0.0	0.0

RESERVOIR 23

Location--Latitude 37°24'33", longitude 103°58'43", sec. 26, T. 30 S, R. 59 W, located in Las Animas County, Colorado, on a tributary of Burke Arroyo. Elevation is 5,280 feet.
Drainage area--0.36 square mile.
Records available--May 1984 to 1985 (late spring and summer months only).
Gage--Reference mark, set to arbitrary datum. Read biweekly.
Remarks--Reservoir capacity is 16.0 acre-feet; spillway elevation is 97.89 feet.

Date and water year	Water-surface elevation (feet)		Inflow stored (acre-feet)	Spill (acre-feet)	Total inflow (acre-feet)	Inflow (acre-feet per square mile)
	Before inflow	After inflow				
August 23, 1984	89.97	93.32	2.4	0.0	2.4	6.7
Total (Partial year)			2.4	0.0	2.4	6.7
October 10, 1984	92.50	93.27	0.8	0.0	0.8	2.2
Total			0.8	0.0	0.8	2.2

Table 24.--*Stock-watering reservoirs with inflow record for water years 1984 and 1985*--Continued

RESERVOIR 24

Location--Latitude 37°24'26", longitude 103°54'26", sec. 28, T. 30 S, R. 58 W, located in Las Animas County, Colorado, on a tributary of Taylor Arroyo. Elevation is 5,110 feet.
Drainage area--1.2 square miles.
Records available--October 1983 to 1985 (late spring and summer months only).
Gage--Reference mark, set to arbitrary datum. Read biweekly.
Remarks--Reservoir capacity is 8.5 acre-feet; spillway elevation is 98.75 feet.

Date and water year	Water-surface elevation (feet)		Inflow stored (acre-feet)	Spill (acre-feet)	Total inflow (acre-feet)	Inflow (acre-feet per square mile)
	Before inflow	After inflow				
August 23, 1984	92.31	94.37	0.6	0.0	0.6	0.3
Total			0.6	0.0	0.6	0.2
October 5, 1984	92.30	92.90	0.1	0.0	0.1	0.04
June 18, 1985	92.30	92.60	0.04	0.0	0.04	0.02
Total			0.14	0.0	0.14	0.06

RESERVOIR 27

Location--Latitude 37°28'38", longitude 104°00'12", sec. 34, T. 29 S, R. 59 W, located in Las Animas County, Colorado, on a tributary of Taylor Arroyo. Elevation is 5,345 feet.
Drainage area--0.11 square mile.
Records available--December 1983 to 1985 (late spring and summer months only).
Gage--Water stage recorder. Read from March to October.
Remarks--Reservoir capacity is 3.1 acre-feet; spillway elevation is 97.28 feet.

Date and water year	Water-surface elevation (feet)		Inflow stored (acre-feet)	Spill (acre-feet)	Total inflow (acre-feet)	Inflow (acre-feet per square mile)
	Before inflow	After inflow				
August 21, 1984	38.92	39.70	0.1	0.0	0.1	0.9
August 22, 1984	39.70	39.85	0.02	0.0	0.02	0.18
August 24, 1984	39.85	42.01	0.4	0.0	0.4	3.6
Total			0.52	0.0	0.52	4.68
November 4, 1984	40.94	41.32	0.1	0.0	0.1	0.9
Total			0.1	0.0	0.1	0.9

Table 24.--*Stock-watering reservoirs with inflow record for water years 1984 and 1985*--Continued

RESERVOIR 28

Location--Latitude 37°22'47", longitude 104°03'26", sec. 06, T. 31 S, R. 59 W, located in Las Animas County, Colorado, on a tributary of Van Bremer Arroyo. Elevation is 5,247 feet.
Drainage area --0.19 square mile.
Records available--October 1983 to 1985 (late spring and summer months only).
Gage--Reference mark, set to arbitrary datum. Read biweekly.
Remarks--Reservoir capacity is 1.6 acre-feet; spillway elevation is 96.84 feet.

Date and water year	Water-surface elevation (feet) Before inflow	After inflow	Inflow stored (acre-feet)	Spill (acre-feet)	Total inflow (acre-feet)	Inflow (acre-feet per square mile)
August 23, 1984	89.78	92.58	0.3	0.0	0.3	1.6
Total			0.3	0.0	0.3	1.6
1985 - No inflow this year			0.0	0.0	0.0	0.0
Total			0.0	0.0	0.0	0.0

RESERVOIR 29

Location--Latitude 37°24'35", longitude 103°59'55", sec. 27, T. 30 S, R. 59 W, located in Las Animas County, Colorado, on a tributary of Burke Arroyo. Elevation is 5,380 feet.
Drainage area--0.18 square mile.
Records available--October 1983 to 1985 (late spring and summer months only).
Gage--Reference mark, set to arbitrary datum. Read biweekly.
Remarks--Reservoir capacity is 0.41 acre-foot; spillway elevation is 98.59 feet.

Date and water year	Water-surface elevation (feet) Before inflow	After inflow	Inflow stored (acre-feet)	Spill (acre-feet)	Total inflow (acre-feet)	Inflow (acre-feet per square mile)
July 24, 1984	94.26	95.53	0.2	0.0	0.2	1.3
Total			0.2	0.0	0.2	1.3
August 23, 1984	96.48	98.59	0.4	0.0	0.4	2.2
Total			0.4	0.0	0.4	2.2
1985 - No inflow this year			0.0	0.0	0.0	0.0
Total			0.0	0.0	0.0	0.0

Table 24.--*Stock-watering reservoirs with inflow record for water years 1984 and 1985*--Continued

RESERVOIR 34

Location--Latitude 37°30'19", longitude 103°59'30", sec. 22, T. 29 S, R. 59 W, located in Las Animas County, Colorado, on a tributary of Taylor Arroyo. Elevation is 5,560 feet.
Drainage area--0.29 square mile.
Records available--October 1983 to 1985 (late spring and summer months only).
Gage--Water stage recorder. Read from March to October.
Remarks--Reservoir capacity is 2.5 acre-feet; spillway elevation is 101.12 feet.

Date and water year	Water-surface elevation (feet)		Inflow stored (acre-feet)	Spill (acre-feet)	Total inflow (acre-feet)	Inflow (acre-feet per square mile)
	Before inflow	After inflow				
April 17, 1984	42.96	48.35	1.2	0.0	1.2	4.1
June 25, 1984	43.00	43.61	0.1	0.0	0.1	0.3
August 22, 1984	42.96	43.70	0.1	0.0	0.1	0.3
Total			1.4	0.0	1.4	4.7
1985 - No inflow this year			0.0	0.0	0.0	0.0
Total			0.0	0.0	0.0	0.0

RESERVOIR 35

Location--Latitude 36°26'05", longitude 103°49'42", sec. 8, T. 30 S, R. 57 W, located in Las Animas County, Colorado, on a tributary of Purgatoire River. Elevation is 5,080 feet.
Drainage area--1.1 square miles.
Records available--October 1983 to 1985 (late spring and summer months only).
Gage--Reference mark, set to arbitrary datum. Read biweekly.
Remarks--Reservoir capacity is 4.9 acre-feet; spillway elevation is 98.00 feet.

Date and water year	Water-surface elevation (feet)		Inflow stored (acre-feet)	Spill (acre-feet)	Total inflow (acre-feet)	Inflow (acre-feet per square mile)
	Before inflow	After inflow				
1984 - No inflow this year			0.0	0.0	0.0	0.0
Total			0.0	0.0	0.0	0.0
1985 - No inflow this year			0.0	0.0	0.0	0.0
Total			0.0	0.0	0.0	0.0

Table 24.--*Stock-watering reservoirs with inflow record for water years 1984 and 1985*--Continued

RESERVOIR 36

Location--Latitude 37°31'106", longitude 103°55'59", sec. 18, T. 29 S, R. 58 W, located in Las Animas County, Colorado, on a tributary of Lockwood Arroyo.
Elevation is 5,342 feet.
Drainage area--0.66 square mile.
Records available--December 1983 to 1985 (late spring and summer months only).
Gage--Water stage recorder. Read from March to October.
Remarks--Reservoir capacity is 1.2 acre-feet; spillway elevation is 49.22 feet.

Date and water year	Water-surface elevation (feet)		Inflow stored (acre-feet)	Spill (acre-feet)	Total inflow (acre-feet)	Inflow (acre-feet per square mile)
	Before inflow	After inflow				
April 17, 1984	43.81	45.81	0.2	0.0	0.2	0.3
August 24, 1984	43.81	44.97	0.1	0.0	0.1	0.2
Total			0.3	0.0	0.3	0.5
1985 - No inflow this year			0.0	0.0	0.0	0.0
Total			0.0	0.0	0.0	0.0

RESERVOIR 40

Location--Latitude 37°28'15", longitude 103°49'50", sec. 31, T. 29 S, R. 57 W, located in Las Animas County, Colorado, on a tributary of Lockwood Arroyo.
Elevation is 5,070 feet.
Drainage area--0.38 square mile.
Records available--July 1984 to 1985 (late spring and summer months only).
Gage--Reference mark, set to arbitrary datum. Read biweekly.
Remarks--Reservoir capacity is 11.4 acre-feet; spillway elevation is 98.81 feet.

Date and water year	Water-surface elevation (feet)		Inflow stored (acre-feet)	Spill (acre-feet)	Total inflow (acre-feet)	Inflow (acre-feet per square mile)
	Before inflow	After inflow				
1984 - No inflow this year			0.0	0.0	0.0	0.0
Total (Partial year)			0.0	0.0	0.0	0.0
September 20, 1984	87.80	90.60	0.4	0.0	0.4	1.1
Total			0.4	0.0	0.4	1.1

Table 24.--*Stock-watering reservoirs with inflow record for water years 1984 and 1985*--Continued

RESERVOIR 41

Location--Latitude 37°29'50", longitude 103°51'29", sec. 24, T. 29 S, R. 58 W, located in Las Animas County, Colorado, on a tributary of Lockwood Arroyo. Elevation is 5,020 feet.
Drainage area--0.51 square mile.
Records available--June 1984 to 1985 (late spring and summer months only).
Gage--Reference mark, set to arbitrary datum. Read biweekly.
Remarks--Reservoir capacity is 2.9 acre-feet; spillway elevation is 94.89 feet.

Date and water year	Water-surface elevation (feet)		Inflow stored (acre-feet)	Spill (acre-feet)	Total inflow (acre-feet)	Inflow (acre-feet per square mile)
	Before inflow	After inflow				
August 24, 1984	86.99	88.42	0.1	0.0	0.1	0.2
Total (Partial year)			0.1	0.0	0.1	0.2
1985 - No inflow this year			0.0	0.0	0.0	0.0
Total			0.0	0.0	0.0	0.0

RESERVOIR 42

Location--Latitude 37°34'37", longitude 103°48'09", sec. 28, T. 28 S, R. 57 W, located in Las Animas County, Colorado, on a tributary of Welsch Canyon. Elevation is 5,085 feet.
Drainage area--0.08 square mile.
Records available--October 1983 to 1985 (late spring and summer months only).
Gage--Reference mark, set to arbitrary datum. Read biweekly.
Remarks--Reservoir capacity is 3.9 acre-feet; spillway elevation is 98.43 feet.

Date and water year	Water-surface elevation (feet)		Inflow stored (acre-feet)	Spill (acre-feet)	Total inflow (acre-feet)	Inflow (acre-feet per square mile)
	Before inflow	After inflow				
April 1, 1984	92.99	95.76	1.1	0.0	1.1	13.8
August 24, 1984	92.99	95.94	1.2	0.0	1.2	15.0
Total			2.3	0.0	2.3	28.8
October 9, 1984	95.57	95.60	0.02	0.0	0.02	0.2
Total			0.02	0.0	0.02	0.2

Table 24.--*Stock-watering reservoirs with inflow record for water years 1984 and 1985*--Continued

RESERVOIR 43

Location--Latitude 37°37'03", longitude 103°39'01", sec. 11, T. 28 S, R. 56 W, located in Las Animas County, Colo. on a tributary of Taylor Arroyo. Elevation is 4,685 feet.
Drainage area--0.14 square mile.
Records available--July 1985 to 1985 (late spring and summer months only).
Gage--Reference mark, set to arbitrary datum. Read biweekly.
Remarks--Reservoir capacity is 2.1 acre-feet; spillway elevation is 93.92 feet.

Date and water year	Water-surface elevation (feet)		Inflow stored (acre-feet)	Spill (acre-feet)	Total inflow (acre-feet)	Inflow (acre-feet per square mile)
	Before inflow	After inflow				
July 22, 1985	88.78	91.98	0.7	0.0	0.7	5.0
Total (Partial year)			0.7	0.0	0.7	5.0

RESERVOIR 45

Location--Latitude 37°33'54", longitude 103°56'06", sec. 31, T. 28 S, R. 58 W, located in Las Animas County, Colorado, on a tributary of Lockwood Arroyo. Elevation is 5,430 feet.
Drainage area--0.13 square mile.
Records available--October 1983 to 1985 (late spring and summer months only).
Gage--Reference mark, set to arbitrary datum. Read biweekly.
Remarks--Reservoir capacity is 2.8 acre-feet; spillway elevation is 98.57 feet.

Date and water year	Water-surface elevation (feet)		Inflow stored (acre-feet)	Spill (acre-feet)	Total inflow (acre-feet)	Inflow (acre-feet per square mile)
	Before inflow	After inflow				
April 1, 1984	92.80	97.39	1.7	0.0	1.7	13.1
Total			1.7	0.0	1.7	13.1
1985 - No inflow this year			0.0	0.0	0.0	0.0
Total			0.0	0.0	0.0	0.0

Table 24.--*Stock-watering reservoirs with inflow record for water years 1984 and 1985*--Continued

RESERVOIR 46

Location--Latitude 37°37'25", longitude 103°50'17", sec. 07, T. 28 S, R. 57 W, located in Las Animas County, Colorado, on a tributary of Bent Canyon. Elevation is 5,140 feet.
Drainage area--0.08 square mile.
Records available--October 1983 to 1985 (late spring and summer months only).
Gage--Reference mark, set to arbitrary datum. Read biweekly.
Remarks--Reservoir capacity is 5.8 acre-feet; spillway elevation is 98.94 feet.

Date and water year	Water-surface elevation (feet)		Inflow stored (acre-feet)	Spill (acre-feet)	Total inflow (acre-feet)	Inflow (acre-feet per square mile)
	Before inflow	After inflow				
April 1, 1984	85.87	96.08	2.6	0.0	2.6	32.5
August 24, 1984	92.00	92.91	0.3	0.0	0.3	3.8
September 3, 1984	92.91	93.25	0.1	0.0	0.1	1.2
Total			3.0	0.0	3.0	37.5
September 25, 1985	85.89	88.20	0.2	0.0	0.2	2.5
Total			0.2	0.0	0.2	2.5

RESERVOIR 47

Location--Latitude 37°37'50", longitude 103°48'42", sec. 05, T. 28 S, R. 57 W, located in Las Animas County, Colorado, on a tributary of Bent Canyon. Elevation is 5,080 feet.
Drainage area--0.25 square mile.
Records available--October 1983 to 1985 (late spring and summer months only).
Gage--Reference mark, set to arbitrary datum. Read biweekly.
Remarks--Reservoir capacity is 15.5 acre-feet; spillway elevation is 99.05 feet.

Date and water year	Water-surface elevation (feet)		Inflow stored (acre-feet)	Spill (acre-feet)	Total inflow (acre-feet)	Inflow (acre-feet per square mile)
	Before inflow	After inflow				
April 1, 1984	92.38	93.25	0.2	0.0	0.2	0.8
August 24, 1984	92.38	95.10	2.0	0.0	2.0	8.0
Total			2.2	0.0	2.2	8.8
1985 - No inflow this year			0.0	0.0	0.0	0.0
Total			0.0	0.0	0.0	0.0

Table 24.--*Stock-watering reservoirs with inflow record for water years 1984 and 1985*--Continued

RESERVOIR 48

Location--Latitude 37°37'53", longitude 103°41'55", sec. 05, T. 28 S, R. 56 W, located in Las Animas County, Colorado, on a tributary of Bent Canyon. Elevation is 4,732 feet.
Drainage area--0.20 square mile.
Records available--July 1985 to 1985 (late spring and summer months only).
Gage--Reference mark, set to arbitrary datum. Read biweekly.
Remarks--Reservoir capacity is 1.5 acre-feet; spillway elevation is 96.25 feet.

Date and water year	Water-surface elevation (feet)		Inflow stored (acre-feet)	Spill (acre-feet)	Total inflow (acre-feet)	Inflow (acre-feet per square mile)
	Before inflow	After inflow				
July 30, 1985	88.27	90.45	0.1	0.0	0.1	0.5
August 7, 1985	90.45	90.55	0.02	0.0	0.02	0.1
August 22, 1985	90.45	90.78	0.04	0.0	0.04	0.2
Total (Partial year)	. . . .		0.16	0.0	0.16	0.8

Table 25.--*Summary of water-quality data for surface-water stations in and near the Pinon Canyon Maneuver Site*

[N, number of water-quality samples; °C, degrees Celsius; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 °Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter, U, uranium; U-nat, natural uranium; Cs-137, cesium 137; NA, not applicable]

Property or constituent	Units	N	Minimum value	Percentiles 25th	Percentiles Median 50th	Percentiles 75th	Maximum
07120620 BIG ARROYO NEAR THATCHER (SITE S1)							
Temperature	(°C)	23	7.0	18.5	19.0	19.0	20.0
Instantaneous streamflow	(ft^3/s)	29	1.8	4.0	17	70	760
Specific conductance	(µS/cm)	11	280	350	450	505	520
pH, laboratory	(standard units).	18	7.6	7.9	8.0	8.1	8.4
Alkalinity, laboratory	(mg/L as $CaCO_3$).	17	35	39	44	60	135
Dissolved calcium	(mg/L)	18	18	38	52	76	180
Dissolved magnesium	(mg/L)	18	2.6	5.9	8.0	12	34
Dissolved sodium	(mg/L)	18	20	29	35	40	88
Dissolved potassium	(mg/L)	18	3.7	5.2	6.4	6.8	7.9
Dissolved chloride	(mg/L)	18	4.5	5.2	6.2	6.8	15
Dissolved fluoride	(mg/L)	18	0.3	0.4	0.4	0.5	0.7
Dissolved sulfate	(mg/L)	18	70	30	200	250	750
Dissolved silica	(mg/L)	18	5.6	6.4	6.6	7.3	9.3
Dissolved nitrite plus nitrate.	(mg/L as N).	18	.10	.37	.55	.75	.79
Dissolved phosphorus	(mg/L)	18	.01	.02	.03	.04	.05
Dissolved solids	(mg/L)	11	185	222	304	345	359
Total recoverable iron	(µg/L)	2	300,000	300,000	310,000	320,000	320,000
Dissolved iron	(µg/L)	18	8	10	20	60	540
Total recoverable lead	(µg/L)	2	180	NA	NA	NA	240
Dissolved manganese	(µg/L)	18	<1	4	5	9	40
Suspended sediment	(mg/L)	19	1,720	5,720	9,800	20,000	49,000
07126200 VAN BREMER ARROYO NEAR MODEL (SITE S3)							
Temperature	(°C)	18	4.5	12.0	17.0	20.0	27.5
Instantaneous streamflow	(ft^3/s)	19	.04	.09	.16	4.1	29
Specific conductance	(µS/cm)	16	800	919	1,890	2,010	2,180
Dissolved oxygen	(mg/L)	3	6.7	6.7	7.5	10.1	10.1
pH, laboratory	(standard units).	9	7.6	7.8	7.9	8.0	8.3
Alkalinity, laboratory	(mg/L as $CaCO_3$).	9	140	190	240	270	280
Dissolved calcium	(mg/L)	9	72	80	160	180	190
Dissolved magnesium	(mg/L)	9	31	36	81	88	95
Dissolved sodium	(mg/L)	9	71	84	160	180	220
Dissolved potassium	(mg/L)	9	9.8	10	11	12	14
Dissolved chloride	(mg/L)	9	12	18	26	32	65
Dissolved fluoride	(mg/L)	9	.4	.5	1.0	1.0	1.0
Dissolved sulfate	(mg/L)	9	230	340	800	860	960
Dissolved silica	(mg/L)	9	6.3	7.0	7.9	9.6	14
Dissolved nitrite plus nitrate.	(mg/L as N).	9	<.10	NA	NA	NA	<.10
Dissolved phosphorus	(mg/L)	9	.01	<0.1	<0.1	.02	.03
Dissolved solids	(mg/L)	6	592	652	1,140	1,690	1,720
Dissolved iron	(µg/L)	9	12	20	40	80	80
Dissolved manganese	(µg/L)	9	5	24	100	120	130

Table 25.--*Summary of water-quality data for surface-water stations in and near the Pinon Canyon Maneuver Site*--Continued

Property or constituent	Units	N	Minimum value	Percentiles 25th	Median 50th	75th	Maximum
			07126300 PURGATOIRE RIVER NEAR THATCHER (SITE S4)				
Temperature	(°C)	33	0.0	8.2	15.0	22.0	26.5
Instanteous streamflow	(ft^3/s)	23	14	34	51	185	1,090
Specific conductance	(µS/cm)	20	490	1,640	2,520	2,880	3,660
Dissolved oxygen	(mg/L)	18	7.0	7.7	8.7	10.8	13.7
pH, laboratory	(standard units).	24	7.3	8.1	8.1	8.2	8.6
Alkalinity, laboratory	(mg/L as ($CaCO_3$).	24	87	140	160	210	290
Dissolved calcium	(mg/L)	23	49	170	230	270	350
Dissolved magnesium	(mg/L)	23	20	92	150	190	250
Dissolved sodium	(mg/L)	23	27	120	180	230	270
Dissolved potassium	(mg/L)	23	2.8	4.4	5.0	5.9	6.5
Dissolved chloride	(mg/L)	23	4.8	15	26	35	40
Dissolved fluoride	(mg/L)	23	.3	.4	.5	.5	.5
Dissolved sulfate	(mg/L)	24	160	920	1,400	1,700	2,000
Dissolved silica	(mg/L)	23	4.5	7.5	8.7	10	13
Dissolved solids	(mg/L)	13	1,220	1,640	2,390	2,730	3,460
Suspended solids	(mg/L)	16	7	28	49	1,540	5,320
Dissolved nitrite plus nitrate.	(mg/L as N).	21	<.10	<.10	.21	.40	.76
Dissolved phosphorus	(mg/L)	21	<.01	<.01	.01	.02	.23
Total recoverable cadmium	(µg/L)	16	<1	<1	<1	1	8
Dissolved chromium	(µg/L)	16	<10	<10	<10	<10	20
Total recoverable copper	(µg/L)	16	4	6	10	100	290
Suspended recoverable iron	(µg/L)	9	70	340	1,500	5,850	180,000
Total recoverable iron	(µg/L)	16	160	470	1,450	71,000	180,000
Dissolved iron	(µg/L)	24	4	30	40	90	250
Total recoverable lead	(µg/L)	16	<1	3	4	60	190
Suspended recoverable manganese.	(µg/L)	9	10	20	40	130	4,200
Total recoverable manganese	(µg/L)	16	20	42	60	1,170	4,200
Dissolved manganese	(µg/L)	24	<1	<10	10	30	70
Total recoverable zinc	(µg/L)	14	<10	20	60	470	810
Suspended total gross alpha	(pCi/L)	2	.5	.5	220	440	440
Dissolved gross beta	(pCi/L)	4	5.7	NA	NA	NA	<29
Suspended total gross beta	(pCi/L)	4	1.0	1.1	1.8	220	290
Dissolved, planchet count Ra-226.	(pCi/L)	4	.1	NA	NA	NA	.1
Dissolved natural uranium	(µg/L as U)	4	2.4	4.6	12	16	17
Dissolved gross alpha	(µg/L as U-nat).	4	<12	NA	NA	NA	<66
Suspended total gross alpha	(µg/L as U-nat).	4	.7	.9	1.4	490	650
Total cyanide	(mg/L)	13	<.01	NA	NA	NA	<.01
Suspended sediment	(mg/L)	32	17	50	212	1,600	12,500

Table 25.--*Summary of water-quality data for surface-water stations in and near the Pinon Canyon Maneuver Site*--Continued

Property or constituent	Units	N	Minimum value	Percentiles 25th	Percentiles Median 50th	Percentiles 75th	Maximum
07126325 TAYLOR ARROYO BELOW ROCK CROSSING, NEAR THATCHER (SITE S5)							
Temperature---------------	(°C)	11	18.5	23.5	24.0	26.5	28.0
Instantaneous streamflow--		10	.01	.9	2.9	40.7	220
Specific conductance------	(μS/cm)	6	140	448	1,320	2,180	2,400
pH, laboratory------------	(standard units).	11	7.6	7.7	7.8	7.9	8.2
Alkalinity, laboratory----	(mg/L as ($CaCO_3$).	11	27	42	48	50	63
Dissolved calcium---------	(mg/L)	11	19	120	270	300	370
Dissolved magnesium-------	(mg/L)	11	2.4	28	51	68	96
Dissolved sodium----------	(mg/L)	11	3.6	34	50	63	110
Dissolved potassium-------	(mg/L)	11	3.1	7.7	11	14	18
Dissolved chloride--------	(mg/L)	11	1.0	3.5	4.0	6.2	7.4
Dissolved fluoride--------	(mg/L)	11	<.1	.3	.6	.6	.7
Dissolved sulfate---------	(mg/L)	11	34	440	970	1,000	1,500
Dissolved silica----------	(mg/L)	11	2.4	4.6	5.4	5.8	6.4
Dissolved nitrite plus nitrate.	(mg/L as N).	11	.64	.83	1.3	1.4	2.8
Dissolved phosphorus------	(mg/L)	11	.01	.01	.01	.02	.10
Dissolved solids----------	(mg/L)	7	717	727	1,530	1,930	2,330
Dissolved iron------------	(μg/L)	11	7	20	30	60	130
Dissolved manganese-------	(μg/L)	11	7	14	19	32	50
Suspended sediment--------	(mg/L)	7	18	34	470	850	24,400
07126390 LOCKWOOD CANYON CREEK NEAR THATCHER (SITE S6)							
Temperature---------------	(°C)	3	0.0	0.0	14.0	23.5	23.5
Instantaneous streamflow--		3	.01	.04	.07	.08	.1
Specific conductance------	(μS/cm)	2	2,660	2,660	2,670	2,680	2,680
Dissolved oxygen----------	(mg/L)	1	10.4	NA	NA	NA	10.4
pH, field-----------------	(standard units).	1	7.9	NA	NA	NA	7.9
pH, laboratory------------	(standard units).	3	7.4	7.4	7.9	7.9	8.0
Alkalinity, laboratory----	(mg/L) as $CaCO_3$).	3	190	190	230	300	300
Dissolved calcium---------	(mg/L)	3	300	300	320	360	360
Dissolved magnesium-------	(mg/L)	3	120	120	130	160	160
Dissolved sodium----------	(mg/L)	3	180	180	190	240	240
Dissolved potassium-------	(mg/L)	3	9.3	9.3	9.8	9.9	9.9
Dissolved chloride--------	(mg/L)	3	25	25	27	38	38
Dissolved fluoride--------	(mg/L)	3	.6	.6	.6	.8	.8
Dissolved sulfate---------	(mg/L)	3	1,400	1,400	1,400	1,600	1,600
Dissolved silica----------	(mg/L)	3	4.1	4.1	9.5	13	13
Dissolved nitrite plus nitrate.	(mg/L as N).	3	<.10	NA	NA	NA	<.10
Dissolved phosphorus------	(mg/L)	3	.02	.02	.02	.02	.04
Dissolved iron------------	(μg/L)	3	60	60	60	100	100
Dissolved manganese-------	(μg/L)	3	20	20	20	380	380

Table 25.--*Summary of water-quality data for surface-water stations in and near the Pinon Canyon Maneuver Site*--Continued

Property or constituent	Units	N	Minimum value	Percentiles 25th	Percentiles Median 50th	Percentiles 75th	Maximum
07126470 CHACUACO CREEK AT MOUTH, NEAR TIMPAS (SITE S8)							
Temperature----------------	(°C)	5	17.5	17.8	18.0	31.0	35.0
Instantaneous streamflow---	(ft^3/s)	4	6.8	16	47	51	51
Specific conductance-------	(µS/cm)	5	290	295	300	925	1,000
pH, laboratory-------------	(standard units).	3	7.6	7.6	7.6	7.7	7.7
Alkalinity, laboratory-----	(mg/L as $CaCO_3$).	3	71	71	78	83	83
Suspended solids-----------	(mg/L)	2	860	860	2,040	3,220	3,220
Dissolved calcium----------	(mg/L)	3	34	34	34	140	140
Dissolved magnesium--------	(mg/L)	3	6.6	6.6	6.7	14	14
Dissolved sodium-----------	(mg/L)	3	7.1	7.1	9.0	22	22
Dissolved potassium--------	(mg/L)	2	4.5	4.5	5.0	5.4	5.5
Dissolved chloride---------	(mg/L)	3	2.3	2.3	3.8	3.1	3.1
Dissolved fluoride---------	(mg/L)	3	.2	.2	.2	.2	.2
Dissolved sulfate----------	(mg/L)	3	71	71	72	390	390
Dissolved silica-----------	(mg/L)	3	5.6	5.6	5.6	6.6	6.6
Dissolved solids-----------	(mg/L)	3	172	172	176	641	641
Dissolved nitrite plus nitrate.	(mg/L as N).	3	.47	.47	.51	.51	.57
Dissolved phosphorus-------	(mg/L)	2	.01	NA	NA	NA	.05
Dissolved chromium---------	(µg/L)	2	<10	NA	NA	NA	<10
Total recoverable copper---	(µg/L)	2	50	50	60	60	60
Total recoverable iron-----	(µg/L)	2	50,000	50,000	60,000	70,000	70,000
Dissolved iron-------------	(µg/L)	3	10	10	60	60	60
Total recoverable lead-----	(µg/L)	2	50	NA	NA	NA	50
Total recoverable manganese.	(µg/L)	2	1,300	1,300	1,400	1,500	1,500
Dissolved manganese--------	(µg/L)	3	4	4	7	38	38
Total recoverable zinc-----	(µg/L)	2	270	270	290	310	310
Dissolved gross beta-------	(pCi/L)	3	5.0	5.0	5.0	11	11
Suspended total gross beta	(pCi/L)	3	1.7	1.7	110	110	110
Dissolved radium-226, planchet count.	(pCi/L)	3	.2	.2	.2	.2	.2
Dissolved uranium----------	(µg/L as U)	3	1.0	1.0	1.0	2.2	2.2
Dissolved gross alpha------	(µg/L)	3	<2.8	NA	NA	NA	<17
Suspended total gross alpha	(µg/L)	3	2.3	2.3	37	37	37
Suspended sediment---------	(mg/L)	2	44	44	313	582	582

Table 25.--*Summary of water-quality data for surface-water stations in and near the Pinon Canyon Maneuver Site*--Continued

Property or constituent	Units	N	Minimum value	Percentiles 25th	Median 50th	75th	Maximum
07126485 PURGATOIRE RIVER AT ROCK CROSSING, NEAR TIMPAS (SITE S10)							
Temperature	(°C)	32	0.5	11.4	17.5	26.4	31.5
Instantaneous streamflow	(ft^3/s)	32	12	34	48	119	861
Specific conductance	(µS/cm)	31	650	1,630	2,200	2,920	3,560
Dissolved oxygen	(mg/L)	16	5.9	7.3	8.0	9.8	13.0
pH, field	(standard units).	15	7.4	8.0	8.2	8.3	8.4
pH, laboratory	(standard units).	19	7.6	8.0	8.2	8.2	8.5
Alkalinity laboratory	(mg/L as $CaCO_3$).	20	110	140	160	210	260
Dissolved calcium	(mg/L)	20	79	150	220	310	340
Dissolved magnesium	(mg/L)	20	22	90	150	210	230
Dissolved sodium	(mg/L)	20	32	120	200	230	270
Dissolved potassium	(mg/L)	20	3.1	4.7	5.2	5.5	8.1
Dissolved chloride	(mg/L)	20	7.5	17	28	34	39
Dissolved fluoride	(mg/L)	20	.1	.4	.4	.5	.5
Dissolved sulfate	(mg/L)	20	270	840	1,250	1,780	2,000
Dissolved silica	(mg/L)	20	2.5	6.4	7.7	9.8	15
Dissolved solids	(mg/L)	9	494	1,380	2,530	2,820	3,120
Suspended solids	(mg/L)	12	6.0	24	40	248	1,140
Dissolved nitrite plus nitrate.	(mg/L as N).	20	<.10	<.10	.10	.24	.70
Dissolved phosphorus	(mg/L)	20	<.01	<.01	.01	.02	.04
Total recoverable cadmium	(µg/L)	12	1	2	2	2	3
Dissolved chromium	(µg/L)	12	<10	<10	<10	<10	20
Total recoverable copper	(µg/L)	12.0	2	5	10	20	430
Suspended recoverable iron	(µg/L)	8	100	300	1,270	11,000	240,000
Total recoverable iron	(µg/L)	12	160	500	1,040	7,600	240,000
Dissolved iron	(µg/L)	20	10	20	40	60	290
Total recoverable lead	(µg/L)	12	1	3	5	7	270
Suspended recoverable manganese.	(µg/L)	12	0	10	55	220	6,300
Total recoverable manganese	(µg/L)	12	30	37.5	70	192	6,400
Dissolved manganese	(µg/L)	20	6	11	20	57	60
Total recoverable zinc	(µg/L)	12	20	30	40	70	1,100
Suspended total gross alpha	(pCi/L as U-nat).	1	1.0	1.0	1.0	1.0	1.0
Dissolved gross beta	(pCi/L)	3	<20	NA	NA	NA	<29
Suspended total gross beta	(pCi/L)	3	.4	.4	1.8	3.4	3.4
Dissolved radium-226, planchet count.	(pCi/L)	3	.1	NA	NA	NA	.2
Dissolved natural uranium	(µg/L as U)	3	8.9	8.9	12	15	15
Dissolved gross alpha	(µg/L)	3	<44	NA	NA	NA	<61
Suspended total gross alpha	(µg/L)	3	<.4	NA	NA	NA	2.8
Total cyanide	(mg/L)	11	.01	NA	NA	NA	.01
Suspended sediment	(mg/L)	24	10	43	116	424	22,000

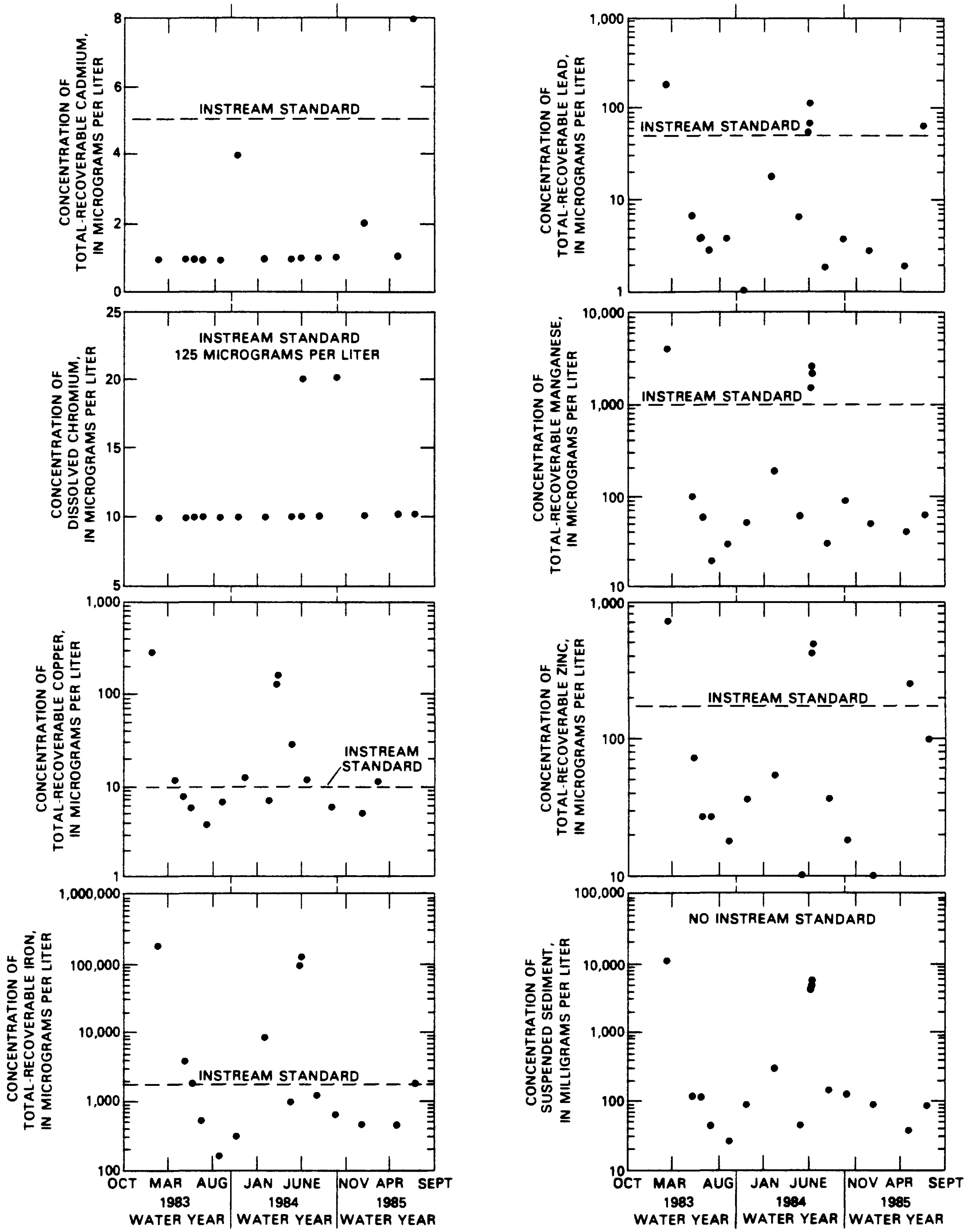


Figure 38.--Selected chemical properties and constituents with instream water-quality standards for the streamflow-gaging station Purgatoire River near Thatcher (site S4), for water years 1983-85.

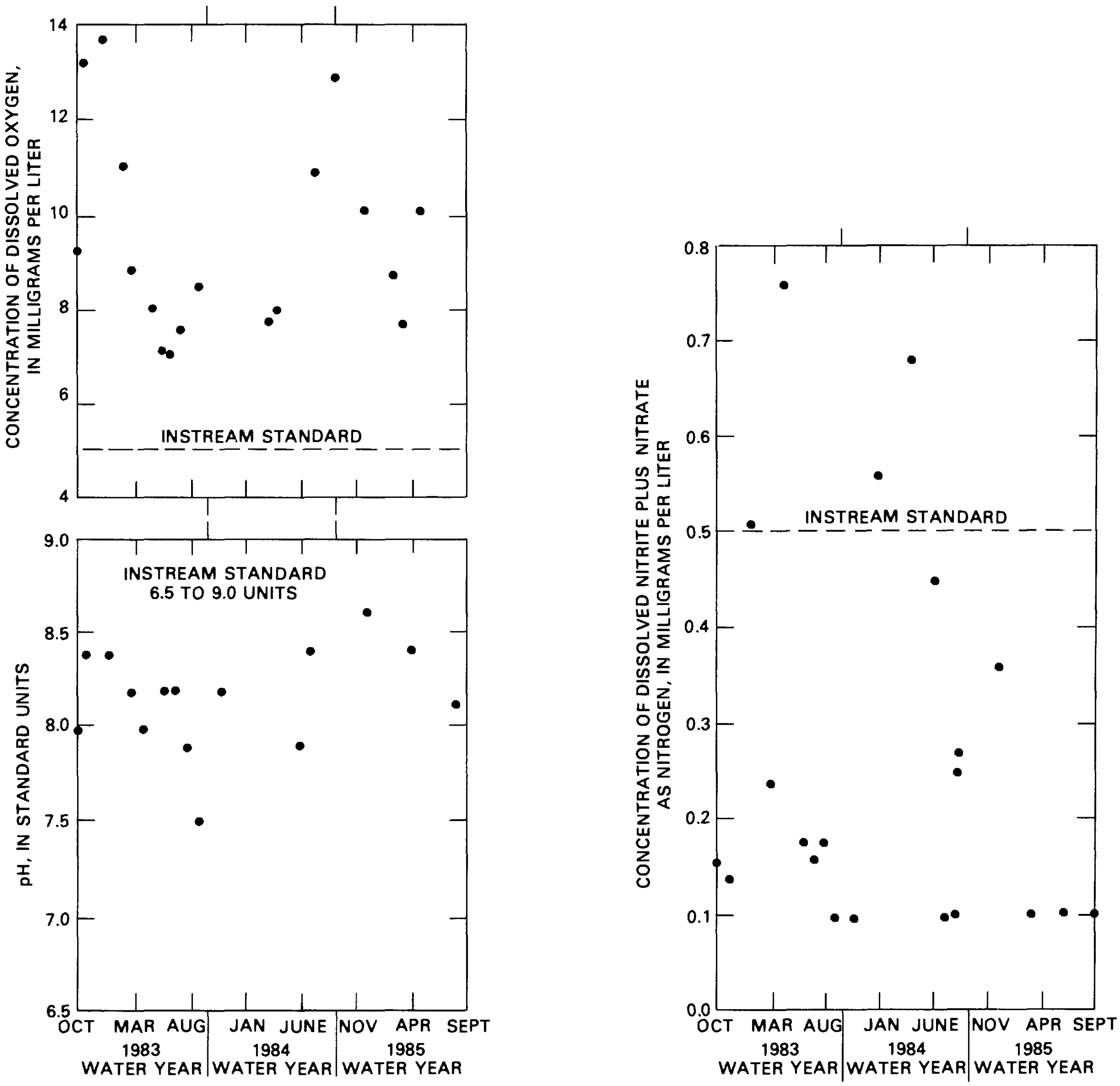


Figure 38.--Selected chemical properties and constituents with instream water-quality standards for the streamflow-gaging station Purgatoire River near Thatcher (site S4), for water years 1983-85--Continued.

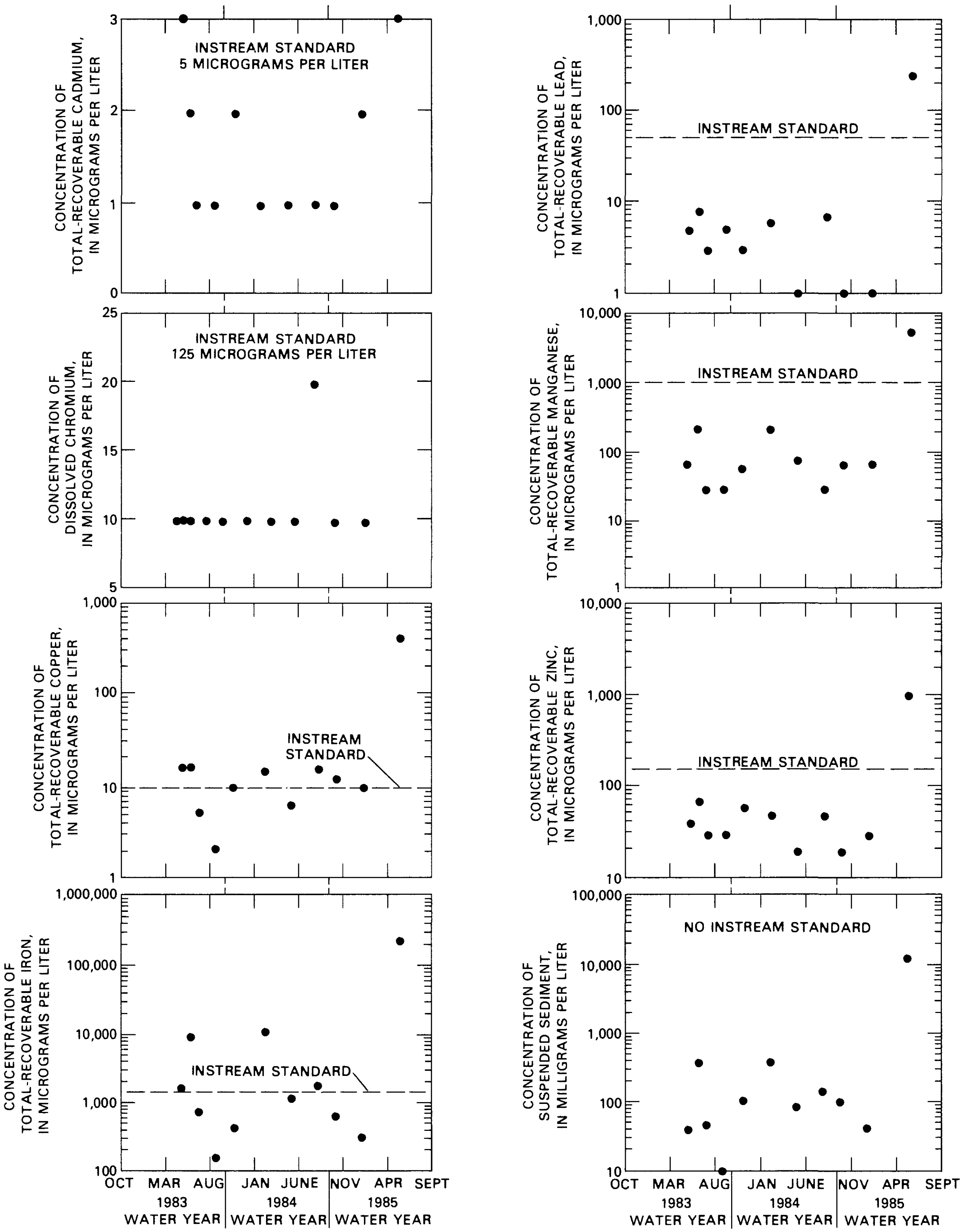


Figure 39.--Selected chemical properties and constituents with instream water-quality standards for the streamflow-gaging station Purgatoire River at Rock Crossing, near Timpas (site S10), for water years 1983-85.

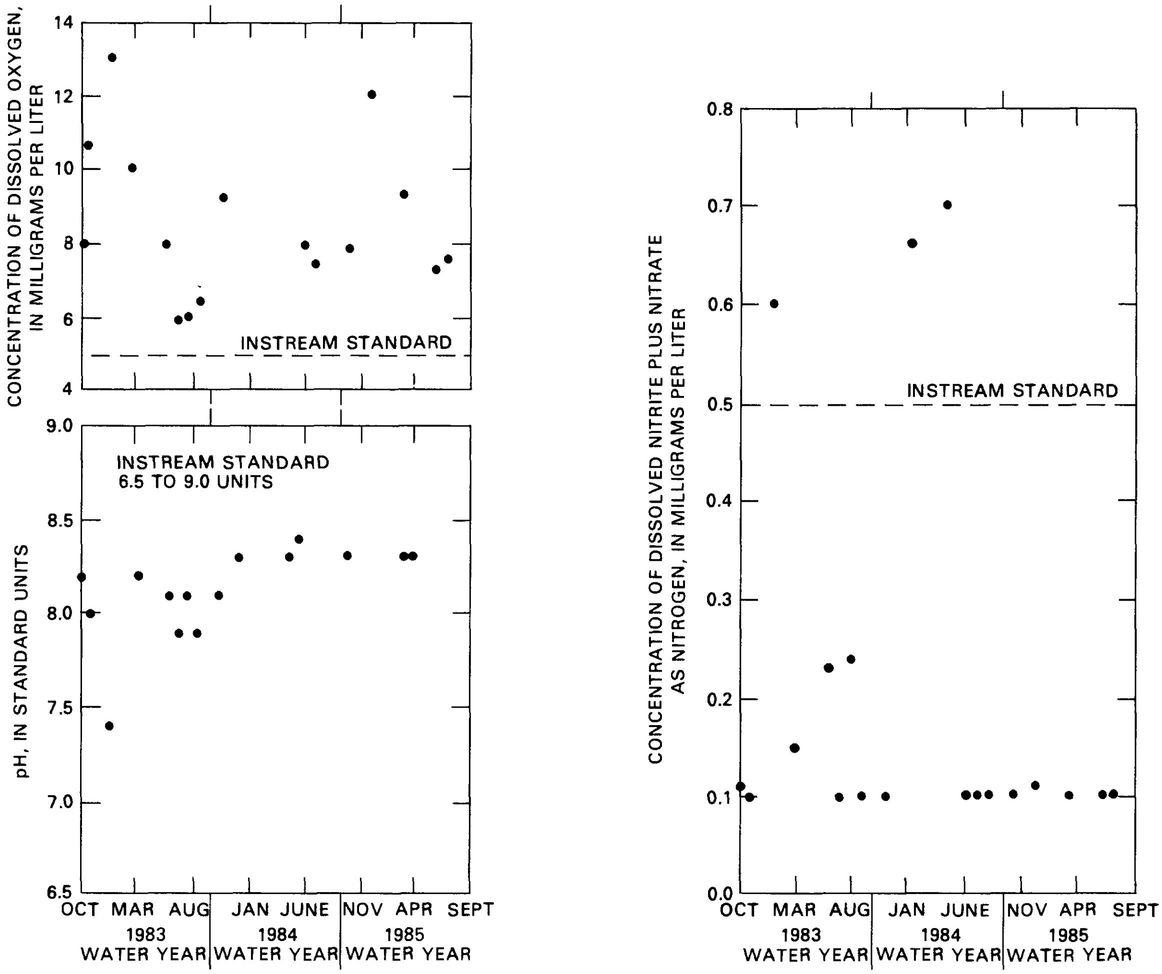


Figure 39.--Selected chemical properties and constituents with instream water-quality standards for the streamflow-gaging station Purgatoire River at Rock Crossing, near Timpas (site S10), for water years 1983-85--Continued.

Table 26.--*Regression equations and statistics for major ions compared to specific conductance in surface water*

[N, number of observation pairs used to compute the regression; K, specific conductance, in microsiemens per centimeter at 25 degrees Celsius]

Constituent (milligrams per liter)	Regression equation	N	Coefficient of determination (R^2)	Standard error of estimate (milligrams per liter)
	07120620 BIG ARROYO NEAR THATCHER (SITE S1)			
Dissolved solids	= (0.70 K) - 24	9	0.96	14
	Cations			
Calcium	= (0.14 K) - 17.87	16	.96	8.3
Magnesium	= (0.027 K) - 5.72	16	.97	1.5
Sodium	= (0.05 K) + 7.02	16	.96	3.4
Potassium	Relation undefined			
	Anions			
Sulfate	= (0.59 K) - 108	17	.97	31
Bicarbonate	Relation undefined			
Chloride	Relation undefined			
Fluoride	Relation undefined			
	07126200 VAN BREMER ARROYO NEAR MODEL (SITE S3)			
Dissolved solids	= (0.89 K) - 199	9	0.99	49
	Cations			
Calcium	= (0.09 K) - 10	8	.98	7.4
Magnesium	= (0.05 K) - 12.8	8	.99	1.3
Sodium	= (0.09 K) - 14.0	8	.94	13
Potassium	Relation undefined			
	Anions			
Sulfate	= (0.52 K) - 208	8	.98	38
Bicarbonate	Relation undefined			
Chloride	Relation undefined			
Fluoride	Relation undefined			

Table 26.--*Regression equations and statistics for major ions compared to specific conductance in surface water*--Continued

Constituent (milligrams per liter)	Regression equation	N	Coefficient of determination (R^2)	Standard error of estimate (milligrams per liter)
	07126300 PURGATOIRE RIVER NEAR THATCHER (SITE S4)			
Dissolved solids	= (1.02 K) - 279	22	0.99	81
	Cations			
Calcium	= (0.093 K) + 2.59	22	.93	22
Magnesium	= (0.076 K) - 32	22	.97	12
Sodium	= (0.083 K) - 24.8	22	.98	11
Potassium	----------------Relation undefined----------------			
	Anions			
Sulfate	= (0.65 K) - 254	20	.98	78
Bicarbonate	----------------Relation undefined----------------			
Chloride	= (0.012 K) - 6.6	20	.84	5.0
Fluoride	----------------Relation undefined----------------			
	07126325 TAYLOR ARROYO BELOW ROCK CROSSING, NEAR THATCHER (SITE S5)			
Dissolved solids	= (1.04 K) - 294	6	0.99	72
	Cations			
Calcium	= (0.16 K) - 19	10	.99	8.6
Magnesium	= (0.04 K) - 6.6	10	.92	8.4
Sodium	= (0.04 K) - 5.0	10	.85	12
Potassium	----------------Relation undefined----------------			
	Anions			
Sulfate	= (0.61 K) - 118	10	.99	55
Bicarbonate	----------------Relation undefined----------------			
Chloride	----------------Relation undefined----------------			
Fluoride	= (0.0003 K) + .06	9	.92	.1
	07126485 PURGATOIRE RIVER AT ROCK CROSSING, NEAR TIMPAS (SITE 10)			
Dissolved solids	= (1.01 K) - 249	18	0.99	64
	Cations			
Calcium	= (0.096 K) - 1.42	19	.96	16
Magnesium	= (0.08 K) - 36.9	19	.98	10
Sodium	= (0.08 K) - 23.3	19	.98	10
Potassium	----------------Relation undefined----------------			
	Anions			
Sulfate	= (0.66 K) - 268	19	.99	59
Bicarbonate	----------------Relation undefined----------------			
Chloride	= (0.01 K) - 1.22	19	.93	2.6
Fluoride	----------------Relation undefined----------------			

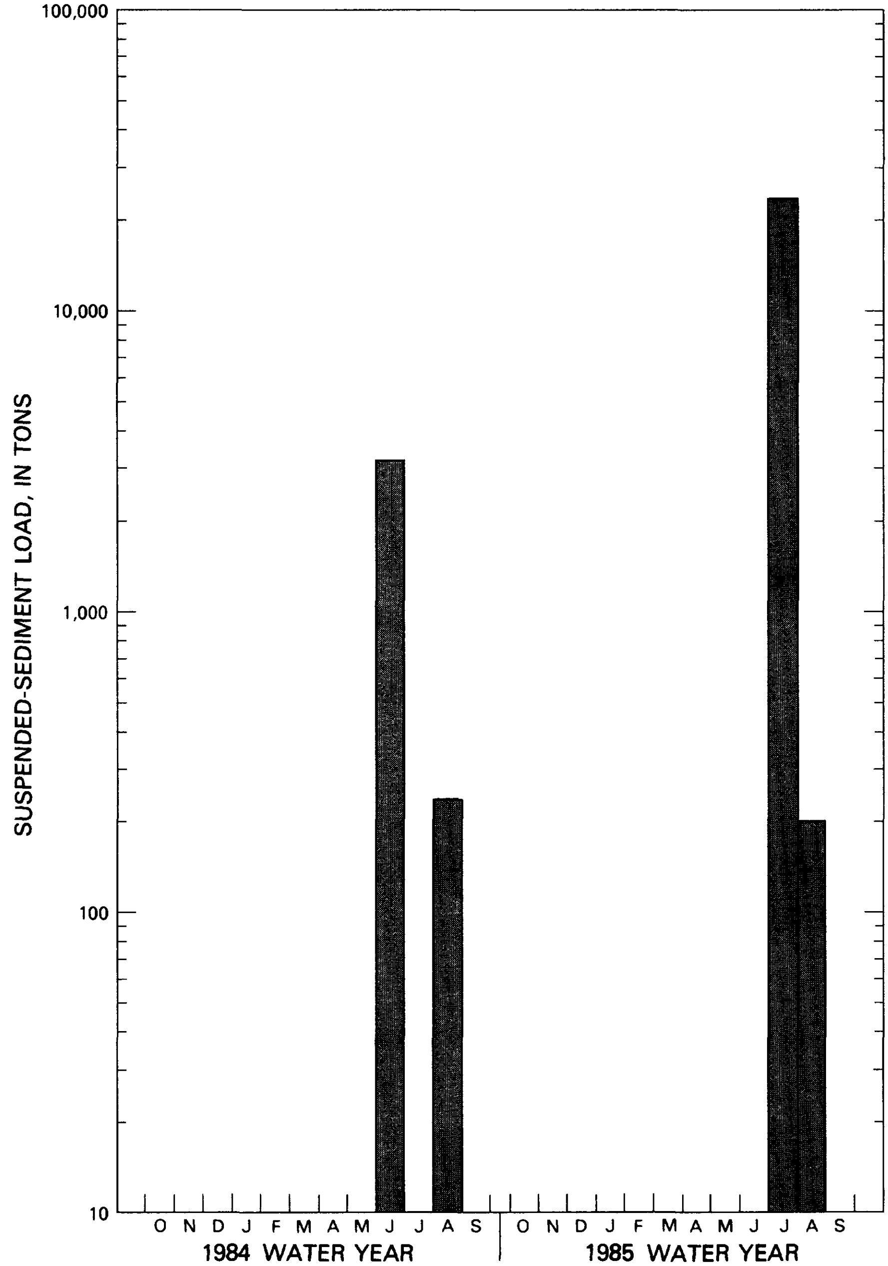


Figure 40.--Monthly suspended-sediment load for the streamflow-gaging station Big Arroyo near Thatcher (site S1), for water years 1984-85.

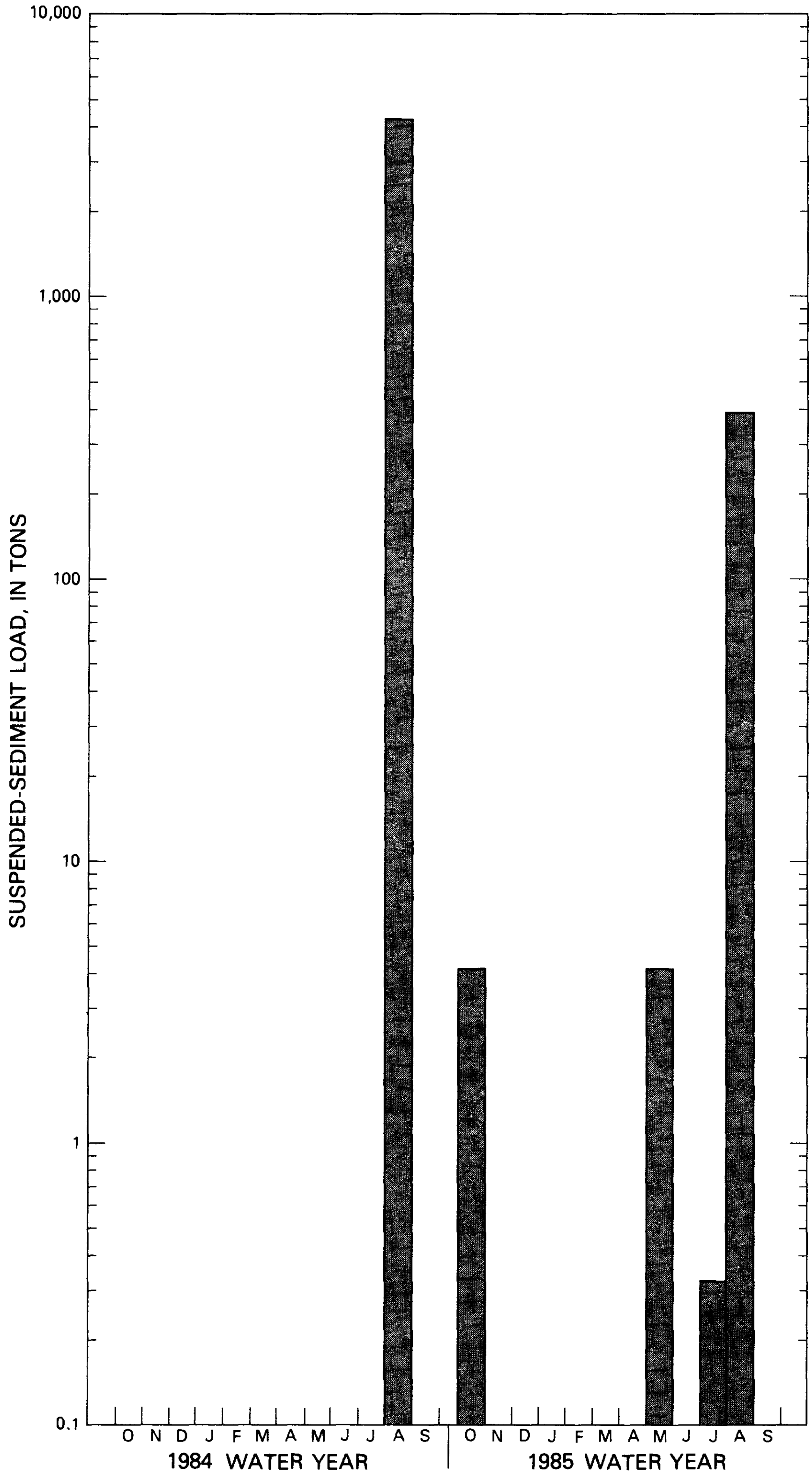


Figure 41.--Monthly suspended-sediment load for the streamflow-gaging station Taylor Arroyo below Rock Crossing, near Thatcher (site S5), for water years 1984-85.

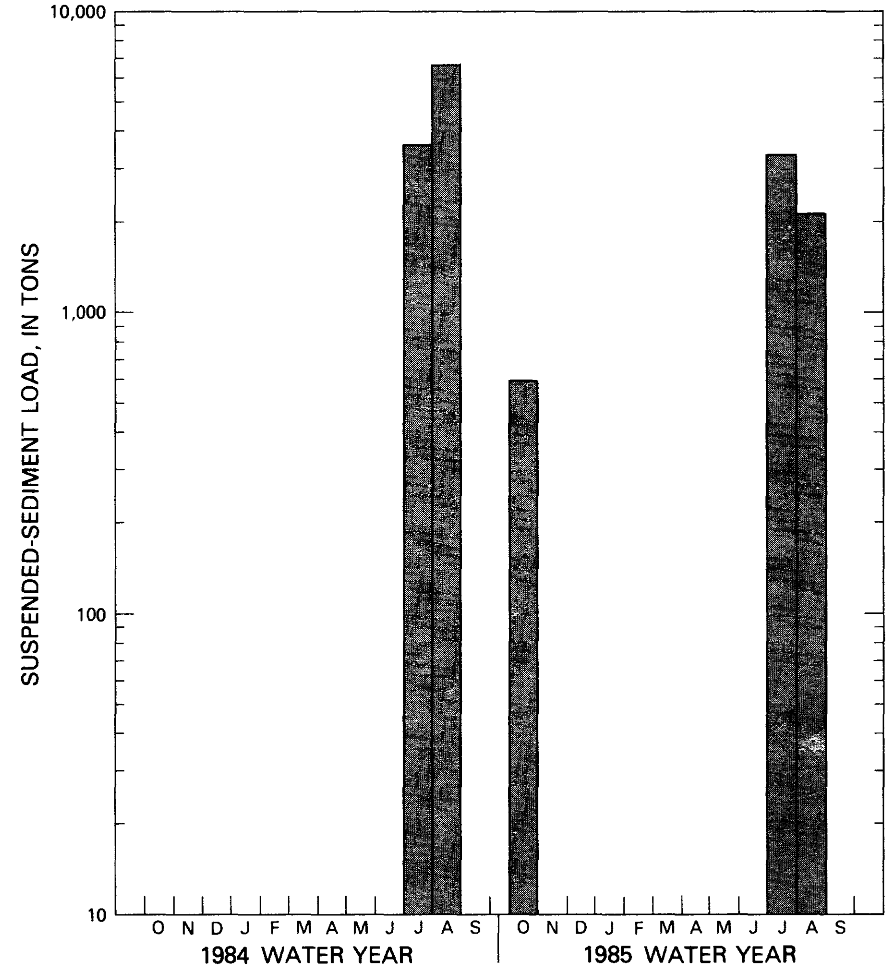


Figure 42.--Monthly suspended-sediment load for the streamflow-gaging station Chacuaco Creek at mouth, near Timpas (site S8), for water years 1984-85.

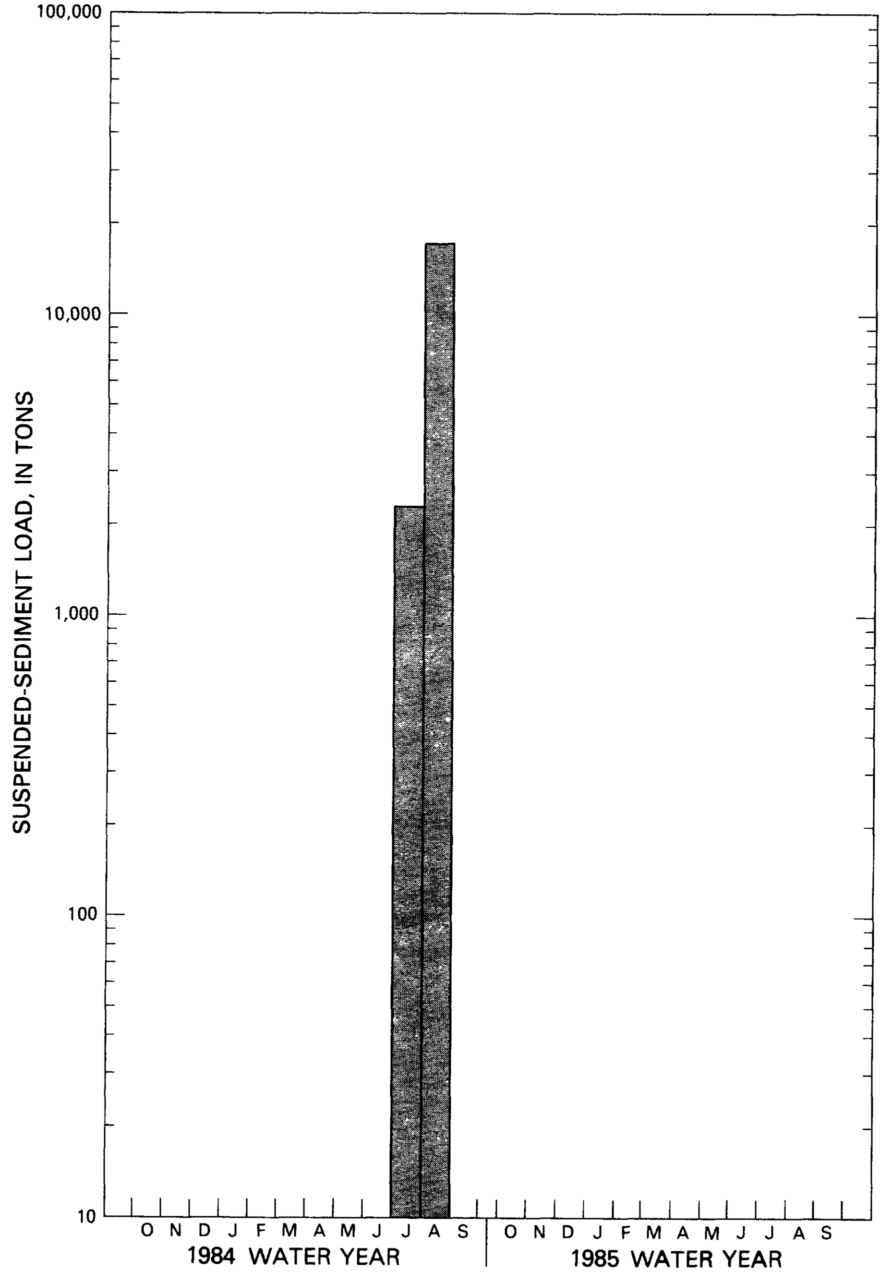


Figure 43.--Monthly suspended-sediment load for the streamflow-gaging station Bent Canyon Creek at mouth, near Timpas (site S9), for water years 1984-85.