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SOURCE AREAS OF SALINITY AND TRENDS OF SALT LOADS IN STREAMFLOW IN THE UPPER COLORADO RIVER, TEXAS

By Jack Rawson

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SOURCE AREAS OF SALINITY AND TRENDS OF SALT LOADS

IN STREAMFLOW IN THE UPPER COLORADO RIVER, TEXAS

By

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U.S. Geological Survey

ABSTRACT

A series of seven studies of the quality and quantity of low flows in a 35.5-mile reach of the Colorado River upstream from Colorado City, Texas, were made from February 1975 to March 1978 to delineate areas of saline inflow. These studies showed generally that ground water contributed throughout the reach is saline, but that loads of dissolved constituents in ground-water accretions are highest in three subreaches. Yields per mile of river channel from these subreaches during the low-flow studies averaged more than 5.5 tons of dissolved solids per day, of which more than 1.8 tons were sodium and 2.9 tons were chloride.

Salt-load trend studies for three long-term continuous streamflow and daily water-quality stations show that the salinity of the flow upstream from Ira (mile 826.3) increased significantly after 1963 but decreased significantly after 1970. Part of the reach upstream from Ira is proximate to oil fields. The production and open-pit disposal of oil-field brines in the area increased significantly in the early 1960's; but a ban on open-pit disposal was enacted in 1969. No significant downward trend of salinity in flow at other daily water-quality stations downstream from Ira occurred after the ban on open-pit disposal of oil-field brines.

The low-flow and salt-load trend studies indicate that part of the salinity in the flow of the Colorado River has resulted from the inflow of oil-field brine; but preponderant evidence indicates that the major part of the salinity is of natural origin. Neither the ban on open-pit disposal nor pumping of saline ground water has significantly reduced the salinity of flow downstream from Cuthbert (mile 810.6).

Diversion of saline low flows from the Colorado River at mile 799.3 upstream from Colorado City since January 1969 has resulted in significant improvement in the quality of water. Decreases in the discharge-weighted averages of dissolved solids and chloride in the flow of the Colorado River at Colorado City (mile 796.3) during the 1969-78 water years were about 420 milligrams per liter and 280 milligrams per liter, respectively.

INTRODUCTION

Purpose and Scope

The upper Colorado River and some of its tributaries between Lake J. B. Thomas and Colorado City yield saline waters that adversely affect the water quality of the river throughout its downstream course to the Gulf of Mexico.

Several water-quality management programs and remedial projects, including a ban on the disposal of oil-field brines in open pits, diversion of saline low flows from the river, and lowering of ground-water heads and possibly the saline base flow of the river by large withdrawals of saline ground water for use in secondary recovery of oil, have been initiated within the past several years. Recent observations by the Colorado River Municipal Water District (Green, Marr, and Logan, 1974, p. 45) have indicated that the remedial projects are reducing the quantity of saline inflow to the upper Colorado River.

Data delineating the source areas of saline inflow and the quantity and quality of the flow are needed for comprehensive basin planning by the Corps of Engineers. The U.S. Geological Survey, in cooperation with the Corps of Engineers, began a study in 1975 to delineate the areas of saline inflow and to determine if water-quality management programs and remedial projects are reducing the salinity loads of the Colorado River. Geologic and ground-water studies of the area were conducted concurrently by the U.S. Army Corps of Engineers.

Previous Studies

The Geological Survey, in cooperation with the Corps of Engineers, the Texas Department of Water Resources (and its predecessor agencies), the Colorado River Municipal Water District, the Lower Colorado River Authority, and other agencies, has operated for many years a network of daily and periodic water-quality stations on streams in the Colorado River basin. Water-quality data collected through the 1972 water year have been summarized by Leifeste and Lansford (1968) and by Rawson, Maderak, and Hughes (1973).

Several other studies concerning the chemical quality of surface waters in the basin have been made since 1946. Most of these studies were directed toward determining the sources of saline inflow to the upper part of the basin. The Geological Survey, in cooperation with the Texas Department of Water Resources and the Texas Electric Service Company, studied the quality of surface waters in the Bull Creek area in Scurry County in 1946 and in the Cuthbert area in Mitchell County in 1948. The results of these studies were summarized by McDowell (1959) in a report describing instrumentation involved in salt-load studies.

Reed (1961), in a consulting report to the Colorado River Municipal Water District concerning the sources of saline water in the Colorado River between Lake J. B. Thomas and Colorado City, presented evidence that brines entering the river are directly related to oil-field operations.

Rawson (1969), in a report concerning the quantity and quality of low flow in the Colorado River between Lake J. B. Thomas and Robert Lee, concluded that the salinity probably resulted from inflow of brines from oil fields and from inflow of saline water not related to oil-field activities.

Green, Marr, and Logan (1974) analyzed data from these and additional studies, supplemented by data collected by the Corps of Engineers during the period from September 1973 to March 1974. They concluded that the data indicate the salinity to be from both natural sources and oil-field activity but that the preponderance of evidence indicates oil-field activities to have been the major contributor.

Metric Conversions

Most units of measurement used in this report are inch-pound units. For those readers interested in using the metric system, the inch-pound units may be converted to metric units by the following factors:

To convert from	Multiply by	To obtain
barrel (bbl) (petroleum, 1 bbl=42 gal)	0.1590	cubic meter (m^3)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
foot	0.3048	meter (m)
mile	1.609	kilometer (km)
ton per day (short ton=2000 pounds)	0.9072	megagram per day (Mg/d)

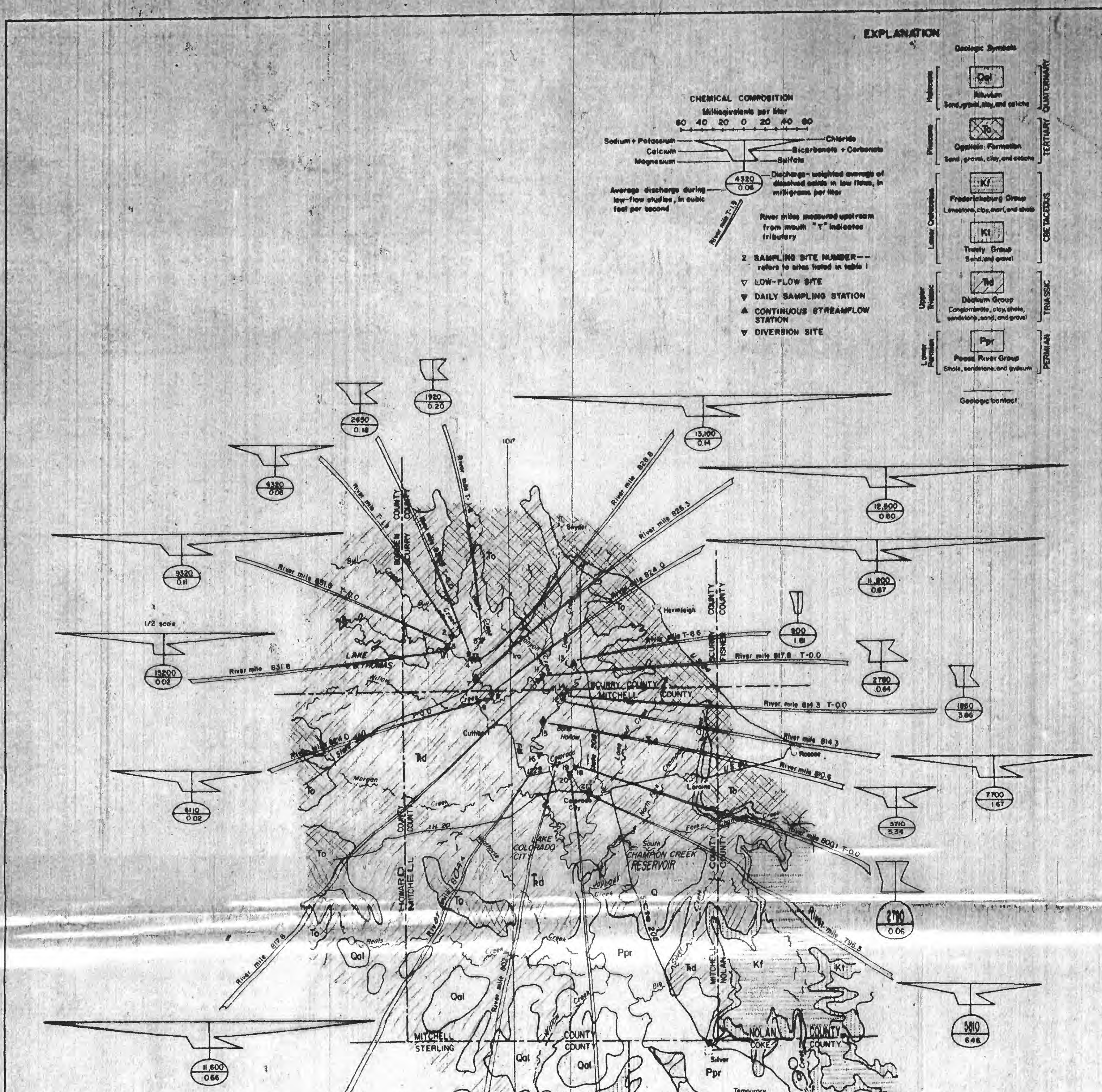

FIGURE 1.-Geology of the upper Colorado River basin and chemical composition of low flows of streams

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DESCRIPTION OF DRAINAGE AREA

Topography, Drainage, and Diversions

The 35.5-mile reach of the Colorado River included in this study extends from the mouth of Bull Creek below Lake J. B. Thomas in southwestern Scurry County to near Colorado City in central Mitchell County (fig. 1).

The topography of most of the area in Scurry and Mitchell Counties is rolling, but the land surface in some places along the Colorado River has been deeply dissected by erosion. The land surface slopes regionally from northwest to southeast and locally toward the Colorado River. Altitudes range from about 2,500 feet above NGVD (National Geodetic Vertical Datum of 1929) along topographic divides to about 2,000 feet above NGVD of 1929 along the Colorado River near Colorado City. Local relief averages from 50 to 100 feet and ranges upward to 150 feet in places along the Colorado River.

Tributaries to the Colorado River in the 35.5-mile reach downstream from Lake J. B. Thomas include Bull Creek, Bluff Creek, Willow Creek, Canyon Creek, Deep Creek, and Bone Hollow. Each of these streams, except Willow Creek, heads in areas east or north of the Colorado River and flows southward. Willow Creek heads west of the river and flows eastward. Most of the streams are intermittent and frequently are dry for long periods, especially during late spring and summer.

Significant diversions of streamflow occur at two sites in or near the area studied. A study was begun in 1946 to locate an adequate, supplementary water supply for several cities in the vicinity of the Colorado River upstream from Colorado City (McDowell, 1959, p. 1). The study delineated areas of saline inflow on the lower reaches of Bull and Bluff Creeks and on the Colorado River in the reach from about 1 mile upstream from Bull Creek to Bluff Creek. On the basis of this study, the proposed site for Lake J. B. Thomas was moved upstream from the area of saline inflow near the western boundary of Scurry County. The study showed the flow in Bull Creek upstream from the Borden-Scurry County line to be of good quality. A dam and canal were constructed near this site to divert flow of Bull Creek into Lake J. B. Thomas. Storage in Lake J. B. Thomas began in 1952; diversions from Bull Creek began in 1953.

The Colorado River Municipal Water District (CRMWD), recognizing a need to improve the quality of streamflow in the Colorado River, constructed in 1969 a low-water dam to divert the saline base flow into an off-channel reservoir upstream from Colorado City. The base flow and saline runoff that results from the first flush of accumulated salts by rainfall are diverted from the river, stored in the off-channel reservoir, and used by oil companies for secondary recovery of oil.

General Geology and Quality of Ground Water

Figure 1 shows the outcrops of the major geologic units in and adjacent to the area of study. The geology of the area has been described by Green, Marr, and Logan (1974, p. 5-8); most of the following discussion has been extracted from this description.

Thick sequences of sand, shale, limestone, and evaporites were deposited in the area during the Permian Period and were followed by the deposition of nonmarine sand, shale, and gravel during the Triassic Period. After a period of erosion, Cretaceous seas advanced from the south and deposited another sequence of sand, shale, and limestone. The sediments of Permian and Triassic age dip gently to the northwest; rocks of Cretaceous age dip gently to the southeast.

The principal rocks that crop out in the study area include the Ogallala Formation of Tertiary age and the Dockum Group of Triassic age. The Ogallala Formation, which consists of caliche, sand, and gravel interbedded with clay, crops out in the northeastern part of the study area. Most tributaries to the Colorado River in the area head in the Ogallala Formation.

The Dockum Group consist of both the Santa Rosa Formation and the equivalent of the Chinle Formation, but most of the Triassic sedimentary rocks in the study area are considered to belong to the Santa Rosa Formation. The Santa Rosa Formation generally consists of a hard, coarse-gravel conglomerate at the base, succeeded upward by alternating beds of red and gray micaceous shale, clay, sand, or gravel. The entire reach of the Colorado River in the area studied and the lower reaches of most tributaries are underlain by the Santa Rosa Formation.

The quality of ground water in parts of the upper Colorado River area has been described by Shamburger (1967), Mount and others (1967), and Green, Marr, and Logan (1974). Additional studies have been conducted by the Corps of Engineers.

A comprehensive discussion of the quality of ground water in the area is beyond the scope of this report. However, the following discussion presents several generalizations that were extracted from previous studies.

The Ogallala Formation is of minor importance as an aquifer in the study area. Information concerning the quality of ground water is meager; but considerable data are available from wells west of and adjacent to the study area.

According to Mount and others (1967, p. 36, 42):

"The chemical quality of the water in the Ogallala aquifer varies widely within relatively short distances. Dissolved solids range from several hundred to several thousand parts per million.

"Variation in chemical quality of the water in the Ogallala are both natural and man made...

"Waters highly mineralized because of natural causes are associated with areas of shallow water-table conditions, notably areas near water-table lakes and near draws. Where the water table is at or very near the land surface, evapotranspiration processes produce highly mineralized ground waters by the concentration of residual salts. Areas of highly mineralized ground water result artificially from surface disposal of oil-field brines and other industrial wastes and possibly from leakage of brine from oil wells. Man-made contamination is a matter of special concern, particularly because of its far reaching effects. A contaminant, once introduced in the aquifer, spreads from the contaminated area, moving in about the same direction and at the same rate as the main body of ground water in the aquifer. Hence, water may be rendered unfit for most beneficial uses over a considerably large area, and because of the slow rate of movement, the effects of contamination may persist for many decades."

The quality of water in the Santa Rosa Formation is highly variable also. Shamburger (1967, p. 63) has shown that ground water from most wells near the eastern limit of the study area in Mitchell County contains less than 1,000 mg/L (milligrams per liter) dissolved solids. The water becomes progressively more mineralized westward toward the Colorado River. Water from most wells near the western limit of the study area in Mitchell County contains more than 3,000 mg/L dissolved solids.

The Santa Rosa Formation is underlain by sedimentary rocks of Permian age. Water associated with petroleum in the Permian rocks is highly mineralized. Several investigators have shown that oil-field brines produced from the Permian rocks have resulted in local degradation of the quality of water in the Santa Rosa Formation and in surface runoff (Grouch, 1964, p. 7-9).

According to Green, Marr, and Logan (1974, p. 24), "It is unknown to what extent, if any, these brines have charged overlying strata through natural artesian pressure or exposure through man-made borings. It is well documented, however, that these brines have contributed to pollution of Triassic waters in the study area through improper surface disposal methods. Due to relatively high chloride concentrations encountered in the Santa Rosa Formation on the west side of the river (ranging from approximately 2200 ppm north of the town of Westbrook to 30,000 ppm near Lake J. B. Thomas) it might be suggested that there is a hydraulic connection, at least locally, between the Permian System and the unconformably overlying Triassic."

Locations of Oil Fields

Several of the preceding sections have indicated that brines from oil fields have contributed to the degradation of the quality of surface and ground waters in the upper Colorado River basin. Locations of oil and gas fields in the area are shown on figure 2.

Green, Marr, and Logan (1974, p. 27-28) have summarized the history of oil exploration and production in the study area. The first well in Scurry County was completed in 1920. Exploration and development peaked in the late 1950's and declined thereafter.

Green, Marr, and Logan (1974, p. 29) have also summarized the production and disposal of oil-field brines in Mitchell and Scurry Counties. Their summary is presented in table 1.

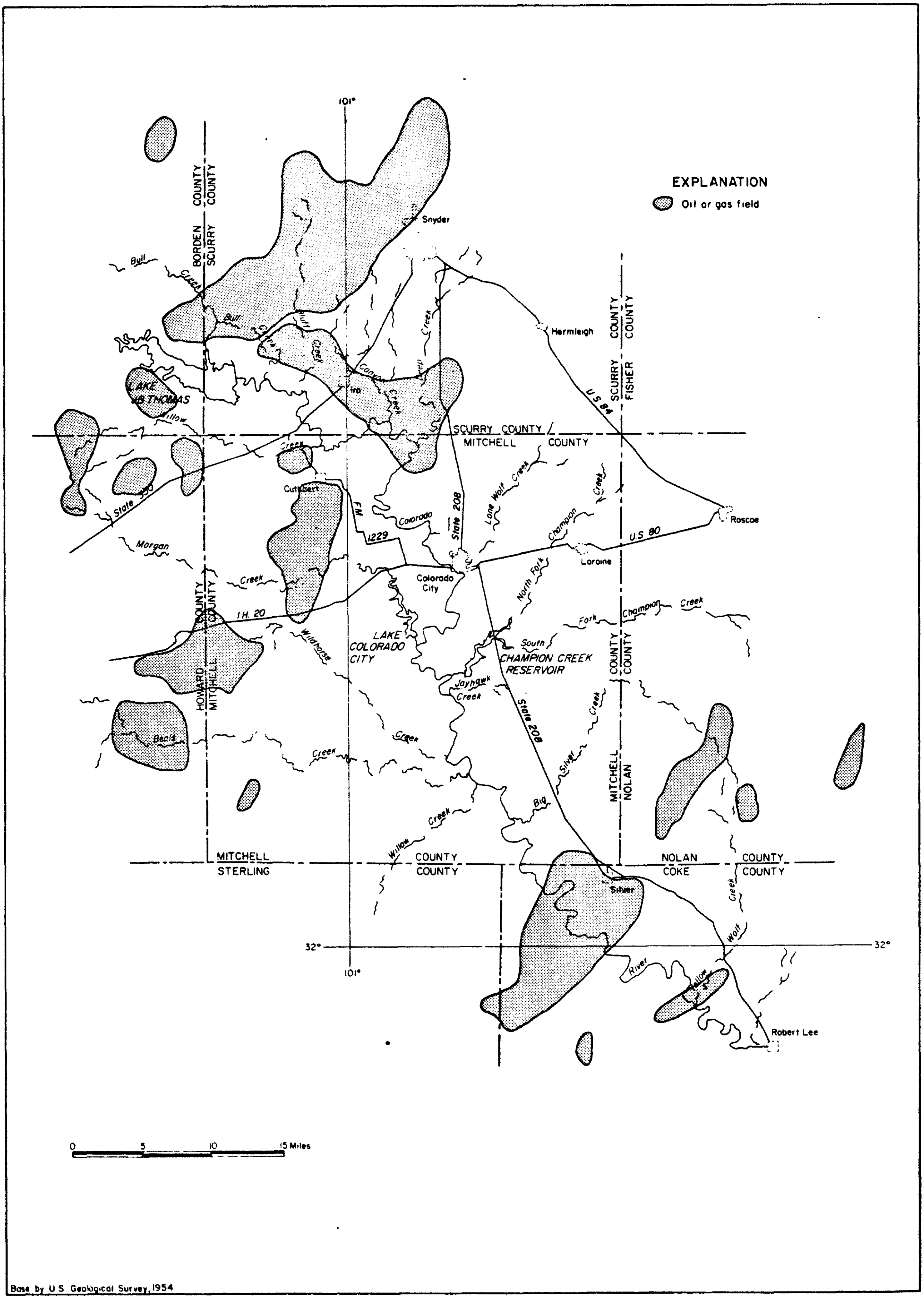

FIGURE 2.-Locations of oil and gas fields

Table 1.--Brine production and disposal in Scurry and Mitchell Counties

County	Year	Total brine production (barrels)	Open-pit disposal		Deep-well disposal		Pressure maintenance		Other methods of disposal	
			Barrels	Percent	Barrels	Percent	Barrels	Percent	Barrels	Percent
Scurry	1956	28,042	13,937	50	10,318	37	3,400	12	350	1
	1961	12,246,288	3,755,499	30	8,476,721	69	10,979	<1	3,089	<1
	1967	14,995,950	355,184	2	8,937,766	60	5,576,138	37	126,862	1
Mitchell	1956	1,412	1,412	100	0	0	0	0	0	0
	1961	1,299,626	891,787	68	405,701	31	Unknown	Unknown	2,130	<1
	1967	3,681,436	46,301	<1	833,652	23	2,790,775	76	10,708	<1

The data in table 1 indicate that annual brine production in Scurry and Mitchell Counties increased from about 29,000 barrels in 1956 to more than 13,000,000 barrels in 1961 and to more than 18,000,000 barrels in 1967. More than 4,600,000 barrels of brine produced in 1961 were disposed of in open-surface pits; only about 400,000 barrels of brine produced in 1967 were disposed of in open pits.

A State law passed in 1969 prohibited open-pit disposal of oil-field brine.

METHODS OF INVESTIGATION

Low-Flow Studies

Some of the earlier studies delineated the general areas of saline inflow (see section "Previous Studies"). To supplement these data and to delineate the areas of saline inflow more precisely, a series of low-flow studies was made for the 35.5-mile reach of the Colorado River upstream from Colorado City. Eight low-flow studies (two studies per water year) were made during the period from February 1975 to March 1978 to cover an anticipated range in climatic conditions. Seven of the low-flow studies were completed after periods of at least a week without significant precipitation when most of the sustained flow was from ground-water accretions. Precipitation occurred during a study in November 1976 and produced small to moderate rises on some streams. The increase in streamflow at some sites during this study caused a significant decrease in salinity. The results of this study are not included in this report.

Duration curves of daily flows at two long-term stations on the upper Colorado River for periods of record after closure of Lake J. B. Thomas are shown on figure 3. The steep slope of the curves indicates that flows of the upper Colorado River between Lake J. B. Thomas and Colorado City are highly variable and are sustained largely by direct runoff. Sustained base flow usually occurs during the cool-weather months when evapotranspiration is minimum; consequently, the seven low-flow studies were made during winter and early spring (January, February, and March).

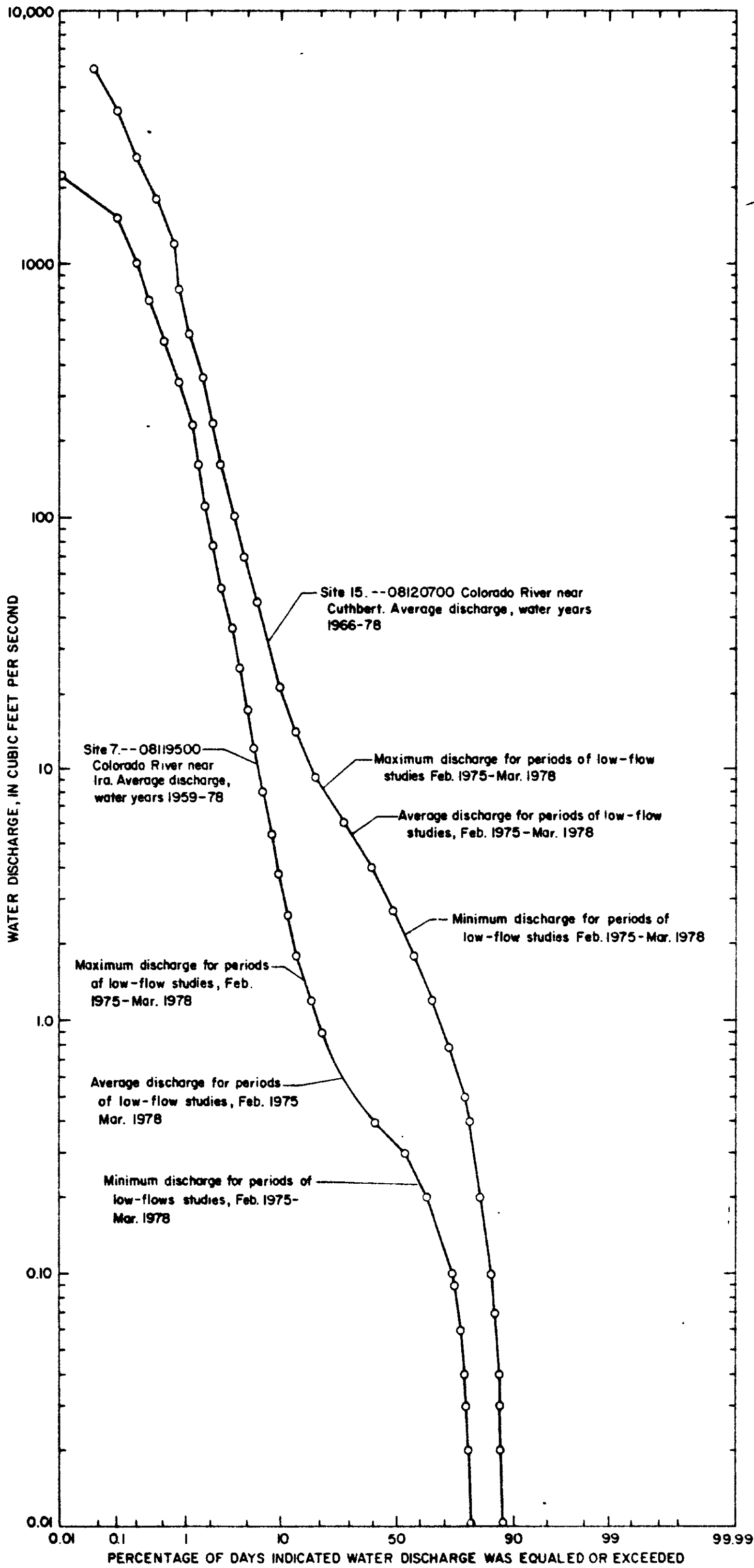

FIGURE 3.- Duration curves of daily flows for selected sites in the upper Colorado River basin

An earlier study by the Corps of Engineers (Green, Marr, and Logan, 1974) indicated the salinity of the Colorado River to be highest in the reach upstream from the Geological Survey's discontinued streamflow station 08119500 Colorado River near Ira (mile 826.3). The study also indicated that the salinity of Bull and Bluff Creeks increased significantly near the mouths of both streams. To substantiate these conclusions and to locate localized sources of salinity in these areas, field reconnaissances of the 1.9-mile reach of Bull Creek upstream from the mouth, 1.8-mile reach of Bluff Creek upstream from the mouth, and the 3.0-mile reach of the Colorado River between Bull and Bluff Creeks were made at the beginning of the low-flow study in Feburary 1975.

No localized source of salinity was found in these reaches during the reconnaissances, but the salinity of each of the three reaches increased significantly as the water flowed downstream. Data on the quality or quantity or both of streamflow were collected at 2 sites on both Bull and Bluff Creeks and at 16 additional sites on the Colorado River and other tributaries during subsequent low-flow studies (fig. 1). Water was impounded or diverted or both at one site (site 19, fig. 1) by the Colorado River Municipal Water District. The quantity of water diverted at this site was added to flows at sites downstream to enable the comparison of the quantity and quality of flows at these sites with those at sites upstream.

Salt-Load Trend Studies

Recent observations by the Colorado River Municipal Water District have indicated that water-quality management programs and remedial projects such as the ban on the disposal of oil-field brines in open pits, diversion of saline low flows from the river, and the lowering of ground-water heads by withdrawals of saline ground water have reduced the salinity loads of the Colorado River.

Cursory examination of water-quality data may be misleading unless variations in streamflow are considered. A method for studying trends in water quality by utilization of double-mass curves of the quantity and quality of streamflow has been described by Searcy and Hardison (1960, p. 42-44). The graph of the cumulative data for one variable (such as yearly mean dissolved-solids loads) versus the cumulative data of a related variable (such as yearly mean water discharges), for example, is a straight line so long as the relation between the variables is a fixed ratio. Breaks in the double-mass curve of such variables reflect changes in the relation between the variables. Poor correlation between the variables can prevent detection of inconsistencies in a record, but an increase in the length of record tends to offset the effect of poor correlation.

The Geological Survey has operated continuous streamflow and daily water-quality stations at three sites on the Colorado River in the area of saline inflow near Colorado City (fig. 1). Station 08119500 Colorado River near Ira, which was discontinued in September 1970, was reestablished in November 1974 to provide additional information on the quantity and quality of streamflow in the area studied. The concurrent periods of continuous streamflow and daily water-quality record for these stations are shown in table 2.

Table 2.--Index of continuous streamflow and daily water-quality stations on the upper Colorado River, Texas

Station		Low-flow site number (fig. 1)	Period of concurrent streamflow and daily water-quality record
08119500	Colorado River near Ira	7	Nov. 1958 to Sept. 1970, Nov. 1974 to 1979
08120700	Colorado River near Cuthbert	15	Mar. 1965 to 1979
08121000	Colorado River at Colorado City	21	May 1946 to Sept. 1954, Nov. 1956 to 1979

Impoundment of water in Lake J. B. Thomas since 1952 has modified the streamflow and water-quality regimes at sites downstream. Most management programs and remedial projects to improve the water quality downstream from Lake J. B. Thomas were initiated in the late 1950's or early 1960's. Consequently, only those records of streamflow and water quality for complete water years after 1957 were utilized in the salt-load trend studies.

The Colorado River Municipal Water District constructed in 1969 a low-water dam to divert the saline base flow of the Colorado River (fig. 1, site 19) into an off-channel reservoir located 3.0 miles upstream from Colorado City. To supplement the records of diversions, a daily sampling station was established at this site during the 1975 water year. These records, supplemented by continuous streamflow and daily water-quality data for station 08121000 Colorado River at Colorado City, were used to determine the effects of the diversions on the quantity and quality of streamflow at the station at Colorado City.

ANALYSIS OF DATA

Synopsis of the Quantity and Quality of Low Flows

General

Locations of 21 sites (11 sites on the main stream, 9 sites on tributaries, and the site of the CRMWD diversion) included in the low-flow studies are shown on figure 1. Descriptions of the sites are given in table 3; results of discharge measurements and chemical analyses are given in table 4.

The discharge-weighted averages of principal dissolved constituents in flow at each site during the 7 days of the low-flow studies were calculated from the results of discharge measurements, results of chemical analyses, and records of diversion at the CRMWD diversion dam. The discharge-weighted average of constituents in low flows represents the approximate concentration of constituents in the water at a site if all water passing that site during a period were impounded in a reservoir and mixed with no adjustment for evaporation, rainfall, or chemical change that might occur during storage.

TABLE 3.--Locations and descriptions of low-flow data-collection sites in the upper Colorado River basin, from February 1975 to March 1978

Site No.	Stream	Location	River mile	Remarks
1	Colorado River	Lat 32°34'58", long 101°05'42", 50 ft upstream from Bull Creek	831.8	Streambed of sand. Grass and scattered trees on banks.
2	Bull Creek	Lat 32°36'00", long 101°05'38", 300 ft upstream from bridge on FM 2085.	T-1.9	Streambed of gravel and sand. Grass and scattered trees on banks.
3	do	Lat 32°34'54", long 101°05'42", 30 ft upstream from Colorado River.	831.8	do.
4	Colorado River	Lat 32°34'17", long 101°03'20", 40 ft upstream from Bluff Creek.	828.8	Streambed of gravel and sand. Grass, brush, and scattered trees on banks.
5	Bluff Creek	Lat 32°35'29", long 101°03'02", at bridge on FM 1606.	T-1.8	Streambed of gravel and sand. Grass and scattered trees on banks.
6	do	Lat 32°34'20", long 101°03'21", 150 ft upstream from mouth.	828.8	Streambed of coarse sand over sandstone. Grass and thin brush on banks.
7	Colorado River	Lat 32°32'18", long 101°03'12", at stream-gaging station 08119500.	826.3	Wide flats and channel with steep banks. Thick stand of saltcedars along banks.
8	do	Lat 32°30'43", long 101°01'42", 30 ft upstream from Willow Creek.	824.0	Streambed of sand and silt. Steep banks with thick stand of saltcedars along left bank.
9	Willow Creek	Lat 32°30'42", long 101°01'46", 300 ft upstream from mouth.	824.0	Streambed of sand. Steep grassy banks with thick stand of brush.
10	Colorado River	Lat 32°32'25", long 100°56'54", 15 ft upstream from Canyon Creek.	817.8	Streambed of sand. Steep banks with thick stand of saltcedars.
11	Canyon Creek	Lat 32°32'26", long 100°56'53", 15 ft upstream from mouth.	817.8	Streambed of gravel and sand. Steep banks with thick stand of brush and trees.
12	Colorado River	Lat 32°30'51", long 100°54'46", 300 ft upstream from Deep Creek.	814.3	Wide sand channel. Thick stand of saltcedars along banks.
13	Deep Creek	Lat 32°32'25", long 100°54'27", at stream-gaging station 08120500.	T-8.6	Streambed of gravel. Steep grassy banks lined with scattered large trees.
14	do	Lat 32°30'51", long 100°54'40", 70 ft upstream from mouth.	814.3	Streambed of sand. Steep grassy banks with thick stand of saltcedars.
15	Colorado River	Lat 32°28'41", long 100°56'54", at stream-gaging station 08120700.	810.6	Wide streambed of gravel and sand. Steep banks with thick stand of saltcedars.
16	do	Lat 32°26'35", long 100°56'45", 1,000 ft downstream from Cedar Bend bridge.	804.4	Streambed of gravel. Steep banks with thich stand of saltcedars.
17	do	Lat 32°25'51", long 100°55'00", 30 ft upstream from low-water crossing 1 mi northwest of CRMWD diversion station.	802.1	Streambed of gravel. Steep banks with scattered saltcedars.
18	Bone Hollow	Lat 32°25'33", long 100°53'43", at right of private dam and 300 ft upstream from mouth.	800.1	Streambed of sandstone and shale. Scattered trees and brush.
19	CRMWD diversion	Lat 32°25'08", long 100°54'21", at CRMWD pump station.	799.3	--
20	Colorado River	Lat 32°24'51", long 100°54'28", 1,500 ft downstream from CRMWD diversion dam.	798.9	Wide streambed of gravel over sandstone. Thick stand of saltcedars along fairly steep banks.
21	do	Lat 32°23'33", long 100°52'42", at stream-gaging station 08121000.	796.3	Streambed of gravel with thick stand of saltcedars.

TABLE 4.--Results of chemical analyses and discharge measurements for streams in the upper Colorado River basin during selected low-flow periods, from February 1975 to March 1978

DATE	TIME	INSTAN-TANEOUS DIS-CHARGE (FT^3/S)	SPECIFIC CONDUCT-ANCE (MICRO-MHOS)	PH (UNITS)	TEM-PERA-TURE (°C)	HARD-NESS (CA,MG) (MG/L)	NON-CAR-BONATE HARD-NESS (MG/L)	DIS-SOLVED CAL-CIUM (CA) (MG/L)	DIS-SOLVED MAGNE-SIUM (MG) (MG/L)	DIS-SOLVED SODIUM (NA) (MG/L)	DIS-SOLVED POTAS-SIUM (K) (MG/L)	BICAR-BONATE (HCO_3) (MG/L)	CAR-BONATE (CO_3) (MG/L)	DIS-SOLVED SUL-FATE (SO_4) (MG/L)	DIS-SOLVED CHLO-RIDE (CL) (MG/L)	DIS-SOLVED SILICA (SIO_2) (MG/L)	DIS-SOLVED SOLIDS (SUM OF CONSTI-TUENTS) (MG/L)
SITE 1.--COLORADO RIVER ABOVE BULL CREEK (MILE 831.8)																	
Feb. 14, 1975	0950	0.00	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Jan. 20, 1976	0930	.00	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Mar. 2, 1976	0820	.00	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Jan. 28, 1977	1210	.03	12300	7.8	4.5	1600	1400	390	150	2400	8.5	284	0	1100	3800	2.4	7990
Mar. 14, 1977	0925	.02	20400	7.7	11.0	1800	1500	380	200	4200	14	310	0	2100	6100	.6	13100
Jan. 16, 1978	0940	a/.09	26100	--	7.0	2200	1900	450	260	5760	16	308	0	2360	8960	1.8	18000
Mar. 20, 1978	0915	.00	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
SITE 2.--BULL CREEK (MILE T-1.9)																	
Feb. 14, 1975	0915	.02	5850	7.7	8.5	1400	1100	350	130	730	6.4	328	0	560	1500	.9	3440
Jan. 20, 1976	0800	.04	5220	7.8	3.5	1200	860	280	110	680	6.0	356	0	480	1300	1.8	3030
Mar. 2, 1976	0800	.04	6730	7.6	11.5	1400	1200	330	150	900	7.0	276	0	700	1700	1.4	3920
Jan. 28, 1977	1045	.16	8600	7.7	5.5	1400	1100	350	120	1400	7.2	276	0	560	2600	1.8	5180
Mar. 14, 1977	0830	.05	7360	7.8	11.0	1500	1300	350	150	1100	7.4	240	0	710	2100	.5	4530
Jan. 16, 1978	0830	.06	6290	7.8	7.0	1400	1200	300	150	860	9.4	260	0	600	1800	2.1	3850
Mar. 20, 1978	0815	.06	6080	7.6	12.5	1400	1200	310	140	850	6.8	240	0	690	1600	.9	3720
SITE 3.--BULL CREEK AT MOUTH (MILE 831.8)																	
Feb. 14, 1975	1000	.17	15200	7.9	12.0	1700	1500	410	170	3000	11	268	0	1400	4600	1.0	9720
Jan. 20, 1976	0935	.16	13600	7.8	6.5	1600	1300	370	160	2500	10	336	0	1400	3700	2.6	8310
Mar. 2, 1976	0825	.14	16400	7.6	14.0	1800	1500	410	180	3100	11	280	0	1700	4600	3.0	10100
Jan. 28, 1977	1140	.11	12200	7.8	5.0	1600	1300	390	140	2400	8.5	292	0	1100	3700	2.4	7880
Mar. 14, 1977	0920	.05	13500	7.8	11.0	1700	1600	400	180	2400	14	220	0	1500	4000	1.7	8600
Jan. 16, 1978	1015	.08	16100	7.7	6.5	1500	1300	390	130	3300	12	270	0	1600	4800	5.2	10400
Mar. 20, 1978	0845	.09	16100	7.7	12.0	1800	1600	410	180	3200	12	200	0	1600	4800	2.0	10300
SITE 4.--COLORADO RIVER ABOVE BLUFF CREEK (MILE 828.8)																	
Feb. 14, 1975	1200	.13	20700	8.0	13.0	1800	1700	430	180	4300	13	188	0	1500	6800	.0	13300
Jan. 20, 1976	1040	.22	19400	7.9	4.5	1800	1600	400	190	3800	12	248	0	1700	5700	.1	11900
Mar. 2, 1976	0940	.13	27500	7.6	--	2300	2100	490	250	5900	18	160	0	2500	8700	.1	17900
Jan. 28, 1977	0810	.30	14500	7.9	4.5	1500	1300	360	150	2900	9.4	220	0	1300	4600	.1	9430
Mar. 14, 1977	1045	.06	20100	7.8	15.0	1900	1700	380	220	4000	17	150	0	1900	6200	.3	12800
Jan. 16, 1978	1300	.13	25600	7.7	6.5	2100	1900	440	240	5500	17	210	0	2200	8400	.2	16900
Mar. 20, 1978	1010	.04	28100	7.5	13.0	2300	2200	490	260	6000	22	120	0	2300	9300	.1	18500
SITE 5.--BLUFF CREEK (MILE T-1.8)																	
Feb. 14, 1975	1045	.15	3040	8.0	9.5	950	730	250	80	330	5.4	268	0	670	500	2.7	1970
Jan. 20, 1976	0955	.15	2740	8.0	5.0	890	640	230	76	275	4.3	298	0	680	380	8.4	1800
Mar. 2, 1976	0855	.15	2960	7.9	12.0	930	730	230	87	340	4.5	252	0	760	460	3.9	2010
Jan. 28, 1977	1000	.28	2740	8.1	5.0	930	660	250	74	270	4.7	324	0	730	380	8.9	1880
Mar. 14, 1977	1000	.20	3160	8.0	11.0	980	770	230	98	340	5.0	250	0	770	530	3.5	2100
Jan. 16, 1978	1120	.35	2670	8.0	7.0	920	700	230	83	240	4.8	260	0	710	380	5.8	1780
Mar. 20, 1978	1000	.15	3200	7.9	13.5	930	750	230	87	340	4.6	220	0	720	540	1.9	2030

a/ Unable to collect representative sample from this site. Analysis estimated on basis of analysis from site 3 and site below mouth of Bull Creek.

TABLE 4.--Results of chemical analyses and discharge measurements for streams in the upper Colorado River basin during selected low-flow periods, from February 1975 to March 1978--Continued

DATE	TIME	INSTANTANEOUS DISCHARGE (FT^3/S)	SPECIFIC CONDUCTANCE (MICROMHOS)	PH (UNITS)	TEMPERATURE (°C)	HARDNESS (CA,MG) (MG/L)	NONCARBONATE HARDNESS (MG/L)	DISSOLVED CALCIUM (CA) (MG/L)	DISSOLVED MAGNESIUM (MG) (MG/L)	DISSOLVED SODIUM (NA) (MG/L)	DISSOLVED POTASSIUM (K) (MG/L)	BICARBONATE (HCO_3) (MG/L)	CARBONATE (CO_3) (MG/L)	DISSOLVED SULFATE (SO_4) (MG/L)	DISSOLVED CHLORIDE (CL) (MG/L)	DISSOLVED SILICA (SIO_2) (MG/L)	DISSOLVED SOLIDS (SUM OF CONSTITUENTS) (MG/L)
SITE 6.--BLUFF CREEK AT MOUTH (MILE 828.8)																	
Feb. 14, 1975	1140	0.19	5380	7.9	12.0	1100	860	270	96	790	7.1	252	0	770	1200	1.0	3260
Jan. 20, 1976	1030	.12	3700	7.8	5.0	970	760	240	91	480	4.4	260	0	830	690	5.8	2470
Mar. 2, 1976	0925	.14	4410	7.9	--	1200	970	280	110	520	5.8	220	0	970	770	.4	2770
Jan. 28, 1977	0730	.23	3400	7.9	6.0	970	730	250	84	400	5.5	288	0	760	600	5.3	2250
Mar. 14, 1977	1015	.11	4000	7.9	15.0	1100	860	240	110	550	6.4	230	0	900	740	1.0	2660
Jan. 16, 1978	1230	.35	3870	7.9	6.5	1000	800	250	94	500	5.6	260	0	830	750	5.3	2560
Mar. 20, 1978	1030	.15	4380	7.9	14.0	1000	870	260	97	590	5.6	220	0	870	830	.4	2760
SITE 7.--COLORADO RIVER (MILE 826.3)																	
Feb. 14, 1975	1320	.44	21100	8.0	16.0	1700	1500	410	160	4500	14	172	0	1500	6700	2.1	13400
Jan. 20, 1976	1120	.38	20100	7.9	5.0	1600	1400	390	160	4000	12	244	0	1400	6100	3.7	12200
Mar. 2, 1976	1020	.36	24000	7.8	14.5	1900	1700	440	200	5000	17	212	0	1800	7600	5.1	15200
Jan. 28, 1977	1255	1.49	15100	7.8	7.0	1500	1300	360	150	3200	10	228	0	1300	4700	1.5	9830
Mar. 14, 1977	1340	.55	18800	7.9	22.0	1600	1500	250	180	3800	22	190	0	1500	5900	2.5	11800
Jan. 16, 1978	1325	.75	24800	7.7	5.5	2200	2000	470	240	5000	18	230	0	1600	8000	5.5	15400
Mar. 20, 1978	1400	.24	24700	7.7	24.0	1900	1800	450	200	5500	23	160	0	1800	8200	4.1	16300
SITE 8.--COLORADO RIVER ABOVE WILLOW CREEK (MILE 824.0)																	
Feb. 14, 1975	1430	.62	18800	7.8	16.0	1800	1700	420	190	3800	13	196	0	1500	5800	.1	11800
Jan. 20, 1976	1205	.72	17600	7.9	5.0	1700	1500	400	170	3500	11	240	0	1500	5300	.6	11000
Mar. 2, 1976	1105	.53	21700	7.6	14.5	1900	1800	450	200	4500	16	192	0	2100	6600	.1	14000
Jan. 28, 1977	1340	1.25	13500	7.9	7.0	1500	1300	340	150	2800	8.8	256	0	1400	4100	1.2	8930
Mar. 14, 1977	1200	.12	16600	7.8	13.0	1800	1600	420	190	3300	15	230	0	1700	5000	.5	10900
Jan. 16, 1978	1410	1.17	2100	7.8	6.0	1900	1700	450	200	4500	15	270	0	1700	7100	6.7	14100
Mar. 20, 1978	1120	.27	20100	7.6	14.0	2000	1900	470	200	4400	18	180	0	2000	6400	.1	13600
SITE 9.--WILLOW CREEK AT MOUTH (MILE 824.0)																	
Feb. 14, 1975	1415	.07	11200	7.8	14.0	1400	1000	330	130	2100	7.5	416	0	1500	3000	.3	7270
Jan. 20, 1976	1220	.03	6690	8.2	4.5	640	260	150	64	1300	4.1	460	0	1000	1500	.8	4250
Mar. 2, 1976	1115	.02	7880	8.0	15.0	740	410	160	83	1500	4.5	402	0	1200	1700	.3	4850
Jan. 28, 1977	1340	.00	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Mar. 14, 1977	1200	.00	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Jan. 16, 1978	1200	.00	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Mar. 20, 1978	1115	.00	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
SITE 10.--COLORADO RIVER ABOVE CANYON CREEK (MILE 817.8)																	
Feb. 14, 1975	1540	.75	16500	8.0	16.5	1700	1500	400	170	3300	13	184	0	1200	5100	.5	10300
Jan. 20, 1976	0920	.65	16800	7.8	1.0	1700	1500	400	170	3200	11	232	0	1400	4900	.9	10200
Mar. 2, 1976	1255	.40	21400	7.6	--	2100	2000	480	220	4300	16	180	0	2000	6600	.6	13700
Jan. 28, 1977	0920	1.28	15000	7.9	6.0	1600	1400	380	160	3100	9.9	260	0	1500	4700	1.1	9980
Mar. 14, 1977	1240	.61	18100	7.9	13.5	2000	1900	450	220	3600	18	210	0	1800	5500	.8	12000
Jan. 16, 1978	1450	.71	23800	7.6	6.0	2100	2000	510	210	4800	17	230	0	1500	7900	2.3	15100
Mar. 20, 1978	0900	.22	22200	7.6	14.5	2200	2100	520	230	4700	17	160	0	2000	6900	.3	14400

TABLE 4.--Results of chemical analyses and discharge measurements for streams in the upper Colorado River basin during selected low-flow periods, from February 1975 to March 1978--Continued

DATE	TIME	INSTANTANEOUS DISCHARGE (FT^3/S)	SPECIFIC CONDUCTANCE (MICROMHOS)	PH (UNITS)	TEMPERATURE (°C)	HARDNESS (CA,MG) (MG/L)	NONCARBONATE HARDNESS (MG/L)	DISSOLVED CALCIUM (CA) (MG/L)	DISSOLVED MAGNESIUM (MG) (MG/L)	DISSOLVED SODIUM (NA) (MG/L)	DISSOLVED POTASSIUM (K) (MG/L)	BICARBONATE (HCO_3) (MG/L)	CARBONATE (CO_3) (MG/L)	DISSOLVED SULFATE (SO_4) (MG/L)	DISSOLVED CHLORIDE (CL) (MG/L)	DISSOLVED SILICA (SIO_2) (MG/L)	DISSOLVED SOLIDS (SUM OF CONSTITUENTS) (MG/L)
SITE 11.--CANYON CREEK AT MOUTH (MILE 817.8)																	
Feb. 14, 1975	0930	0.66	4710	7.9	9.0	1300	990	270	160	660	5.1	420	0	1200	760	2.0	3260
Jan. 20, 1976	0930	.57	3930	7.9	3.5	1100	770	210	140	540	3.8	404	0	1200	530	2.1	2830
Mar. 2, 1976	0820	.52	3880	8.0	14.0	1100	800	200	150	520	3.5	382	0	1200	490	1.8	2750
Jan. 28, 1977	0900	.98	4040	8.0	5.5	1200	800	230	150	560	3.9	428	0	1300	510	4.2	2960
Mar. 14, 1977	0945	.68	3870	8.1	13.5	1100	800	200	150	550	4.2	380	0	1200	450	2.2	2750
Jan. 16, 1978	0925	.53	3050	8.1	6.5	1000	680	190	130	380	3.7	400	0	1000	320	3.1	2220
Mar. 20, 1978	0910	.51	3390	8.1	14.0	1000	730	190	130	440	3.7	340	0	1100	370	1.0	2400
SITE 12.--COLORADO RIVER ABOVE DEEP CREEK (MILE 814.3)																	
Feb. 14, 1975	1035	1.42	11800	7.9	12.5	1600	1300	340	170	2100	9.8	280	0	1200	3100	.4	7060
June 20, 1976	1010	1.21	11900	7.8	4.0	1600	1300	340	170	2200	8.5	300	0	1300	3300	.5	7470
Mar. 2, 1976	0900	1.11	11700	7.8	14.5	1600	1400	340	180	2100	9.0	288	0	1400	3100	.8	7270
Jan. 28, 1977	1015	2.79	11000	7.9	5.0	1500	1200	340	160	2200	7.8	336	0	1400	3200	2.2	7480
Mar. 14, 1977	1055	1.63	11900	7.9	16.5	1700	1500	360	190	2100	12	280	0	1500	3200	.9	7700
Jan. 16, 1978	1005	2.43	14300	7.7	7.0	1700	1500	390	180	2700	10	320	0	1300	4100	3.4	8840
Mar. 20, 1978	1010	1.09	11600	7.9	18.0	1600	1400	340	170	2100	9.0	240	0	1300	3200	.7	7240
SITE 13.--DEEP CREEK (MILE T-8.6)																	
Feb. 14, 1975	1630	2.22	1470	7.8	11.5	380	140	110	26	170	9.1	292	0	210	190	11	871
Jan. 20, 1976	1320	1.57	1380	7.5	6.0	330	90	94	23	150	10	292	0	180	170	9.0	782
Mar. 2, 1976	1220	1.68	1520	7.4	14.5	320	41	89	23	200	14	336	0	190	190	22	896
Jan. 28, 1977	1045	2.19	--	--	6.0	--	--	--	--	--	--	--	--	--	--	--	--
Mar. 14, 1977	1140	1.95	1720	7.9	14.0	420	110	120	30	210	13	380	0	250	230	18	1060
Jan. 16, 1978	1145	2.30	1570	7.8	5.5	370	21	100	28	190	11	420	0	190	190	15	931
Mar. 20, 1978	1130	.79	1490	7.8	16.0	360	61	100	26	190	9.8	360	0	190	190	11	894
SITE 14.--DEEP CREEK AT MOUTH (MILE 814.3)																	
Feb. 14, 1975	1110	4.48	3210	7.9	9.5	890	600	190	100	420	10	348	0	760	520	7.3	2180
Jan. 20, 1976	1025	2.67	2350	7.7	4.0	650	390	150	67	290	10	320	0	610	260	4.2	1550
Mar. 2, 1976	0920	2.95	2340	8.3	14.5	630	350	140	68	280	11	336	0	620	250	14	1550
Jan. 28, 1977	1040	4.84	3030	7.8	5.0	860	550	180	99	380	8.2	380	0	910	340	6.9	2110
Mar. 14, 1977	1115	4.77	2920	8.2	13.0	880	580	190	98	340	11	370	0	840	330	6.3	2000
Jan. 16, 1978	1030	4.70	2290	8.2	5.5	700	380	160	73	260	9.2	390	0	600	250	7.8	1550
Mar. 20, 1978	1030	2.63	2620	8.2	15.0	830	530	180	92	310	8.4	360	0	790	280	3.3	1840
SITE 15.--COLORADO RIVER (MILE 810.6)																	
Feb. 14, 1975	1230	7.16	5790	8.0	10.5	1000	740	230	110	900	9.9	352	0	920	1200	2.7	3550
Jan. 20, 1976	1120	3.80	5860	7.9	3.5	960	690	220	100	910	10	336	0	810	1300	1.3	3520
Mar. 2, 1976	1010	4.42	5450	8.3	14.5	980	700	210	110	860	13	340	0	860	1200	3.0	3420
Jan. 28, 1977	1000	8.72	6210	8.1	7.0	1100	820	250	120	1000	8.2	360	0	1000	1400	2.2	3960
Mar. 14, 1977	1030	5.26	6010	8.3	13.0	1200	900	260	130	950	15	350	0	1000	1300	1.3	3830
Jan. 16, 1978	1050	5.73	6070	8.1	6.0	1100	750	240	110	950	10	370	0	860	1400	4.3	3760
Mar. 20, 1978	1035	2.27	5710	8.2	15.0	990	710	200	120	960	9.4	350	0	900	1300	.4	3660

TABLE 4.--Results of chemical analyses and discharge measurements for streams in the upper Colorado River basin during selected low-flow periods, from February 1975 to March 1978--Continued

DATE	TIME	INSTANTANEOUS DISCHARGE (FT^3/S)	SPECIFIC CONDUCTANCE (MICROMHOS)	PH (UNITS)	TEMPERATURE (°C)	HARDNESS (CA,MG) (MG/L)	NONCARBONATE HARDNESS (MG/L)	DISSOLVED CALCIUM (CA) (MG/L)	DISSOLVED MAGNESIUM (MG) (MG/L)	DISSOLVED SODIUM (NA) (MG/L)	DISSOLVED POTASSIUM (K) (MG/L)	BICARBONATE (HCO_3) (MG/L)	CARBONATE (CO_3) (MG/L)	DISSOLVED SULFATE (SO_4) (MG/L)	DISSOLVED CHLORIDE (CL) (MG/L)	DISSOLVED SILICA (SIO_2) (MG/L)	DISSOLVED SOLIDS (SUM OF CONSTITUENTS) (MG/L)
SITE 16.--COLORADO RIVER (MILE 804.4)																	
Feb. 14, 1975	1330	6.38	6780	8.3	13.5	1100	840	250	120	1100	10	344	0	970	1500	0.3	4120
Jan. 20, 1976	1210	4.37	6480	8.2	5.0	1100	770	240	110	1100	10	340	0	880	1500	.3	4010
Mar. 2, 1976	1040	4.95	6380	8.3	16.5	1100	860	240	130	1000	12	332	0	1000	1400	.2	3950
Jan. 28, 1977	1135	8.57	6480	8.2	6.5	1200	900	260	130	1100	8.0	346	0	1000	1500	.6	4170
Mar. 14, 1977	1215	5.84	6860	7.7	15.5	1300	1000	260	150	1100	12	290	0	1100	1600	.4	4370
Jan. 16, 1978	1120	6.19	6600	8.1	7.0	1100	820	250	120	1100	10	360	0	980	1600	3.4	4240
Mar. 20, 1978	1125	4.29	6570	7.6	17.5	1100	870	230	120	1100	10	240	0	1000	1500	.1	4080
SITE 17.--COLORADO RIVER (MILE 802.1)																	
Feb. 14, 1975	1440	6.94	7340	8.4	16.0	1200	890	250	120	1200	10	308	12	850	1800	.0	4400
Jan. 20, 1976	1250	4.44	6610	8.4	7.0	1100	800	250	110	1100	9.7	324	8	950	1500	.3	4090
Mar. 2, 1976	1130	4.73	7540	8.3	17.5	1200	920	250	130	1300	17	292	0	1100	1900	.1	4840
Jan. 28, 1977	1230	7.86	7610	8.1	6.5	1200	950	280	130	1400	8.7	346	0	1100	1900	.6	4990
Mar. 14, 1977	1315	6.47	7240	7.7	20.0	1400	1100	280	160	1200	12	270	0	1200	1700	.4	4690
Jan. 16, 1978	1200	6.88	8790	8.1	7.0	1300	960	290	130	1600	11	360	0	1100	2400	2.9	5710
Mar. 20, 1978	1215	4.36	7840	7.7	19.0	1200	1000	260	130	1400	11	230	0	1100	2000	.1	5010
SITE 18.--BONE HOLLOW AT MOUTH (MILE 800.1)																	
Feb. 14, 1975	1630	.004	2620	8.1	16.5	760	610	190	70	270	10	180	0	760	290	.3	1680
Jan. 20, 1976	1410	.04	3100	8.1	8.5	1100	920	230	130	330	10	228	0	1100	340	.2	2250
Mar. 2, 1976	1245	.03	3800	7.9	18.5	1400	1200	260	170	410	11	220	0	1400	460	.1	2820
Jan. 28, 1977	1435	.04	3740	7.9	8.0	1300	1100	270	160	400	10	268	0	1300	460	.4	2730
Mar. 14, 1977	1500	.04	4200	7.7	23.0	1600	1400	330	200	500	16	270	0	1500	520	.4	3200
Jan. 16, 1978	1325	.17	3710	8.0	6.0	1300	1100	250	170	430	9.8	320	0	1300	460	5.0	2780
Mar. 20, 1978	1400	.09	3970	8.0	22.0	1400	1100	260	170	490	9.1	280	0	1400	480	.1	2950

SITE 19.--COLORADO RIVER MUNICIPAL WATER DISTRICT DIVERSION DAM AND PUMP STATION (MILE 799.3)

Feb. 14, 1975 Water was flowing over low-water dam; no pumping during preceding week.
Jan. 20, 1976 No pumping during preceding week; however, all flow was being impounded by low-water dam.
Mar. 2, 1976 Entire flow of river at this site was being impounded by low-water dam and being pumped into CRMWD off-channel reservoir.
Jan. 28, 1977 Entire flow of river at this site was being impounded by low-water dam and being pumped into CRMWD off-channel reservoir.
Mar. 14, 1977 Entire flow of river at this site was being impounded by low-water dam and being pumped into CRMWD off-channel reservoir.
Jan. 16, 1978 Entire flow of river at this site was being impounded by low-water dam and being pumped into CRMWD off-channel reservoir.
Mar. 20, 1978 Entire flow of river at this site was being impounded by low-water dam and being pumped into CRMWD off-channel reservoir.

TABLE 4.--Results of chemical analyses and discharge measurements for streams in the upper Colorado River basin during selected low-flow periods, from February 1975 to March 1978--Continued

DATE	TIME	INSTANTANEOUS DISCHARGE (FT^3/S)	SPECIFIC CONDUCTANCE (MICROMHOS)	PH (UNITS)	TEMPERATURE (°C)	HARDNESS (CA,MG) (MG/L)	NONCARBONATE HARDNESS (MG/L)	DISSOLVED CALCIUM (CA) (MG/L)	DISSOLVED MAGNESIUM (MG) (MG/L)	DISSOLVED SODIUM (NA) (MG/L)	DISSOLVED POTASSIUM (K) (MG/L)	BICARBONATE (HCO_3) (MG/L)	CARBONATE (CO_3) (MG/L)	DISSOLVED SULFATE (SO_4) (MG/L)	DISSOLVED CHLORIDE (CL) (MG/L)	DISSOLVED SILICA (SIO_2) (MG/L)	DISSOLVED SOLIDS (SUM OF CONSTITUENTS) (MG/L)
SITE 20.--COLORADO RIVER (MILE 798.9)																	
Feb. 14, 1975	1600	8.99	8830	8.4	15.5	1200	990	270	130	1600	9.4	240	12	1000	2300	0.4	5440
Jan. 20, 1976	1320	.08	60600	7.3	7.5	4400	4200	1100	390	14000	35	162	0	3500	22000	2.3	41100
Mar. 2, 1976	1200	.00	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Jan. 28, 1977	1325	.12	15000	7.7	11.0	1500	1400	330	160	3200	12	120	0	1400	4700	.3	9860
Mar. 14, 1977	1420	.07	61100	6.7	26.0	4200	4100	1000	410	15000	46	82	0	3600	23000	3.7	43100
Jan. 16, 1978	1245	.15	65600	6.7	7.0	3900	3700	810	450	16000	46	170	0	3700	24000	5.6	45100
Mar. 20, 1978	1320	.09	79200	7.2	27.0	5800	5800	1500	510	19000	130	84	0	4200	31000	1.0	56400
SITE 21.--COLORADO RIVER (MILE 796.3)																	
Feb. 14, 1975	1550	11.1	8940	8.4	15.0	1200	1100	270	130	1600	8.9	232	4	960	2400	.2	5490
Jan. 20, 1976	1445	.16	13500	7.7	9.5	1700	1400	340	200	2500	11	328	0	1800	3500	1.2	8510
Mar. 2, 1976	1320	.19	12700	7.5	18.5	2100	1900	460	220	2400	13	226	0	2100	3500	.9	8810
Jan. 28, 1977	0855	.21	8240	7.8	4.0	1500	1200	300	180	1400	8.5	324	0	1500	2000	1.2	5550
Mar. 14, 1977	0930	.34	10100	7.6	13.5	1700	1500	330	210	1800	13	280	0	1800	2500	1.1	6790
Jan. 16, 1978	0935	.48	22200	7.5	6.5	2100	1900	480	230	4600	17	300	0	2100	7200	2.4	14800
Mar. 20, 1978	0920	.20	24300	7.4	14.0	2300	2100	520	250	5300	21	240	0	2300	7900	1.0	16400

The average discharge and discharge-weighted averages of dissolved constituents in low flow at sites downstream from the CRMWD diversion dam were adjusted to show the estimated flows and concentrations that would have resulted had no diversion occurred. Profiles of the average discharges and the discharge-weighted averages and loads for selected constituents in the low flows throughout the reach studied are shown on figures 4 and 5. These figures show generalized areas where significant gains and losses of streamflow and changes in chemical quality occurred, but the quantity and quality of ground-water accretions are masked somewhat by the effects of inflow from tributaries.

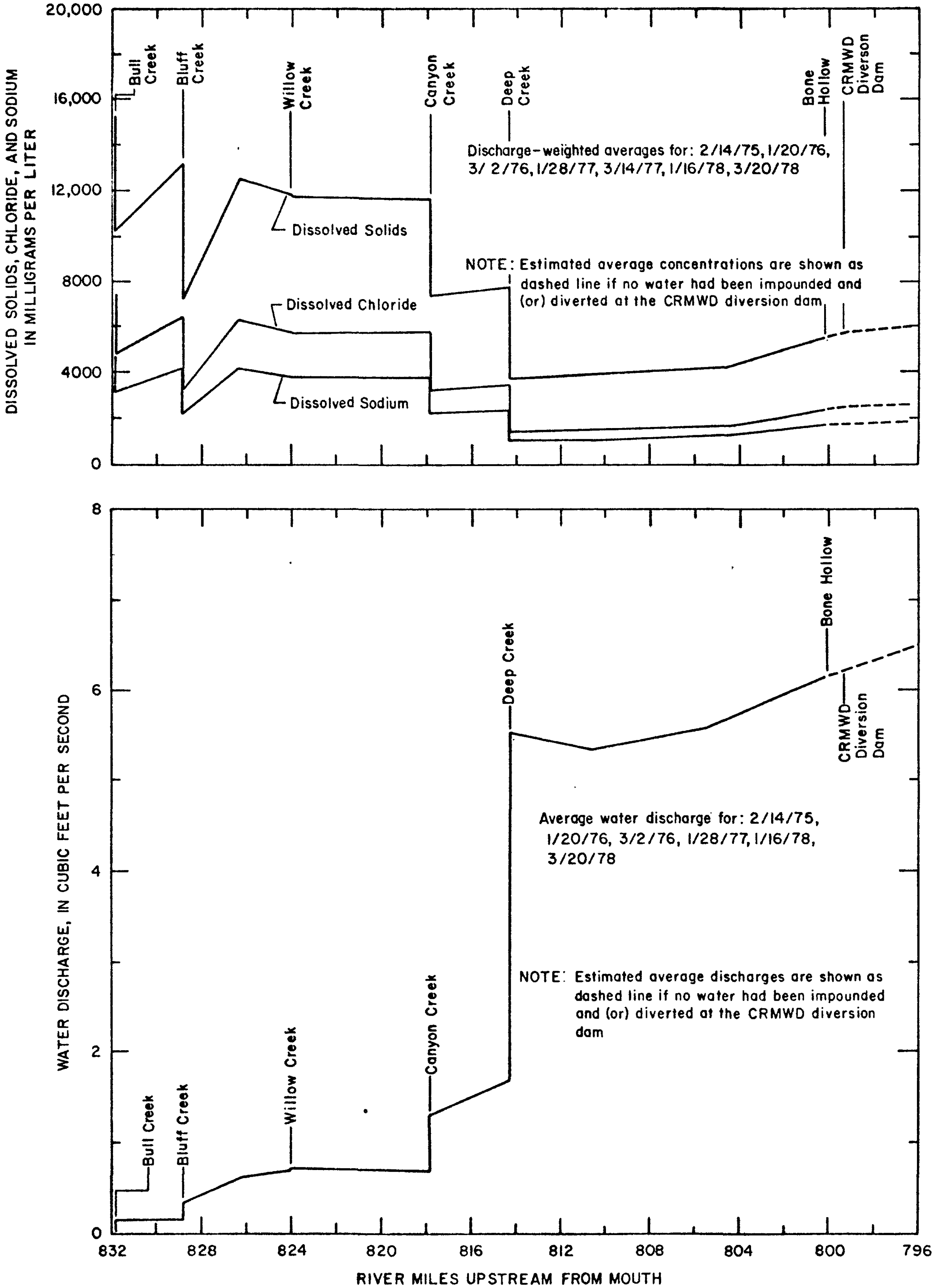

FIGURE 4.-Dissolved-solids, sodium, and chloride concentrations and water discharge for the Colorado River during selected low-flow periods, from February 1975 to March 1978

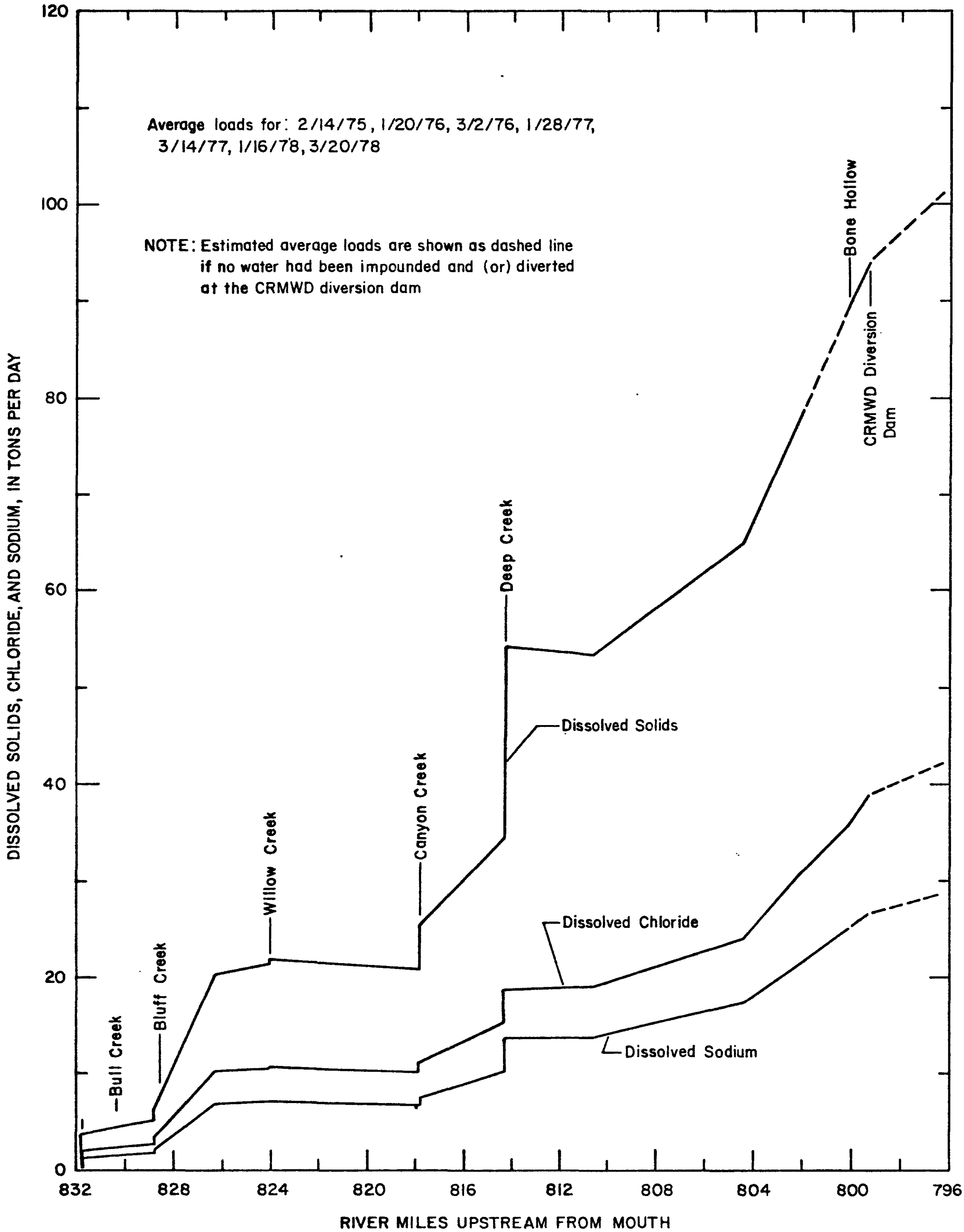

FIGURE 5.-Dissolved-solids, sodium, and chloride loads for the Colorado River during selected low-flow periods, from February 1975 to March 1978

Gains and losses of flow for subreaches of the main stem Colorado River were estimated by use of the following equations:

$$Q_g = Q_d - Q_u - Q_t \qquad \text{or} \qquad Q_l = Q_d - Q_u - Q_t$$

where

Q_g = gain in streamflow between adjacent sites,

Q_l = loss in streamflow between adjacent sites,

Q_d = streamflow at downstream site,

Q_u = streamflow at upstream site, and

Q_t = inflow from tributary.

The concentrations of dissolved constituents in ground-water accretions (gains) were estimated by the following equation:

$$C_g = \frac{Q_d C_d - Q_u C_u - Q_t C_t}{Q_g}$$

where

C_g = concentration of dissolved constituent in ground-water accretion,

C_d = concentration of dissolved constituent in flow at downstream site,

C_u = concentration of dissolved constituent in flow at upstream site, and

C_t = concentration of dissolved constituent in inflow from tributary.

The average quantity and quality of ground-water accretions and the average quantity of water lost along the main stem of the Colorado River during the seven low-flow studies are shown on figure 6. The average loads of selected constituents for the ground-water accretions are shown on figure 7.

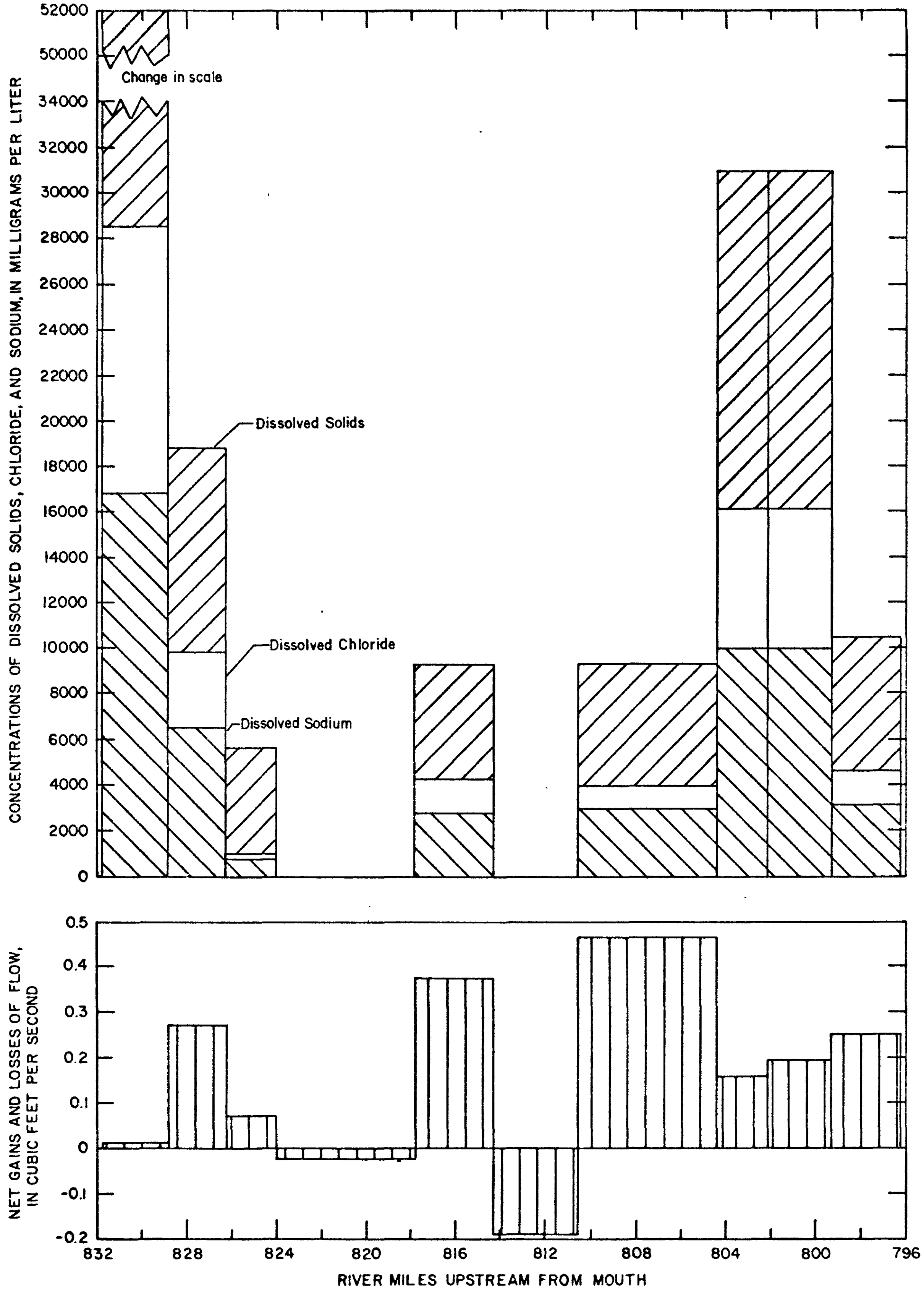

FIGURE 6.-Quantity and quality of ground-water accretions and quantity of water lost along the main stem of the Colorado River during selected low-flow periods, from February 1975 to March 1978

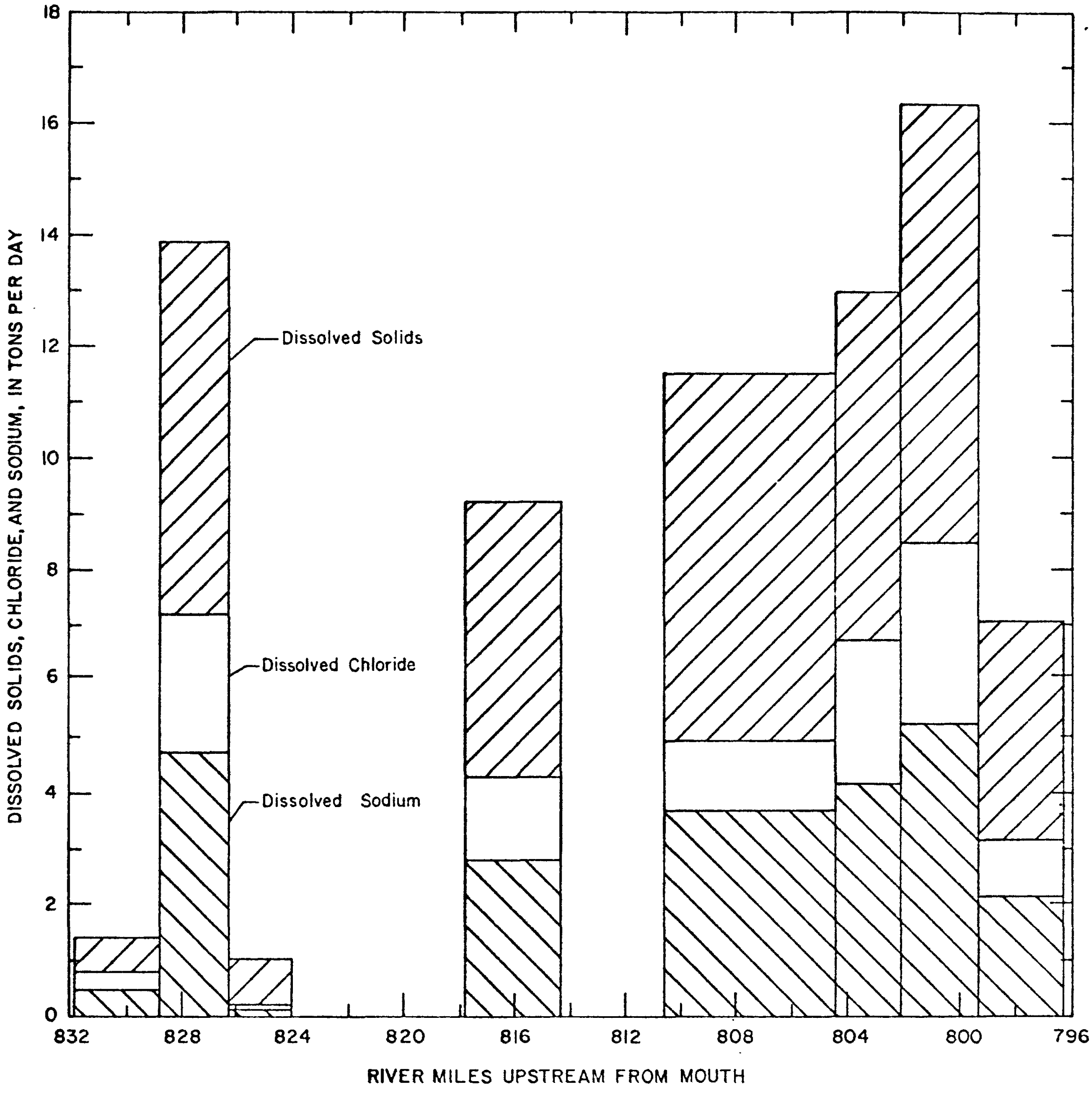

FIGURE 7.-Dissolved-solids, sodium, and chloride loads for ground-water accretions along the main stem of the Colorado River during selected low-flow periods, from February 1975 to March 1978

The chemical composition of waters from different sources often differs significantly. The chemical composition of water at each of the low-flow sites, based on discharge-weighted averages of constituents during the seven low-flow periods, is shown on figures 1 and 8. The shape of each pattern diagram on figure 1 is indicative of the relative concentration of the principal chemical constituents; the size is roughly indicative of the degree of mineralization. For example, the water represented by the pattern below the heading "Chemical Composition" on figure 1 is of the sodium chloride type and contains 4,320 mg/L dissolved solids.

Several of the previous sections have indicated that water was impounded or diverted or both at mile 799.3 (site 19, fig. 1). To enable the comparison of streamflow and water-quality data for sites downstream from the diversion with similar data for sites upstream, the quantity of water diverted was added to flows at sites downstream and the concentrations of dissolved constituents were adjusted accordingly. The data in the following discussion, then, are treated as if no diversion occurred.

Data on figure 4 show that the average flow in the Colorado River during the seven low-flow studies increased from 0.02 ft^3/s (cubic foot per second) at mile 831.8 (site 1) to 6.46 ft^3/s at mile 796.3 (site 21). Inflow from tributaries averaged 4.87 ft^3/s; ground-water accretions averaged 1.57 ft^3/s. Although the average flow increased between miles 831.8 and 796.3, losses of flow occurred within some of the subreaches.

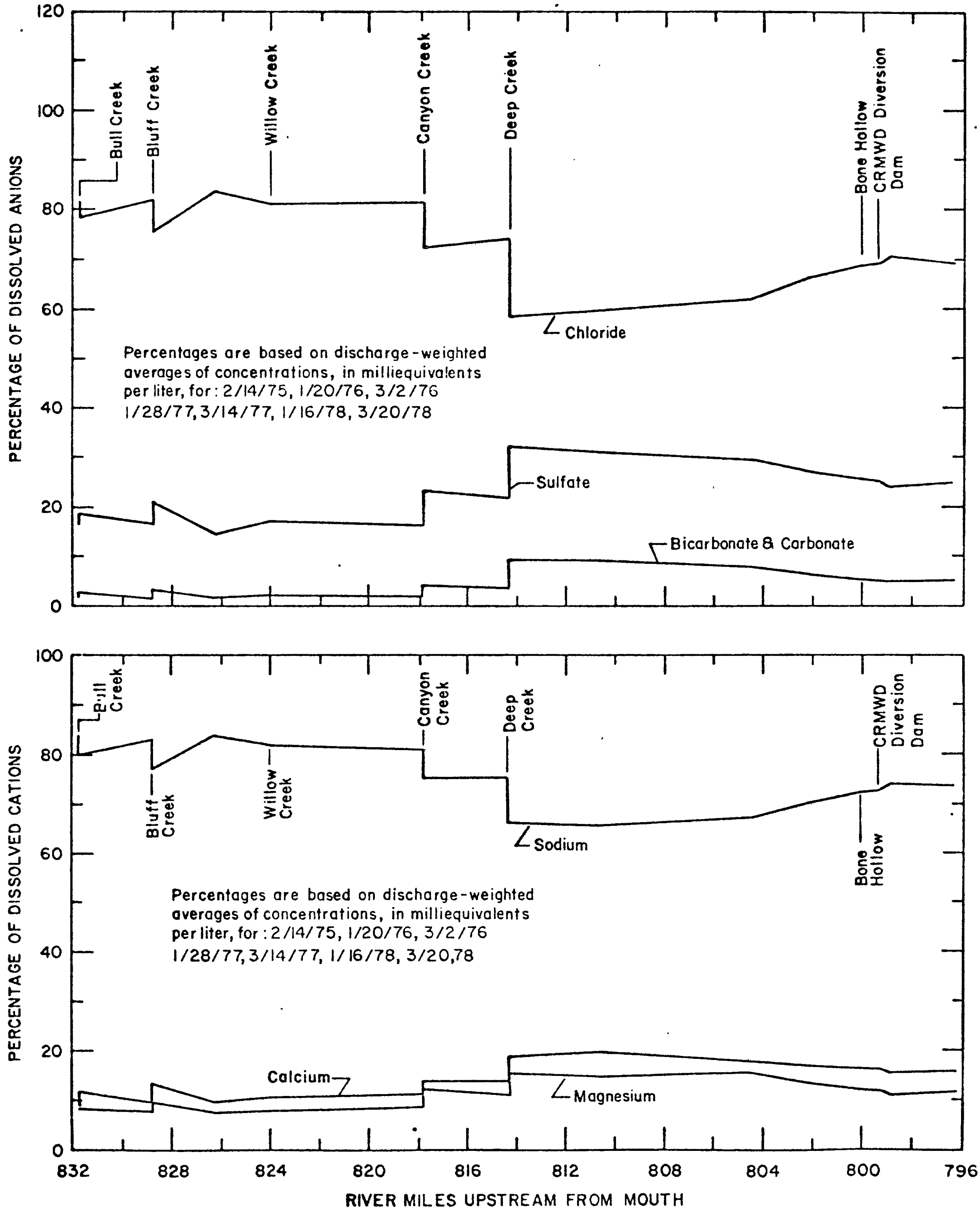

FIGURE 8.-Percentage of major dissolved cations and anions for the Colorado River during selected low-flow periods, from February 1975 to March 1978

Inflows from most tributaries were significantly less mineralized than direct ground-water accretions to the main stem (figs. 1, 4, and 6) and resulted in decreases in the concentrations of principal dissolved constituents downstream from tributaries between miles 831.8 and 796.3. The discharge-weighted average of dissolved-solids concentrations in low flows decreased from 15,200 mg/L at mile 831.8 to 5,810 mg/L at mile 796.3; the dissolved-sodium concentration decreased from 4,820 mg/L to 1,640 mg/L; and the dissolved-chloride concentration decreased from 7,450 mg/L to 2,410 mg/L. The concentrations of dissolved solids, chloride, and sodium in inflow from tributaries averaged 2,210 mg/L, 470 mg/L, and 430 mg/L, respectively. Concentration of dissolved solids, chloride, and sodium in direct ground-water accretions to the main stem averaged about 16,900 mg/L, 8,400 mg/L, and 5,400 mg/L, respectively. Although the average concentrations of the principal dissolved constituents decreased between miles 831.8 and 796.3, significant increases occurred within some of the subreaches.

Low flow at each of the sites on the main stem Colorado River is of the sodium chloride type (figs. 1 and 8). The chemical composition of inflow from tributaries varies. Highly mineralized low flows contributed by Bull and Willow Creeks (sites 3 and 9, fig. 1), which drain almost entirely from formations of the Dockum Group, are of the sodium chloride type and are similar in chemical character to low flows in the main stem Colorado River. Low flows from other tributaries, most of which head in areas underlain by the Ogallala Formation, are significantly less mineralized and are of mixed chemical types. Inflow of water from these tributaries usually results in a decrease in the salinity and the percentage of sodium and chloride in low flows at sites downstream on the main stem.

Salt loads of streamflow are dependent on both the quantity and quality of the streamflow. Although concentrations of the principal dissolved constituents in low flows of the Colorado River usually decrease at sites immediately downstream from tributaries (fig. 4), salt loads usually increase (fig. 5). The average load of dissolved solids in low flows of the main stem increased from about 0.8 ton per day at mile 831.8 to more than 101 tons per day at mile 796.3. The average loads of dissolved sodium and chloride in the reach increased from less than 0.3 ton per day to more than 28 tons per day and from about 0.4 ton per day to more than 42 tons per day, respectively. The average load of dissolved solids contributed by low flows from tributaries was about 29 tons per day, of which about 6 tons were sodium and 6 tons were chloride. The average load of dissolved solids contributed by ground-water accretions was more than 71 tons per day, of which about 23 tons were sodium and 35 tons were chloride. These data indicate that less than 25 percent of the gain in streamflow in the upper Colorado River was contributed by ground-water accretions; whereas, about 71 percent of the gain in the load of dissolved solids, about 80 percent of the gain in the load of dissolved sodium, and about 85 percent of the gain in the load of dissolved chloride were contributed by ground-water accretions. Both the quantity and loads of ground-water accretions varied significantly within several subreaches.

The Geological Survey has operated continuous streamflow and daily water-quality stations at three sites on the Colorado River in the area of saline inflow. In the following discussion, the area studied has been divided into three reaches on the basis of the locations of these stations. Each of these reaches has been subdivided to delineate the source areas of saline inflow.

Reach from Mile 831.8 to Mile 826.3

Low flows at mile 831.8 (site 1) on the Colorado River, which ranged from 0.00 ft^3/s during four of the studies to 0.09 ft^3/s on January 16, 1978, averaged 0.02 ft^3/s. Low flows at mile 826.3 (site 7, station 08119500 Colorado River near Ira), which ranged from 0.24 ft^3/s on March 20, 1978, to 1.49 ft^3/s on January 28, 1977, averaged 0.60 ft^3/s. Inflows from Bull and Bluff Creeks, which join the Colorado River in this 5.5-mile reach, averaged 0.30 ft^3/s. Direct ground-water accretions to the Colorado River averaged 0.28 ft^3/s (more than 48 percent of the total gain in flow).

The concentrations of dissolved solids, sodium, and chloride in low flows at mile 831.8 averaged 15,200 mg/L, 4,820 mg/L, and 7,450 mg/L, respectively (fig. 4). The concentrations of dissolved solids, sodium, and chloride in inflow from Bull and Bluff Creeks averaged 5,200 mg/L, 760 mg/L, and 2,130 mg/L, respectively. Calculations based on these data indicate that the concentrations of dissolved solids, sodium, and chloride in ground-water accretions between miles 831.8 and 826.3 averaged 20,000 mg/L, 7,550 mg/L, and 10,500 mg/L, respectively. The average concentrations in ground-water accretions were highest in the subreach between the mouths of Bull Creek (mile 831.8) and Bluff Creek (mile 828.8). The concentrations of dissolved solids, sodium, and chloride in ground-water accretions averaged 52,000 mg/L, 16,800 mg/L, and 28,500 mg/L, respectively in the 3.0-mile subreach between miles 831.8 and 828.8;and 18,800 mg/L, 6,430 mg/L, and 9,800 mg/L, respectively in the 2.5-mile subreach between miles 828.8 and 826.3.

The average load of dissolved solids during the low-flow studies increased from about 0.8 ton per day at mile 831.8 to about 20.3 tons per day at mile 826.3 (fig. 5). The average loads of dissolved sodium and chloride in the reach increased from about 0.3 and 0.4 ton per day to about 6.6 and 10.1 tons per day, respectively. Loads of dissolved solids contributed by inflow from Bull and Bluff Creeks averaged about 4.2 tons per day, of which about 0.6 ton was sodium and 1.7 tons were chloride.

The quantity of ground-water accretions and thus the loads of dissolved constituents were highest in the 2.5-mile subreach downstream from the mouth of Bluff Creek (fig. 7). The load of dissolved solids in this subreach averaged about 13.9 tons per day, of which about 4.7 tons were sodium and 7.2 tons were chloride.

A previous study by the Corps of Engineers (Green, Marr, and Logan, 1974) indicated the salinity of Bull and Bluff Creeks to increase significantly near the mouths of both streams. Localized sources of salinity were found on neither of these streams nor on the main stem Colorado River between the mouths of Bull and Bluff Creeks during the reconnaissance in February 1975; but results of low-flow studies at two sites on each of these tributaries show the salinity of low flows to increase significantly toward the mouths. The channel of each stream is more deeply incised toward the Colorado River than in the headwaters. Ground water contributed by areas toward the mouths of both Bull and Bluff Creeks near the Colorado River apparently are more mineralized than ground water contributed by areas upstream.

According to Mount and others (1967, p. 36-37), in a discussion concerning the chemical quality of water in the Ogallala Formation, "Waters highly mineralized because of natural causes are associated with areas of shallow water-table conditions, notably near water-table lakes and near draws. Where the water table is at or near the land surface, evaporation processes produce highly mineralized ground waters by the concentration of residual salts."

Ground water in areas near the mouths of Bull and Bluff Creeks probably is significantly nearer land surface than ground water in areas upstream; and part of the increase in mineralization of ground-water accretions probably results from concentration by evaporation.

Reach from Mile 826.3 to Mile 810.6

Low flows at mile 810.6 (site 15, station 08120700 Colorado River near Cuthbert), which ranged from 2.27 ft^3/s on March 20, 1978, to 8.72 ft^3/s on January 28, 1977, averaged 5.34 ft^3/s (figs. 1 and 4).

The gain in low flows of the 15.7-mile reach of the Colorado River between mile 826.3 (site 7) and mile 810.6 (site 15) averaged 4.74 ft^3/s. Inflows from Willow, Canyon, and Deep Creeks, which join the Colorado River in this reach averaged 4.52 ft^3/s. Direct ground-water accretions to the main stem averaged only about 0.22 ft^3/s (less than 5 percent of the total gain in flow).

The concentrations of dissolved solids, sodium, and chloride in low flows at mile 810.6 averaged 3,710 mg/L, 940 mg/L, and 1,310 mg/L, respectively. The concentrations of dissolved solids, sodium, and chloride in inflow from tributaries averaged 2,010 mg/L, 360 mg/L, and 360 mg/L, respectively. Inflow from Deep Creek (site 14) averaged 3.86 ft^3/s (more than 80 percent of the total gain in flow between mile 826.3 and mile 810.6. The concentrations of dissolved solids, sodium, and chloride in inflow from Deep Creek averaged 1,860 mg/L, 330 mg/L, and 330 mg/L, respectively.

Calculations based on these data indicate that the concentrations of dissolved solids, sodium, and chloride in ground-water accretions between miles 826.3 and 810.6 averaged 14,400 mg/L, 4,160 mg/L, and 7,330 mg/L, respectively. Losses of flow occurred within two subreaches of the main stem during most of the low-flow studies (figs. 4 and 6). Losses of flow averaged less than 0.03 ft^3/s in the 6.2-mile subreach of the main stem between the mouths of Willow and Canyon Creeks (miles 824.0 and 817.8) and about 0.20 ft^3/s in the 3.7-mile subreach downstream from the mouth of Deep Creek (miles 814.3 and 810.6). Gains resulting from ground-water inflow and the concentrations of dissolved constituents were greatest in the 3.5-mile subreach between the mouths of Canyon and Deep Creeks (miles 817.8 and 814.3). The quantity of ground-water accretions in this subreach averaged about 0.37 ft^3/s; the concentrations of dissolved solids, sodium, and chloride in the ground-water accretions averaged 9,190 mg/L, 2,750 mg/L, and 4,250 mg/L, respectively.

The average load of dissolved solids for this 15.7-mile reach of the main stem Colorado River during the low-flow studies increased from about 20.3 tons per day at mile 826.3 to about 53.5 tons per day at mile 810.6. The average loads of dissolved sodium and chloride in the reach increased from about 6.6 and 10.1 tons per day to about 13.6 and 18.9 tons per day, respectively (fig. 5). Loads of dissolved solids contributed by inflow from tributaries averaged about 24.5 tons per day, of which about 4.4 tons were sodium and 4.4 tons were chloride. Losses of flow, and thus part of the loads of dissolved constituents, occurred in the 6.2-mile subreach between the mouth of Willow and Canyon Creeks and the 3.7-mile subreach downstream from the mouth of Deep Creek.

The quantity of ground-water accretions and thus the loads of dissolved constituents were greatest in the 3.5-mile subreach between the mouths of Canyon and Deep Creeks (miles 817.8 and 814.3). The load of dissolved solids contributed by ground water in this subreach averaged about 9.3 tons per day, of which about 2.8 tons were sodium and 4.3 tons were chloride.

Reach from Mile 810.6 to Mile 796.3

Low flows at mile 796.3 (site 21, station 08121000 Colorado River at Colorado City) plus low flows impounded or diverted or both at mile 799.3 (site 19) averaged 6.46 ft^3/s (figs. 1 and 4). The gain in low flows of the 14.3-mile reach of the Colorado River between mile 810.6 (site 15) and mile 796.3 (site 21) averaged 1.12 ft^3/s. Inflow from Bone Hollow, the only tributary in the reach, averaged 0.06 ft^3/s. Direct ground-water accretions to the main stem averaged 1.06 ft^3/s (about 95 percent of the total gain in flow).

The concentrations of dissolved solids, sodium, and chloride in low flows at mile 810.6 plus low flows impounded or diverted or both at mile 799.3 averaged 5,810 mg/L, 1,640 mg/L, and 2,410 mg/L, respectively. The concentrations of dissolved solids, sodium, and chloride in inflow from Bone Hollow averaged 2,790 mg/L, 430 mg/L, and 460 mg/L, respectively.

Calculations based on these data indicate that the concentrations of dissolved solids, sodium, and chloride in ground-water accretions between miles 810.6 and 796.3 averaged 16,500 mg/L, 5,230 mg/L, and 8,030 mg/L, respectively. Average concentrations of dissolved constituents were greatest in the ground-water accretions in the subreaches between miles 804.4 and 802.1 and between miles 802.1 and 799.3. The concentrations of dissolved solids, sodium, and chloride in ground-water accretions in these subreaches averaged 31,000 mg/L, 9,940 mg/L, and 16,100 mg/L, respectively.

The average load of dissolved solids during the low-flow studies increased from about 53.5 tons per day at mile 810.6 to 101.3 tons per day at mile 796.3. The average loads of dissolved sodium and chloride in the reach increased from about 13.6 and 18.9 tons per day to about 28.6 and 42.0 tons per day, respectively (fig. 5). Loads of dissolved solids in ground-water accretions averaged about 47.3 tons per day, of which about 15.0 tons were sodium and 23.0 tons were chloride. The loads of dissolved constituents in ground-water accretions were largest in the subreach between miles 802.1 and 799.3. The load of dissolved solids averaged about 16.3 tons per day, of which about 5.2 tons were sodium and 8.5 tons were chloride.

All flow of the Colorado River was impounded or diverted or both at mile 799.3 (site 19) during each of the low-flow studies, except for the study on February 14, 1975. The combined flows from small seeps along the river bed and channel about 1,500 feet downstream from the diversion dam (mile 798.9) ranged from 0.07 ft^3/s on March 14, 1977, to 0.15 ft^3/s on January 16, 1978. The concentration of dissolved solids in the combined flow ranged from 9,860 mg/L to 56,400 mg/L. The concentration of dissolved sodium ranged from 3,200 mg/L to 19,000 mg/L and the concentration of dissolved chloride ranged from 4,700 mg/L to 31,000 mg/L.

Delineation of Source-Areas of Saline Inflow

The small seeps downstream from the diversion dam at mile 798.9 were the only localized sources of saline inflow found during the low-flow studies. Some of the previous sections have shown that ground water contributed throughout most of the area studied is saline. The average concentrations of dissolved solids in ground water contributed directly to the main stem Colorado River during the low-flow studies ranged from 5,620 mg/L in the 2.3-mile subreach between miles 826.3 and 824.0 to 52,000 mg/L in the 3.0-mile subreach between miles 831.8 and 828.8. The average concentrations of dissolved sodium and chloride in ground water contributed to these subreaches ranged from 840 mg/L to 16,800 mg/L and from 1,010 mg/L to 28,500 mg/L, respectively.

The previous sections have shown generally that the quantities of ground-water inflow, and thus the loads of dissolved constituents, vary significantly within the reach studied. The areas of saline inflow and salt yields from subreaches are delineated more precisely on figure 9. Data on figure 9 show that the average yields of dissolved solids in ground-water inflow per mile of channel along the main stem Colorado River ranged from less than 0.5 ton per day to more than 5.8 tons per day. The average yields of dissolved sodium and chloride per mile of channel ranged from less than 0.1 ton per day to more than 1.9 tons per day and 2.9 tons per day, respectively.

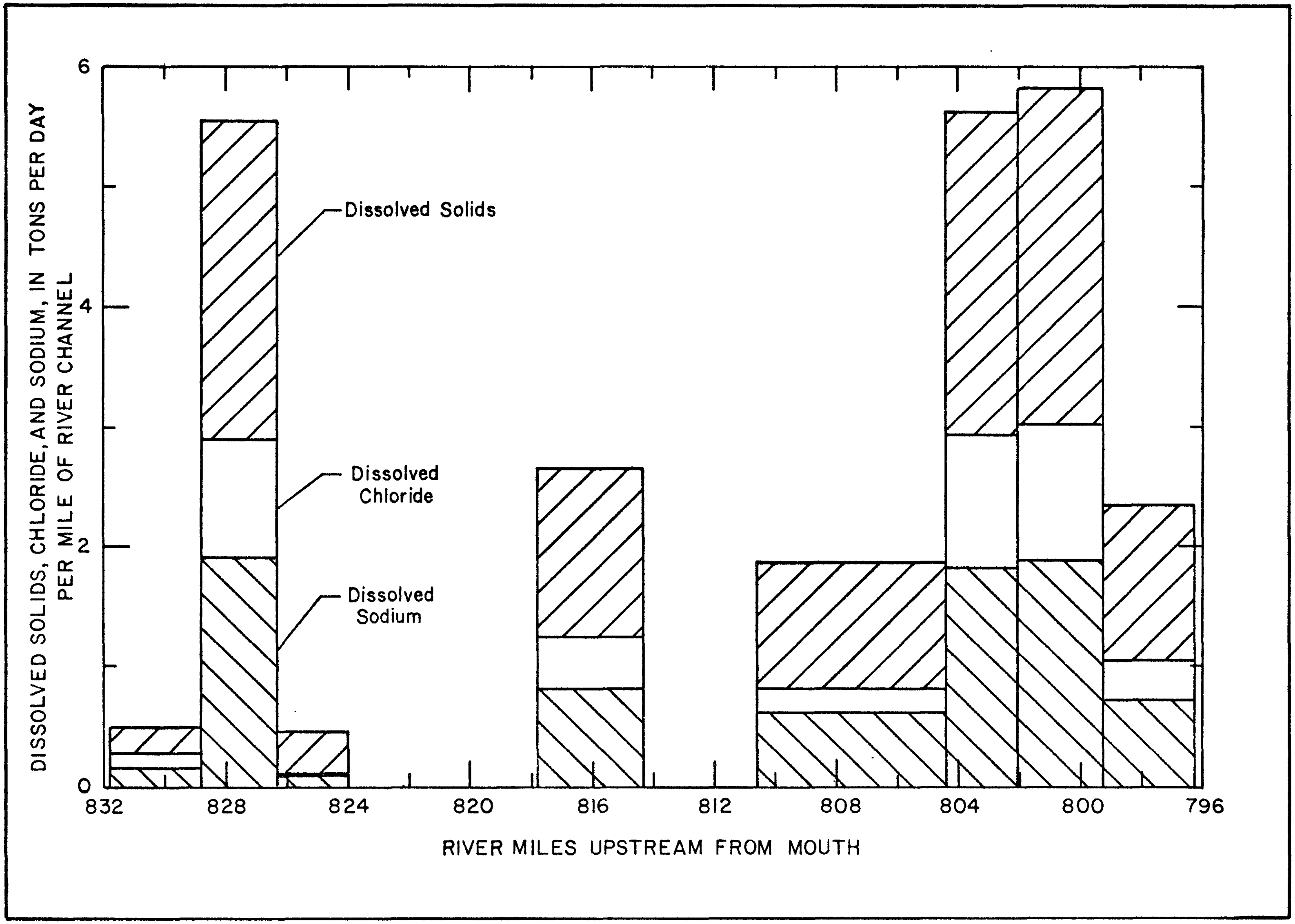

FIGURE 9.-Dissolved-solids, sodium, and chloride yields for ground-water accretions along the main stem of the Colorado River during selected low-flow periods, from February 1975 to March 1978

Yields per mile of channel along three subreaches (between miles 828.8 and 826.3, between miles 804.4 and 802.1, and between miles 802.1 and 799.3) averaged more than 5.5 tons of dissolved solids per day, of which more than 1.8 tons were sodium and more than 2.9 tons were chloride.

A comparison of the locations of these subreaches with the locations of oil fields in the area studied (figs. 1 and 2) shows that only the subreach between miles 828.8 and 826.3 is proximate to oil fields. Salt yields from some of the intervening subreaches (between miles 826.3 and 804.4) that traverse oil fields are significantly less than those downstream from mile 804.4. These data indicate that a large part of the salinity probably results from the inflow of saline water of natural origin.

Synopsis of Salt-Load Trend Studies

Recent observations by the Colorado River Municipal Water District have indicated that the ban on the disposal of oil-field brines in open pits and withdrawal of saline ground water have reduced the salinity loads of the Colorado River.

Double-mass curves of cumulative yearly mean dissolved-solids loads and yearly mean water discharges for each of three continuous streamflow and daily water-quality stations (figs. 10, 11, and 12) were prepared to show trends in water quality and to determine if the water-quality management projects are reducing the salinity loads of the Colorado River. Saline low flows upstream from the station at Colorado City have been impounded or diverted or both since January 1969. The quantity of water diverted at mile 799.3 was added to the flow for the station at Colorado City and the loads of dissolved solids for the station were adjusted so that the double-mass curve for the 1958-78 water years could be prepared.

Daily water-quality sampling for the station near Ira was discontinued during the 1971 water year but was reestablished during the 1974 water year. Loads for the 1971-73 water years were estimated from records collected before October 1970 and after November 1974.

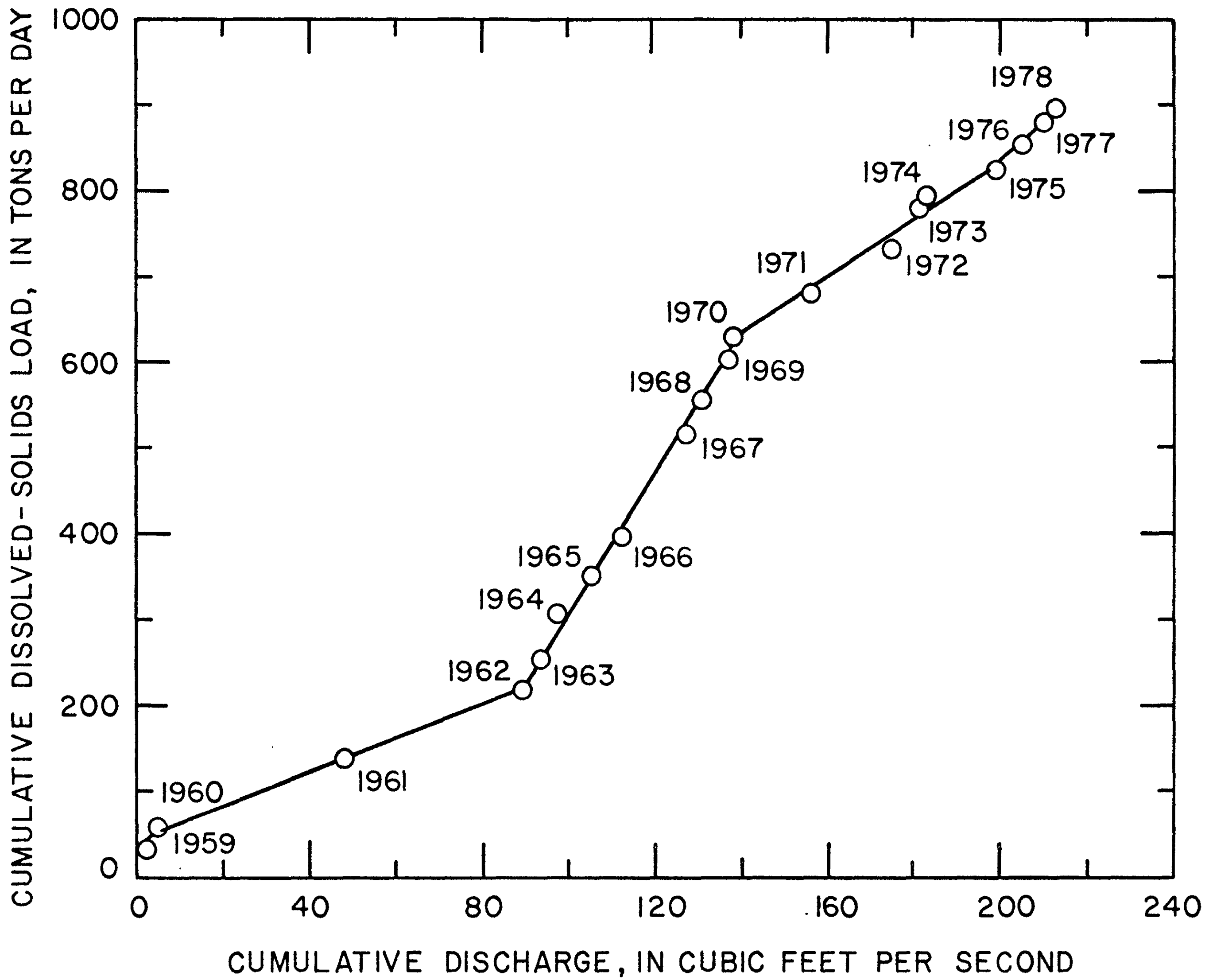

FIGURE 10.-Double-mass curve of cumulative discharge and cumulative dissolved-solids load, Colorado River near Ira

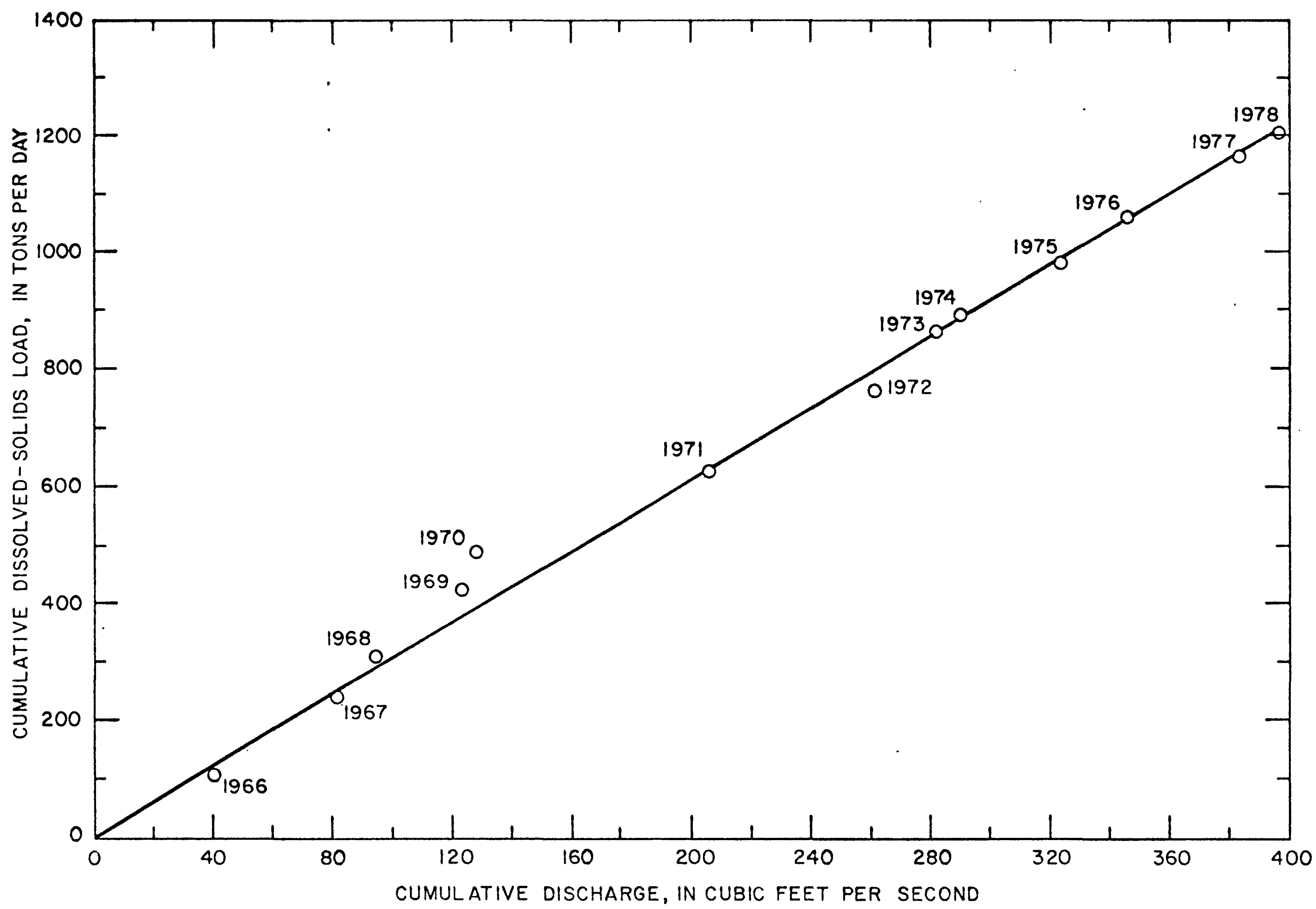

FIGURE 11.-Double-mass curve of cumulative discharge and cumulative dissolved-solids load, Colorado River near Cuthbert

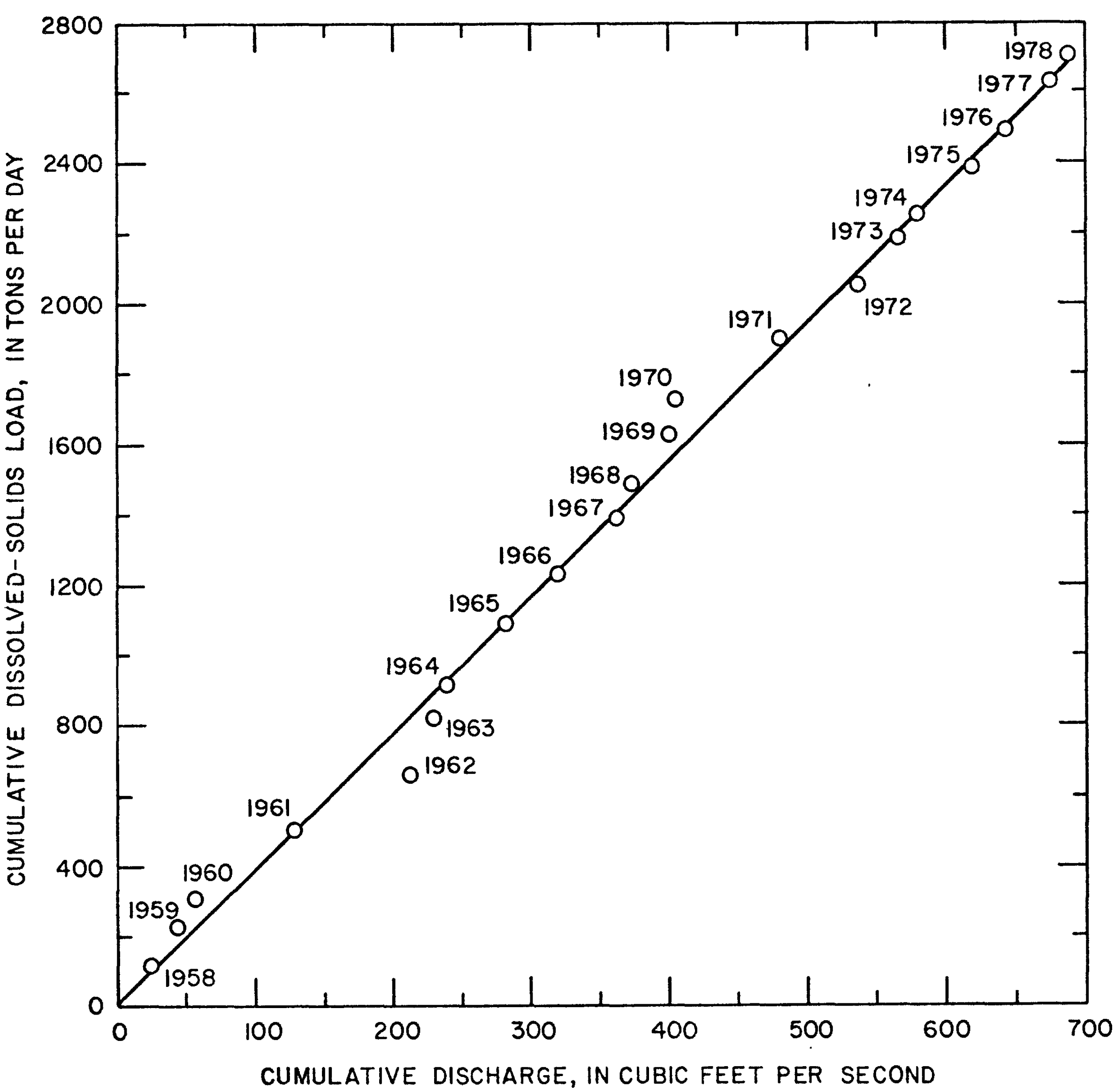

FIGURE 12.-Double-mass curve of cumulative discharge and cumulative dissolved-solids load, Colorado River at Colorado City

Changes in the slope of the double-mass curve (fig. 10) for the station 08119500 Colorado River near Ira (site 7, fig. 1) indicate that significant changes in the relation between the load of dissolved solids and water discharge occurred during two periods. A significant increase in the slope of the curve occurred during the water years from 1963 to 1970; a significant decrease in the slope occurred after 1970. Comparisons of increments of cumulative streamflow for selected periods before 1963 with equal increments of streamflow during the water years from 1963 to 1970 and of the corresponding cumulative dissolved-solids loads for these periods show that the load and thus the concentration of dissolved solids for a given increment of streamflow increased significantly after 1963. Comparison of these data for the period from 1963 to 1970 with data after 1970 shows that the load and thus the concentration of dissolved solids for a given increment of streamflow decreased significantly after 1970. The loads and concentrations of dissolved solids for equal increments of streamflow before 1963 and after 1970 were approximately equal. These data indicate that the salinity of inflow upstream from the station increased significantly after 1963 but decreased significantly after 1970.

The production and disposal of oil-field brines in Scurry and Mitchell Counties are summarized in the section "Locations of Oil Fields." These data show that the production of oil-field brine increased greatly during the early 1960's (from about 29,000 barrels in 1956 to more than 13,000,000 barrels in 1961). More than 4,600,000 barrels of brine produced in 1961 were disposed in open-surface pits. The production of brine increased to more than 18,000,000 barrels in 1967, but only about 400,000 barrels were disposed of in open pits. A State law prohibiting open-pit disposal was passed in 1969.

The increased production of brine and its subsequent disposal in open pits during the early 1960's and the corresponding increase of salinity in flow of the Colorado River near Ira during the period from 1963 to 1970 and the subsequent decrease of salinity after the ban on open-pit disposal are evidence that part of the salinity resulted from oil-field brines. However, the preponderant evidence collected during the low-flow studies and the water-quality trends for other daily sampling stations indicate that the major part of the salinity is of natural origin.

No significant breaks are apparent in the double-mass curves of cumulative yearly mean dissolved-solids loads and yearly mean water discharge (figs. 11 and 12) for the stations 08120700 Colorado River near Cuthbert (site 15, fig. 1) and 08121000 Colorado River near Colorado City (site 21, fig. 1). The correlation between loads and streamflow of each station for 1 or more years is inconsistent, but the general slope of the curve for each station is constant throughout the period of record. These data indicate that neither the ban on open-pit disposal of oil-field brines nor the pumpage of saline ground water has resulted in significant reduction of the salinity of streamflow at these stations and are additional evidence that the major part of the salinity is of natural origin.

Reduction of Salinity by Diversions of Saline Low Flows

Diversion of saline low flows from the Colorado River upstream from Colorado City at mile 799.3 (site 19, fig. 1) was begun in January 1969 by the Colorado River Municipal Water District. Records indicate that diversions of saline low flows at this site averaged about 5.7 ft^3/s during the 1969-78 water years. Water-quality records for this site and for the daily sampling station 08121000 Colorado River at Colorado City indicate that the load of dissolved solids removed by the diversion averaged about 51 tons per day, of which about 30 tons were chloride. Diversion of the saline low flows resulted in a significant improvement in the quality of water at downstream sites. Decreases in the discharge-weighted averages of dissolved solids and chloride in flow of the Colorado River at Colorado City due to the diversions during the 1969-78 water years were about 420 mg/L and 280 mg/L, respectively.

SUMMARY OF CONCLUSIONS

The average flow in a 35.5-mile reach of the upper Colorado River during seven low-flow studies from February 1975 to March 1978 increased from 0.02 ft^3/s at mile 831.8 (upstream from Bull Creek) to 6.46 ft^3/s at mile 796.3 (at Colorado City). Inflow from tributaries average 4.87 ft^3/s, of which 3.86 ft^3/s were contributed by Deep Creek. Direct ground-water accretions to this reach of the main stem Colorado River averaged 1.57 ft^3/s.

Inflows from most tributaries were significantly less mineralized than direct ground-water accretions and resulted in a decrease in the concentrations of the principal dissolved constituents in flow of the Colorado River. The discharge-weighted averages of dissolved solids, sodium, and chloride in tributary inflows were 2,210 mg/L, 470 mg/L, and 430 mg/L, respectively; those for direct ground-water accretions were 16,900 mg/L, 8,400 mg/L, and 5,400 mg/L, respectively. The discharge-weighted average of dissolved solids in low flows in the main stem Colorado River decreased from 15,200 mg/L at mile 831.8 to 5,810 mg/L at mile 796.3. The average concentrations of dissolved sodium and chloride (the principal constituents) decreased from 4,820 mg/L to 1,640 mg/L and from 7,450 mg/L to 2,410 mg/L, respectively.

Small seeps downstream from the Colorado River Municipal Water District diversion dam at mile 798.9 were the only localized sources of saline inflow found during the low-flow studies. Ground water contributed throughout most of the area studied is saline; but loads of dissolved constituents are highest in three subreaches. Yields from the subreaches of the Colorado River between miles 828.8 and 826.3, between miles 804.4 and 802.1, and between miles 802.1 and 799.3 during the low-flow studies averaged more than 5.5 tons of dissolved solids per day per mile of channel, of which more than 1.8 tons were sodium and more than 2.9 tons were chloride. Results of the low-flow studies, records of the production and disposal of oil-field brines, and salt-load trend studies indicate that part of the salinity resulted from oil-field brines; but preponderant evidence indicates that the major part of the salinity is of natural origin.

Salt-load trend studies for the continuous streamflow and daily water-quality station Colorado River near Ira (mile 826.3) show that the salinity of the flow increased significantly after 1963. The production of oil-field brines and its disposal in open-surface pits also increased greatly during the early 1960's. A ban on open-pit disposal of oil-field brines was enacted in 1969; the salinity of streamflow at the station near Ira decreased significantly after 1970. No significant downward trend of salinity in flow at daily water-quality stations downstream from Ira occurred after the ban on open-pit disposal of oil-field brines. Neither the ban on open-pit disposal nor pumpage of saline ground water has resulted in significant reduction of the saline inflow downstream from the continuous streamflow and daily water-quality station 08120700 Colorado River near Cuthbert (mile 810.6).

Diversion of saline low flows from the Colorado River at mile 799.3 since January 1969 has averaged about 5.7 ft^3/s. The load of dissolved solids removed by the diversion during the 1969-78 water years averaged about 51 tons per day, of which about 30 tons were chloride. Decreases in the discharge-weighted average of dissolved solids and chloride in flow of the Colorado River downstream from the diversion at Colorado City (mile 796.3) were about 420 mg/L and 280 mg/L, respectively.

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