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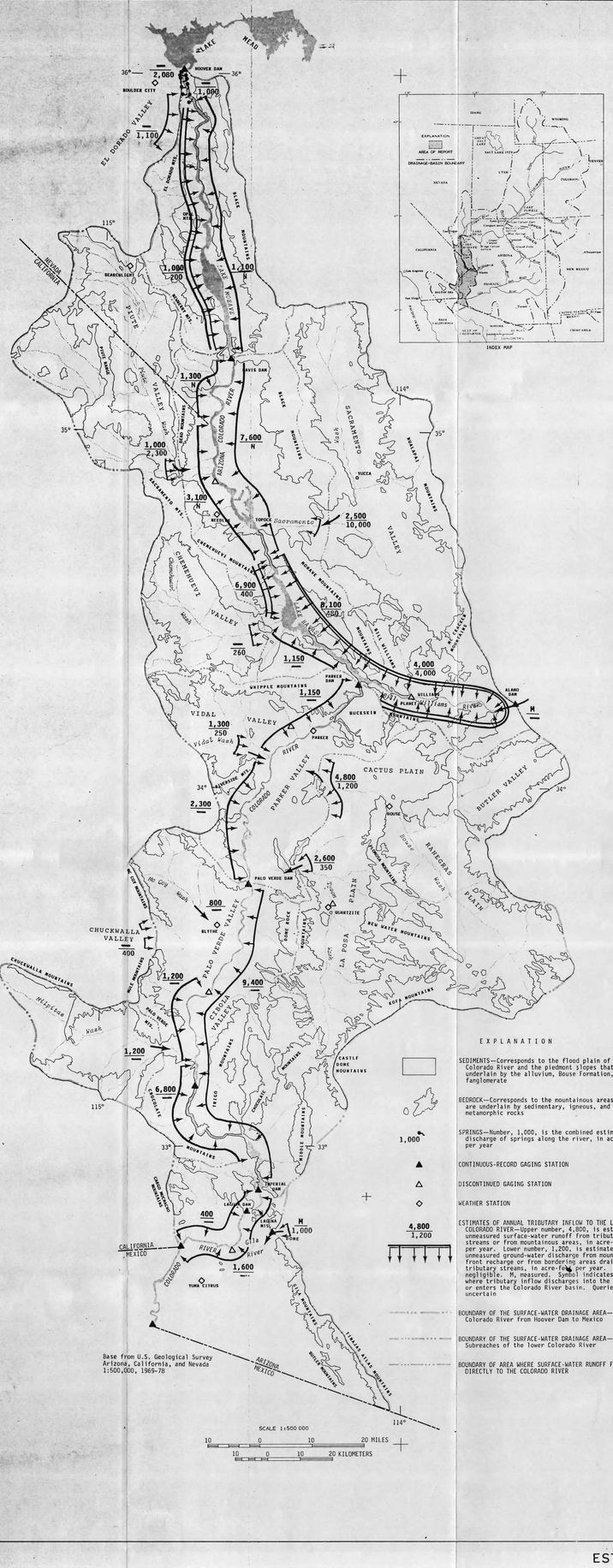


INTRODUCTION

The Colorado River Compact of 1922 divided the Colorado River basin into upper and lower basins at the compact point near Lees Ferry, Arizona (Fig. 1), and apportioned to perpetuity the exclusive beneficial consumptive use of 7,500,000 acre-ft/yr of water to each of the two basins (Ely, 1965, p. 28). The consumptive use assigned to each basin was based on a computed average annual virgin flow at the compact point of 15 million acre-ft between 1922 and 1921. In 1944, the Rio Grande, Colorado, and Tijuana Treaty allotted a guaranteed annual quantity of 1,500,000 acre-ft of Colorado River water to be delivered to Mexico (Ely, 1965, p. 42). A U.S. Supreme Court (1964) decree apportioned the annual consumptive use of mainstream water in the lower basin as follows: 2,800,000 acre-ft to Arizona, 4,400,000 acre-ft to California, and 300,000 acre-ft to Nevada. The decree is very specific about the responsibility of the Secretary of the Interior to maintain records of the diversions, return flows, and consumptive use of mainstream water by each diverter, point of diversion, and State (Cohen de la Torre, 1982, p. 6).

The water supply of the lower Colorado River is overappropriated and in the future will be fully used to meet the demands for water in the United States. Average annual runoff from flow at the compact point was about 15.1 million acre-ft between 1905 and 1983 (John Billings, hydrologist, U.S. Bureau of Reclamation, oral comm., 1986). The basic apportionments to the upper and lower basins and the treaty delivery to Mexico total 16.5 million acre-ft/yr and exceed the natural flow of the river. At present (1986), the apportionments to the upper and lower basins are not fully used; the treaty delivery to Mexico is fully satisfied. In the lower basin, California receives its full apportionment; Arizona will be taking its full apportionment when the Central Arizona Project (CAP) canal is completed in the 1990's, and Nevada is projected to use its full apportionment shortly after the year 2000. The upper basin is projected to use its full apportionment by 2040. The overapportionment of the water supply is a problem that needs to be resolved before the demands for water cannot be met.

In 1984 the U.S. Geological Survey, in cooperation with the U.S. Bureau of Reclamation, began a study to develop an accounting system for water and consumptive use along the lower Colorado River. The accounting system will use a water budget to estimate the amount of consumptive use. Digital-image analysis of satellite imagery will be used to distribute annual consumptive use by agricultural water users.

Tributaries are defined to be a drainage to the U.S. Supreme Court (1964) as the waters of all streams and rivers that naturally drain into the mainstream of the Colorado River, including reservoirs thereon. Tributaries provide water to the Colorado River system as surface water flow to the Bill Williams and Gila Rivers and surface water and ground-water flow within the Colorado River valley and from adjacent basins (Fig. 2). Estimates of the amount of unmeasured tributary inflow that reaches the river each year are needed because tributary inflow is a component in the water budget that will be used to estimate consumptive use along the lower Colorado River between Hoover Dam and the northerly international boundary with Mexico. The decree does not affect the rights or priorities of the States or water in the tributaries except in that in the Gila River. Tributary waters are accountable under the decree upon entry into the mainstream of the Colorado River. Tributaries used by the States that does not reach the Colorado River is not considered to be an inflow component in a water budget for the river.

The quantification of unmeasured tributary inflow is of concern because (1) tributary inflow is a component in a water budget and (2) the dynamic nature of tributary inflow is a problem makes quantification difficult and the quantity can only be estimated by indirect means. Tributary ground-water inflow commingles with water that originates as infiltrated surface water in the Colorado River flood plain. The methods selected by the States to assign rights and priorities to tributary inflow need to be considered in the proposed accounting system.

This report summarizes all-waters and areal distribution of tributary inflow to the lower Colorado River from Hoover Dam to Mexico (Fig. 2). Most of the estimates of tributary inflow are values determined in previous studies that used mean annual precipitation for 1931-60. Because mean annual precipitation for 1951-80 is not significantly different from the earlier period, it was assumed that mean annual precipitation had not significantly changed with time. In the areas where estimates were not available, values were calculated. The estimates provided in the report will be used by the States as a basis from which to allocate tributary inflow. The Geological Survey and the Bureau of Reclamation will determine these allocated quantities to be incorporated in the accounting system. The accounting of water and consumptive use is reported on a calendar year basis as stated in the decree; therefore, all annual data values given in this report are for calendar years.

PREVIOUS INVESTIGATIONS

Hydrologic studies of the lower Colorado River basin have been ongoing since 1960. Between 1960 and 1970, the U.S. Geological Survey completed a comprehensive study of the water resources of the lower Colorado River-Salton Sea area. The purpose was to determine the quantity and extent of the surface-water and ground-water resources and the relations among the various components (McMahon and Leetly, 1976, p. 7). The results of the study, which includes all tributary inflow, were published as 11 chapters of U.S. Geological Survey Professional Paper 486. Between 1970 and 1983, the Geological Survey and the Bureau of Reclamation developed methods of estimating ground-water return flow and determined the quantities of ground-water return flow from irrigation in some areas where tributary water have deposited alluvium. The river widens in the areas of alluvium, into which much of the surface water infiltrates; some of the infiltrated water returns to the river downstream in the next reach of bedrock-lined canyon. Short-term studies of ground-water return flow in 30 ft have been reported by well owners along the river, and these fluctuations correlate with the amount of water diverted and the amount of water pumped (1981). Ground water is pumped to irrigate four areas of agriculture that totaled about 1,000 acres of alfalfa and 440 acres of cotton in 1984; consumptive water use by the crops was estimated to be about 6,200 acre-ft. In a well measured periodically, the water level rose about 1 ft from 1981 to 1985 even though more than twice the estimated ground-water recharge is pumped from the alluvium to irrigate the croplands. Water levels in the Bill Williams River below Alamo Dam are affected by the water level of Lake Havasu. The rise in stage in Lake Havasu caused a backwater effect in the Bill Williams River during 1981 and 1984. Depth to water is less than 50 ft in the irrigated areas and less than 10 ft near the river. Ground-water withdrawals probably are being partially replaced by recharge from surface flow in the Bill Williams River. The average annual flow estimated to reach the Colorado River (table 2) is 64 percent of the average annual flow below Alamo Dam.

PRECIPITATION

During the lower Colorado River-Salton Sea study, unmeasured runoff and infiltration that resulted in ground-water recharge were estimated to be significant in some areas. The average annual runoff rates (1964). Mean annual precipitation ranges from about 3 in. near Yuma to more than 20 in. in the Hualapai Mountains and generally increases from south to north with increasing altitude. In most of the study area the mean annual precipitation is less than 8 in. Mean annual precipitation exceeds 8 in. in about 75 percent of the area and 12 in. in 1 percent of the area. Areas of precipitation in excess of 8 in. are confined mainly to the mountains in the northern part of the area, although most of Sacramento Valley receives more than 8 in. (Hely, 1965, pl. 3).

Estimates of unmeasured runoff and ground-water recharge determined in previous studies were evaluated for present (1986) use by comparing mean annual precipitation for 1931-60 with that for 1951-80 for selected weather stations in the study area (table 1). The differences in mean annual precipitation are negligible except for precipitation varies from season to season and year to year. Means for the two periods differ by less than one standard error of the mean and, therefore, are not significantly different.

Table 1.--Mean annual precipitation for selected weather stations, for 1931-60 and 1951-80, in inches

Station	1931-60	1951-80
Boulder City	4.29	5.54
Needles	4.51	4.09
Parker	4.51	4.59
Blythe	3.39	3.07
Palo Verde Citrus Station	2.55	2.67

The seasonal totals of precipitation at selected stations in the study area are shown on bar graphs (Fig. 3). About 30 to 40 percent of the precipitation occurs in the summer. The shape of the line on graphs showing accumulated departures from the mean for the period of record indicates wet and dry periods (Fig. 3); departures from the mean show short-term normal precipitation, and upward trends indicate above-normal precipitation. Wet and dry periods occur during the same time intervals throughout the study area. Both the 1931-60 and 1951-80 periods of record overly periods of below normal and above normal precipitation.

MEASURED TRIBUTARY INFLOW

The Bill Williams and Gila Rivers are the two major tributary streams in the lower Colorado River valley. Most of the Colorado River water is diverted from spring stations where flow into the lower Colorado River valley is measured. Estimates of surface water inflow were based on precipitation data, rainfall runoff relations, character of terrain, and other parameters in addition to ground-water data and precipitation-altitude relations. Estimates of ground-water inflow were based on an empirical relation between precipitation and ground-water recharge determined for central Nevada (Eakin and others, 1951) and adjusted for climate conditions in the lower Colorado River basin. The percentage of precipitation that contributes to ground-water recharge in Nevada were revised by Metzger and Loeltz (1973, p. 35-36) for use in the lower Colorado River basin in proportion of less favorable conditions for recharge from precipitation and the lower percentage of precipitation that falls as snow. Ground-water discharge from Tyson Wash, Chuckwalla Valley, and Milpitas wash was treated as spring sources; ground-water discharge from Chuckwalla Valley and water-level gradients measured in augered wells (Metzger and others, 1973). The measured and estimated tributary inflow to the lower Colorado River valley are shown on the map, and summarized in table 2.

Table 2.--Average annual water budget for the Bill Williams River below Alamo Dam, in acre-feet

[illegible]

Table 3.--Unmeasured average annual tributary inflow to reaches of the lower Colorado River, in acre-feet per year

[illegible]

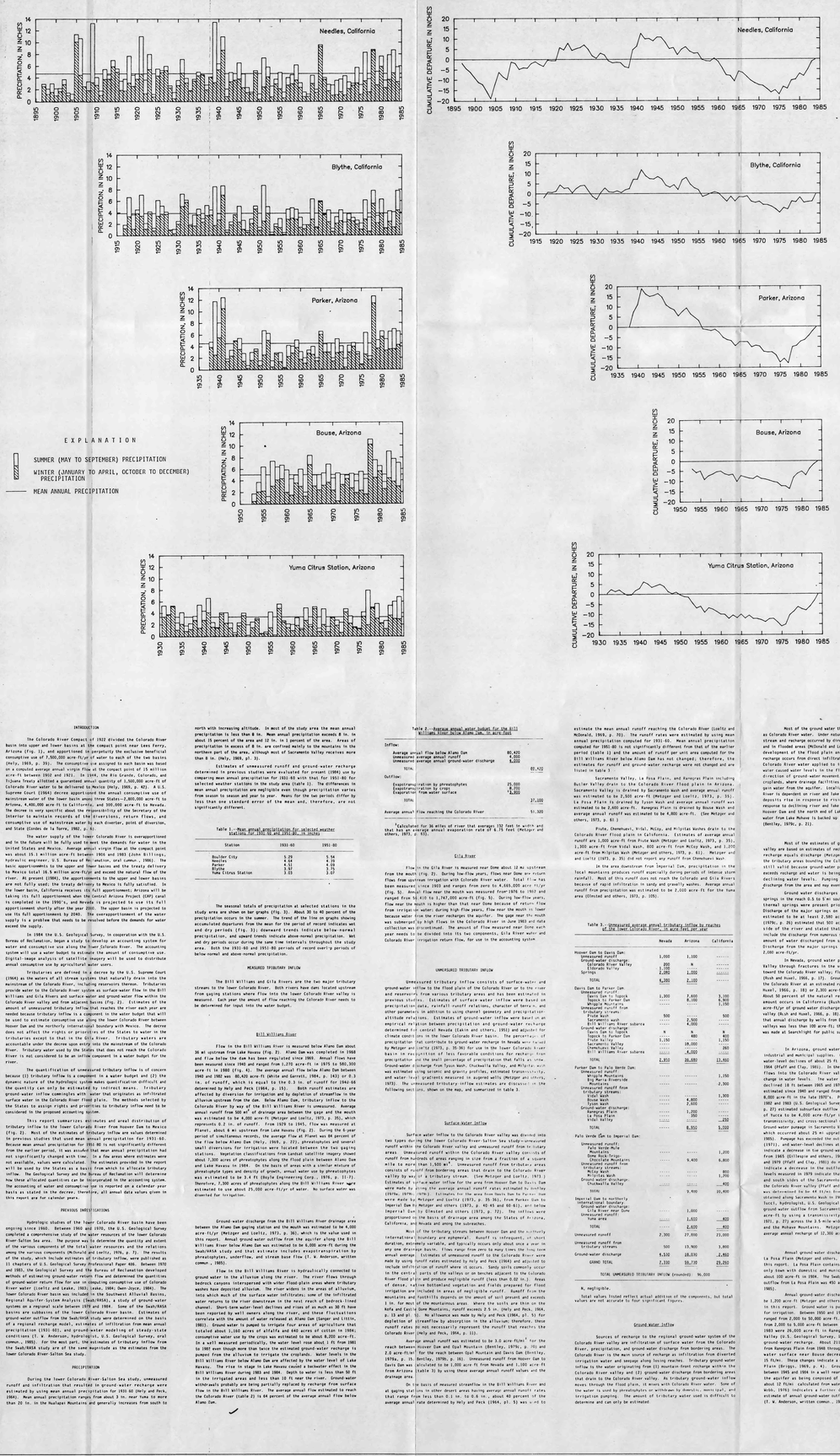
EXPLANATION

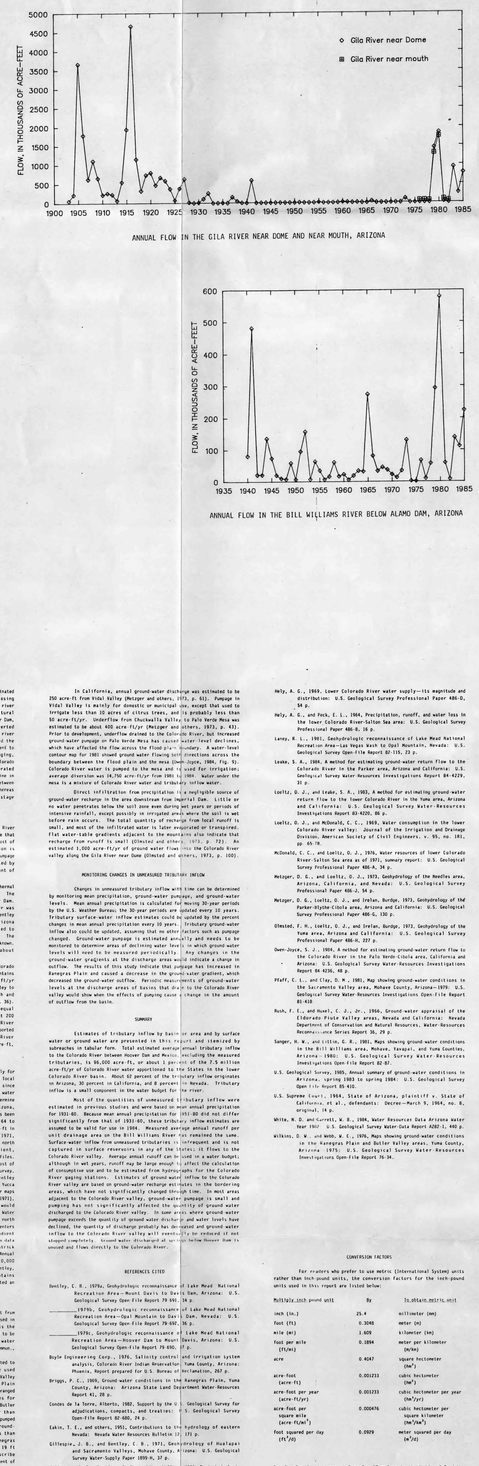
SUMMER (MAY TO SEPTEMBER) PRECIPITATION

WINTER (JANUARY TO APRIL, OCTOBER TO DECEMBER) PRECIPITATION

MEAN ANNUAL PRECIPITATION

SEASONAL PRECIPITATION AND CUMULATIVE DEPARTURES FROM MEAN ANNUAL PRECIPITATION FOR SELECTED STATIONS





ANNUAL FLOW IN THE GILA RIVER NEAR DOME AND NEAR MOUTH, ARIZONA

ANNUAL FLOW IN THE BILL WILLIAMS RIVER BELOW ALAMO DAM, ARIZONA

SUMMARY

Estimates of tributary inflow by basin or area and by surface water and ground water are presented in this report and summarized by subreaches in tabular form. Total estimated average annual tributary inflow to the Colorado River between Hoover Dam and Mexico, including the measured tributaries, is 96,000 acre-ft, or about 1 percent of the 7.5 million acre-ft/yr of Colorado River water apportioned to the States in the lower Colorado River basin. About 62 percent of the tributary inflow originates in Arizona, 38 percent in California, and 1 percent in Nevada. Tributary inflow is a small component in the water budget for the river.

Most of the estimates of unmeasured tributary inflow were estimated in previous studies and were based on mean annual precipitation for 1931-60. Because mean annual precipitation for 1951-80 did not differ significantly from that of 1931-60, those tributary inflow estimates are assumed to be valid for use in the present study. Measured average annual runoff per unit drainage area on the Bill Williams River was remained the same. Surface-water inflow from unmeasured tributaries is infrequent and is not captured in surface reservoirs in any of the states; it flows to the Colorado River valley. Average annual runoff is used in a water budget, although in wet years, runoff may be large enough to affect the calculation of consumptive use and to be estimated from hydrographs for the Colorado River gaging stations. Estimates of ground-water inflow to the Colorado River valley are based on ground-water recharge estimates in the bordering areas, which have not significantly changed through time. In most areas adjacent to the Colorado River valley, ground-water withdrawal and water pumping has not significantly affected the quantity of ground-water discharged to the Colorado River valley. In areas where ground-water pumping exceeds the quantity of ground-water discharge and water levels have declined, the quantity of discharge probably has decreased and ground-water inflow to the Colorado River valley will eventually be reduced if not stopped completely. Ground-water withdrawal and pumping below Hoover Dam is unused and flows directly to the Colorado River.

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CONVERSION FACTORS

For readers who prefer to use metric (International System) units rather than inch-pound units, the conversion factors for the inch-pound units used in this report are listed below:

Multiply	inch-pound unit	By	To obtain metric unit
	inch (in.)	25.4	millimeter (mm)
	foot (ft)	0.3048	meter (m)
	mile (mi)	1.609	kilometer (km)
	foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
	acre	0.4047	square hectometer (hm^2)
	acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
	acre-foot per year (acre-ft/yr)	0.001233	cubic hectometer per year (hm^3/yr)
	acre-foot per square mile (acre-ft/mi^2)	0.000476	cubic hectometer per square kilometer (hm^3/km^2)
	foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)

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 of 1929."

ESTIMATES OF AVERAGE ANNUAL TRIBUTARY INFLOW TO THE LOWER COLORADO RIVER, HOOVER DAM TO MEXICO

BY