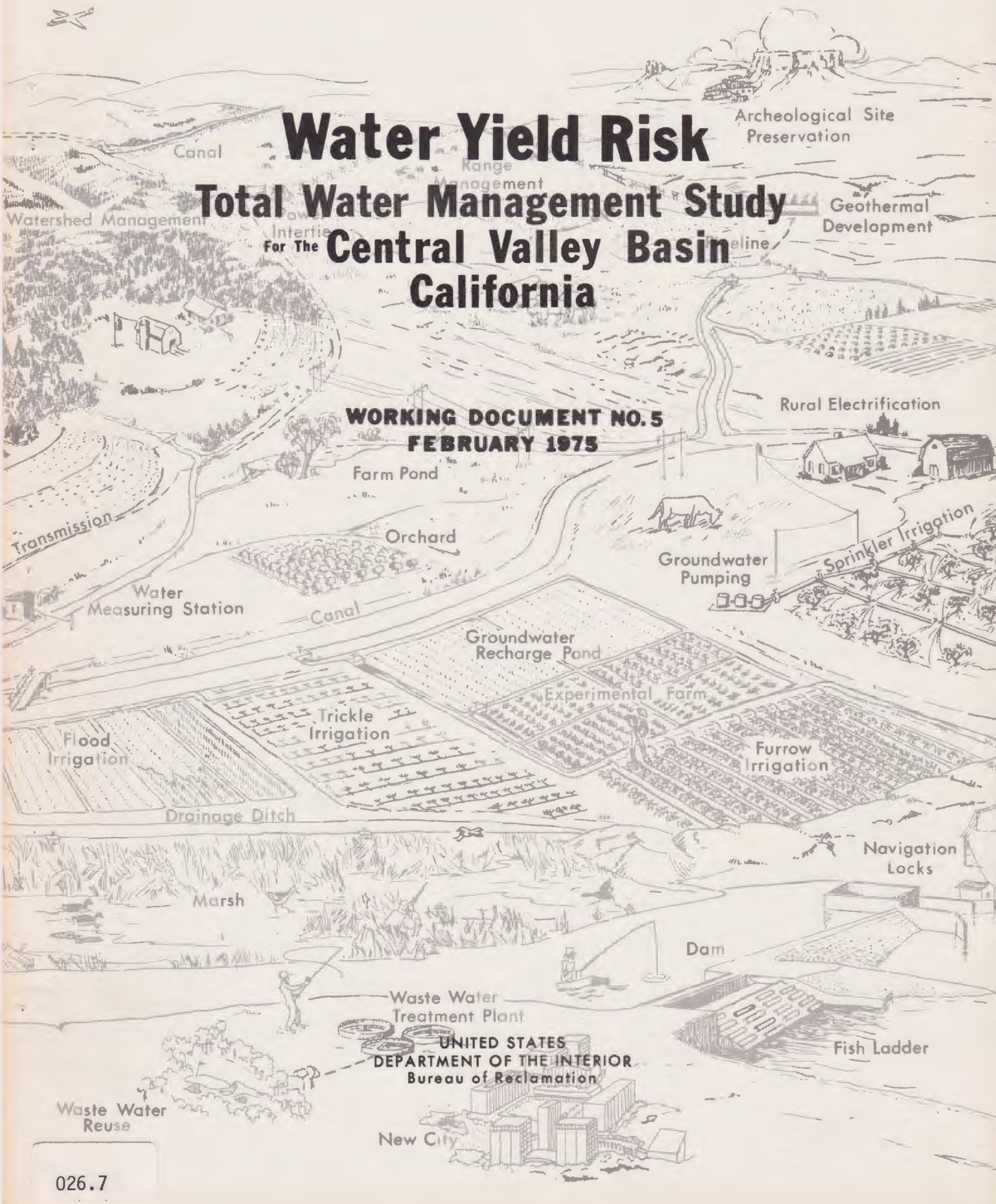
# Water Yield Risk

## Total Water Management Study For The Central Valley Basin California

WORKING DOCUMENT NO. 5
FEBRUARY 1975



UNITED STATES
DEPARTMENT OF THE INTERIOR
Bureau of Reclamation

# TOTAL WATER MANAGEMENT STUDY
# FOR THE
# CENTRAL VALLEY BASIN, CALIFORNIA

## CENTRAL VALLEY PROJECT

## WATER YIELD RISK

WORKING DOCUMENT NO. 5

February 1975

Bureau of Reclamation

Mid-Pacific Region

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# INTRODUCTION

## PURPOSE AND SCOPE

The amount of water which can be delivered from the Central Valley Project during normal years is presently based on project limitations identified in a theoretical operation of the project through the worst drought recorded in the area. This drought occurred during the years 1928 through 1934.

This document is an initial step in determining the probabilities and risks of changing those limitations, and the impacts of those changes on various water services.

Frequencies of the critical year and critical dry period as defined in the present operation of the Central Valley Project are discussed. The desirability of their continued use as constraints in determining the firm annual water supply yield is considered. The use of synthetic hydrology as an additional data source in determination of probabilities of project yields and corresponding risks of water shortages is explored.

Ability of municipal water users to withstand shortages in their normal water supplies during water-short years is then examined.

The potential for expanding the yield of the Central Valley Project during water-short years by increasing the maximum allowable deficiencies in municipal and industrial supplies, and agricultural supplies is also examined.

## BASIN DESCRIPTION

The Central Valley Basin is comprised of two major river basins, the Sacramento on the north and the San Joaquin on the south. The combined basin is nearly 500 miles long and about 120 miles wide. It contains 38 million acres of land, or more than one-third of the area of California. Nearly one-third of the basin area is valley floor, where the bulk of the population, industry, and agriculture is located. The foothills and mountains in the two-thirds of the basin surrounding the valley floor receive most of the precipitation and provide the main source of the water supply for the valley. Since the summers are hot and usually rainless, and most of the stream runoff occurs in the winter or spring, water carryover storage is essential for the successful development of the valley.

## Introduction

The water supply of the Central Valley is derived chiefly from runoff of the Sierra Nevada, with minor amounts from the Coast Ranges, and from precipitation on the valley floor.

Runoff varies widely within a given year and from year to year. The annual runoff can vary from more than twice to less than one-third of the annual average. Annual runoff into the valley since 1904 has varied from an estimated maximum of more than 60 million acre-feet to a recorded minimum of less than 8.5 million acre-feet, with the long-term average annual about 33 million acre-feet. However, in the 7-year critically dry period, 1928 through 1934, runoff averaged only 18 million acre-feet. Precipitation records at Sacramento indicate that this 7-year period was the driest in over 120 years of record. The average annual natural runoff for the 7-year critical period and a long-term normal period are shown in table 1 for the major streams entering the Central Valley.

Runoff within any year also varies widely from season to season, being highest in the winter and spring, and low in the summer and fall months. Many streams in the area are intermittent, with flow only during wet periods of the year. Variation in flow is common on a weekly or hourly basis as, for example, during flood periods.

Because of the wide variation in flow, regulation through storage is necessary if the water is to be used during those periods of the year when runoff is minimal.

Water development in the basin spans a period of more than 120 years. Basically, it progressed through four stages. In the first stage, local diversions were made directly from the rivers. The second stage was the widespread use of ground-water pumping adjacent to rivers. In the third, water was stored for use within a river basin. In all of these stages, the water facilities were constructed and operated by individuals, companies, districts, or other water service organizations.

Large-scale Federal water development in the Central Valley began in 1935 with the initial phases of construction of the Central Valley Project by the Bureau of Reclamation. This inaugurated the fourth stage and marked the beginning of coordinated interbasin water development in the Central Valley. In 1961, construction began on the California State Water Project, including joint Federal and State facilities. The primary source of water

Table 1. Natural runoff of Central Valley streams

| Stream | Location of gaging station | Average annual runoff<br>7-year critical period[a] | <br>40-year long-term normal period[b] |
|---|---|---|---|
| | | (1,000 acre-feet) | |
| Sacramento River | Red Bluff | 4,950 | 8,350 |
| Feather River | Oroville | 2,600 | 4,450 |
| Yuba River | Smartsville | 1,400 | 2,350 |
| Bear River | Van Trent | 160 | 320 |
| Cache Creek | Capay | 150 | 460 |
| Putah Creek | Winters | 170 | 430 |
| Stony Creek | Orland | 170 | 390 |
| Deer Creek | Vina | 135 | 210 |
| Mill Creek | Los Molinos | 135 | 200 |
| Thomes Creek | Paskenta | 110 | 190 |
| American River | Fair Oaks | 1,550 | 2,750 |
| Mokelumne River | Clements | 440 | 770 |
| Cosumnes River | Michigan Bar | 170 | 370 |
| Calaveras River | Jenny Lind | 70 | 200 |
| San Joaquin River | Friant | 1,060 | 1,820 |
| Tuolumne River | La Grange | 1,150 | 1,900 |
| Stanislaus River | Knights Ferry | 680 | 1,200 |
| Merced River | Merced Falls | 570 | 1,020 |
| Fresno River | Adobe Ranch | 45 | 120 |
| Chowchilla River | Buchanan Damsite | 35 | 100 |
| Kings River | Piedra | 1,010 | 1,720 |
| Kern River | Bakersfield | 370 | 760 |
| Kaweah River | Three Rivers | 240 | 420 |
| Tule River | Success Damsite | 55 | 140 |
| Other streams | Edge of Valley | 975 | 2,360 |
| Central Valley Basin Total | | 18,400 | 33,000 |

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[a] Average for 7-year period, water year 1927-28 to 1933-34, inclusive.
[b] Average for 40-year period, water year 1903-04 to 1942-43, inclusive.

for the two projects is the Sacramento River Basin, although some water is derived from the San Joaquin Valley, and some is imported from the Trinity River.

The Central Valley Project is a series of storage facilities, conveyance systems, and powerplants constructed, under construction, or proposed, to make multipurpose use of the water supplies that can be controlled by the facilities. The main storage facilities that are considered in this report are Shasta, Friant, Clair Engle, Whiskeytown, Folsom, Auburn, New Melones and San Luis Reservoirs. All but Auburn and New Melones are presently in operation. The reservoirs of the Central Valley Project are coordinated in their operation to make maximum use of the available water supply.

## WATER SUPPLY

The use of water from the Central Valley is governed by Federal Reclamation laws and agreements made pursuant thereto. Project functions or services are provided for these purposes: Flood control, power production, maintenance of navigation flow, recreation, fish conservation, water quality, and the provision of firm dependable water supplies for agriculture, and municipal and industrial uses. Firm annual water supply yield is the amount of water supply that can be provided each year on a usable pattern to meet project obligations, with allowable deficiencies in critically dry years.

Accomplishments of the Central Valley Project, both with and without proposed additions, are identified by means of operation studies. The studies, made on a monthly basis, consider inflow and storage in each CVP reservoir in relation to the obligations which must be met from all of the reservoirs.

The future level of development considered in most CVP operation studies is that which is expected to occur in the year 2020. Historic data (1922-70) are modified to represent flows at the year 2020 level of development. The modifications include: Effects of reservoirs that either have been constructed since the historic record or are projected to be constructed; the change in the level of development within a hydrologic basin that has occurred or is estimated to occur; or the change in the amount of exports from or imports to a basin that have occurred or are estimated to occur. Allowances are also made for prior rights by reducing the inflow by an appropriate amount, or by considering the prior right to be an obligation to be met from the CVP reservoirs if physically possible.

# Introduction

When a year has a normal or above normal runoff, more water may be available than required for the firm CVP yield. However, contracts with potential CVP water users are, for the most part, based on the availability of maximum dependable water supply for the critical dry period (1928-34).

At the beginning of the critical dry period in April 1928, all of the carryover storage in the main regulatory reservoirs in the Central Valley Project would be filled from flows exceeding firm supplies in prior years. As the reservoirs are integrally operated, nearly all of this carryover storage would be emptied by December 1934. At the 2020 level of development, with Auburn Dam as a part of the Central Valley Project, none of the reservoirs spill during this period. Any Delta surpluses, or flows into the Delta in excess of Delta needs and uses, would be the large accretions from winter runoff below the regulatory facilities. At times those accretions are large enough to satisfy any CVP requirements below the points where they enter the system, with any surplus spilling out into the Delta. In all other years of record, water supply yields demonstrated for the critical period can be easily supplied.

To reduce the effect of the critical dry period on water supply yields and utilize the abundant water supply in normal years, deficiency criteria have been established. In past studies, it has been assumed that in the agricultural supply, deficiencies totaling 100 percent of one year's supply can be tolerated during the 7-year critical dry period. In navigation releases, through scheduling of shipping on the Sacramento River, a saving equivalent to 1,000 cubic feet per second in a month can be realized. For municipal and industrial supplies, no deficiencies are assumed, but for water rights and fishery supplies, varying degrees of deficience are accepted.

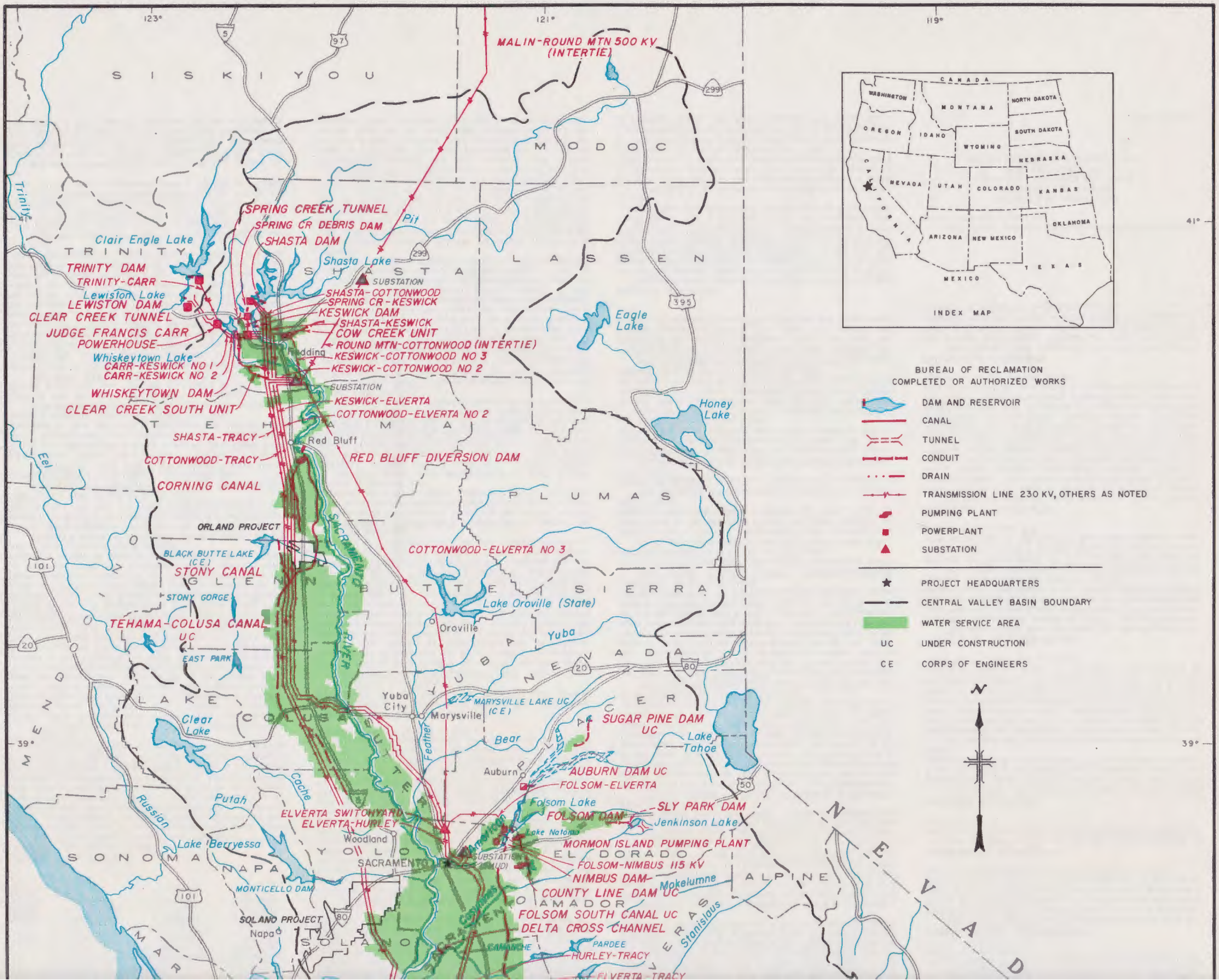
Deficiencies are applied to releases at Keswick Dam for maintenance of fish and wildlife resources. Deficiencies are only taken at Nimbus Dam when the estimated natural inflow to Folsom Reservoir, during the period from April 1 to September 30 is less than 600,000 acre-feet, and is further limited to the percentage of the deficiency taken in the agricultural supply for the American River service areas.

The Millerton Lake service area takes deficiencies in its class 1 supply based on the total inflow to Millerton Lake. When the inflow to Millerton is insufficient to satisfy the total class 1 requirements of 800,000 acre-feet, each water user's supply is reduced on a prorated basis and no class 2 water is available during that year.

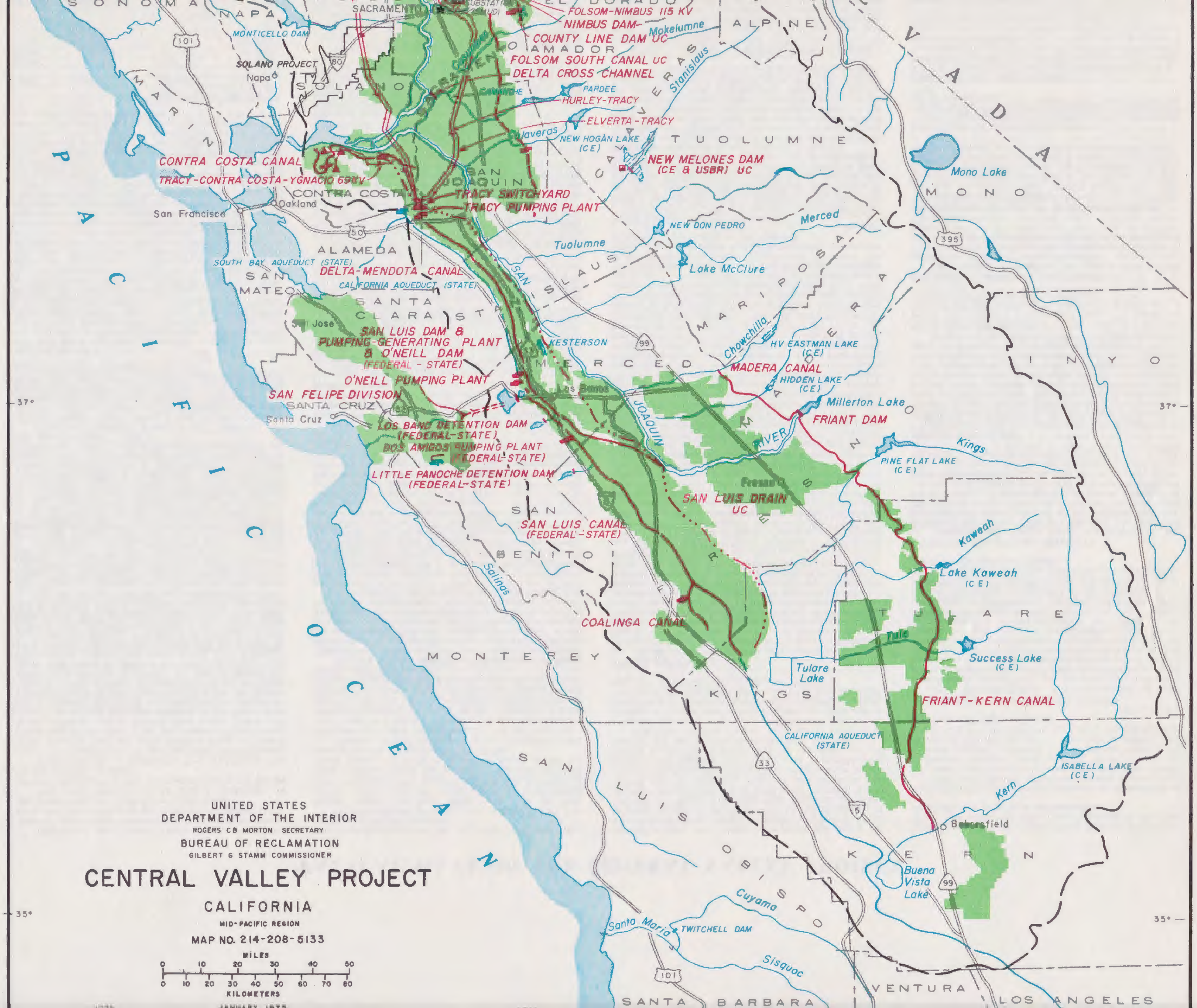
## Introduction

In current operation studies, the municipal and industrial supplies, releases for maintenance of fish and wildlife at Trinity, Whiskeytown, and Friant Dams, and all water quality releases are not reduced by deficiency criteria.

The State Water Resources Control Board's Decisions 1400 and 1379 place different requirements and deficiency criteria on the releases at Nimbus for fish and wildlife maintenance, and water quality in the Delta. Neither decision has been considered in determining the present water supply.



BUREAU OF RECLAMATION
COMPLETED OR AUTHORIZED WORKS
DAM AND RESERVOIR
CANAL
TUNNEL
CONDUIT
DRAIN
TRANSMISSION LINE 230 KV, OTHERS AS NOTED
PUMPING PLANT
POWERPLANT
SUBSTATION
★ PROJECT HEADQUARTERS
CENTRAL VALLEY BASIN BOUNDARY
WATER SERVICE AREA
UC UNDER CONSTRUCTION
CE CORPS OF ENGINEERS
N
INDEX MAP
CANADA
WASHINGTON
MONTANA
NORTH DAKOTA
OREGON
IDAHO
SOUTH DAKOTA
WYOMING
NEBRASKA
CALIFORNIA
NEVADA
UTAH
COLORADO
KANSAS
OKLAHOMA
ARIZONA
NEW MEXICO
TEXAS
MEXICO
123°
121°
119°
41°
39°
MALIN-ROUND MTN 500 KV (INTERTIE)
SISKIYOU
MODOC
LASSEN
SHASTA
TRINITY
TEHAMA
PLUMAS
GLENN
BUTTE
SIERRA
YUBA
NEVADA
PLACER
LAKE
COLUSA
SUTTER
YOLO
SONOMA
NAPA
SOLANO
SACRAMENTO
EL DORADO
AMADOR
ALPINE
CALAVERAS
MENDOCINO
MARIN
NEVADA
SPRING CREEK TUNNEL
SPRING CR DEBRIS DAM
SHASTA DAM
Shasta Lake
Pit
SUBSTATION
Clair Engle Lake
TRINITY DAM
TRINITY-CARR
Lewiston Lake
LEWISTON DAM
CLEAR CREEK TUNNEL
JUDGE FRANCIS CARR POWERHOUSE
Whiskeytown Lake
CARR-KESWICK NO 1
CARR-KESWICK NO 2
WHISKEYTOWN DAM
CLEAR CREEK SOUTH UNIT
SHASTA-COTTONWOOD
SPRING CR-KESWICK
KESWICK DAM
SHASTA-KESWICK
COW CREEK UNIT
ROUND MTN-COTTONWOOD (INTERTIE)
KESWICK-COTTONWOOD NO 3
KESWICK-COTTONWOOD NO 2
Redding
SUBSTATION
KESWICK-ELVERTA
COTTONWOOD-ELVERTA NO 2
SHASTA-TRACY
COTTONWOOD-TRACY
Red Bluff
RED BLUFF DIVERSION DAM
CORNING CANAL
Eagle Lake
Honey Lake
Trinity
Eel
ORLAND PROJECT
BLACK BUTTE LAKE (CE)
STONY CANAL
STONY GORGE
TEHAMA-COLUSA CANAL UC
EAST PARK
SACRAMENTO RIVER
COTTONWOOD-ELVERTA NO 3
Lake Oroville (State)
Oroville
Yuba
Yuba City
Marysville
MARYSVILLE LAKE UC (CE)
SUGAR PINE DAM UC
Lake Tahoe
Feather
Bear
Clear Lake
Auburn
AUBURN DAM UC
FOLSOM-ELVERTA
Folsom Lake
FOLSOM DAM
SLY PARK DAM
Jenkinson Lake
Lake Natoma
American
MORMON ISLAND PUMPING PLANT
SUBSTATION (SMUD)
FOLSOM-NIMBUS 115 KV
NIMBUS DAM
Mokelumne
COUNTY LINE DAM UC
FOLSOM SOUTH CANAL UC
DELTA CROSS CHANNEL
Cosumnes
CAMANCHE
PARDEE
HURLEY-TRACY
ELVERTA-TRACY
Stanislaus
Cache
Putah
Russian
Lake Berryessa
ELVERTA SWITCHYARD
ELVERTA-HURLEY
Woodland
SACRAMENTO
MONTICELLO DAM
SOLANO PROJECT
Napa
5
97
299
395
101
20
80
50



UNITED STATES
DEPARTMENT OF THE INTERIOR
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# CENTRAL VALLEY PROJECT

CALIFORNIA

MID-PACIFIC REGION

MAP NO. 214-208-5133

# CRITICAL YEAR AND CRITICAL PERIOD FREQUENCY

## CRITICAL YEAR CRITERIA

To evaluate the water yield risk of the Central Valley Project, the frequency of a critical year and of the critical period on which the firm water supply yield is based were determined.

A critical year, as defined in the May 1956 contract for the exchange of water and in water rights settlement contracts in the Sacramento basin, is said to exist if:

1. The forecasted full natural inflow to Shasta Lake for the current water year (October 1 of the preceding calendar year through September 30 of the current calendar year), as such forecast is made by the United States, on or before February 15, and reviewed as frequently thereafter as conditions and information warrant, is equal to or less than 3,200,000 acre-feet, or

2. The total accumulated actual deficiencies of inflow below 4 million acre-feet in the immediately prior water year or series of successive water years, each of which had inflows of less than 4 million acre-feet, together with the forecasted deficiency for the current water year, exceed 800,000 acre-feet.

For the purpose of determining a critical year, the computed inflow to Shasta Lake under present upstream development above Shasta Lake is to be used as the full natural inflow to Shasta Lake. The computed inflow to Shasta Lake used to define a critical year is adjusted to eliminate the effect of any major construction above Shasta Lake, which materially alters the present regimen of the contributory stream systems.

The critical and noncritical years for the historical period water years 1921-22 through 1934-35, an unusually dry period, are:

| Water year | Inflow to Shasta L. | Deficiencies below 4 million acre-feet | Accumulated deficiencies | Type of year |
|---|---|---|---|---|
| | (1,000 acre-feet) | | | |
| 1921-22 | 4,620 | 0 | 0 | Noncritical |
| 1922-23 | 3,650 | 350 | 350 | Noncritical |
| 1923-24 | 2,480 | 1,520 | 1,870 | Critical |
| 1924-25 | 5,060 | 0 | 0 | Noncritical |
| 1925-26 | 3,730 | 270 | 270 | Noncritical |
| 1926-27 | 6,990 | 0 | 0 | Noncritical |
| 1927-28 | 5,120 | 0 | 0 | Noncritical |
| 1928-29 | 3,210 | 790 | 790 | Noncritical |
| 1929-30 | | 0 | 0 | Noncritical |
| 1930-31 | 2,540 | 1,460 | 1,460 | Critical |
| 1931-32 | 3,690 | 310 | 1,770 | Critical |
| 1932-33 | 3,470 | 530 | 2,300 | Critical |
| 1933-34 | 3,320 | 680 | 2,980 | Critical |
| 1934-35 | 4,920 | 0 | 0 | Noncritical |

## Critical Year and Critical Period Frequency

The criteria used for defining a critical dry year were empirically derived to include four critical years during the period 1928 through 1934. During the period 1922 through 1954 of the CVP operation study, 1924 would be the only other critical year as defined by the criteria.

When a year was considered to be critical, the effect of the deficiency allowances in the determination of the project "firm yield" is to build in a degree of risk. This risk has been generally assumed to average five critical years during any 100-year period.

### CRITICAL YEAR FREQUENCY

In estimating the frequency of the critical year, two methods were used. The first was a statistical evaluation of Shasta annual inflow, employing the Log Pearson Type III procedure and the second, the Monte Carlo procedure. Results of both methods of analysis show the critical year as presently defined could occur an average of eight times during any given 100-year period.

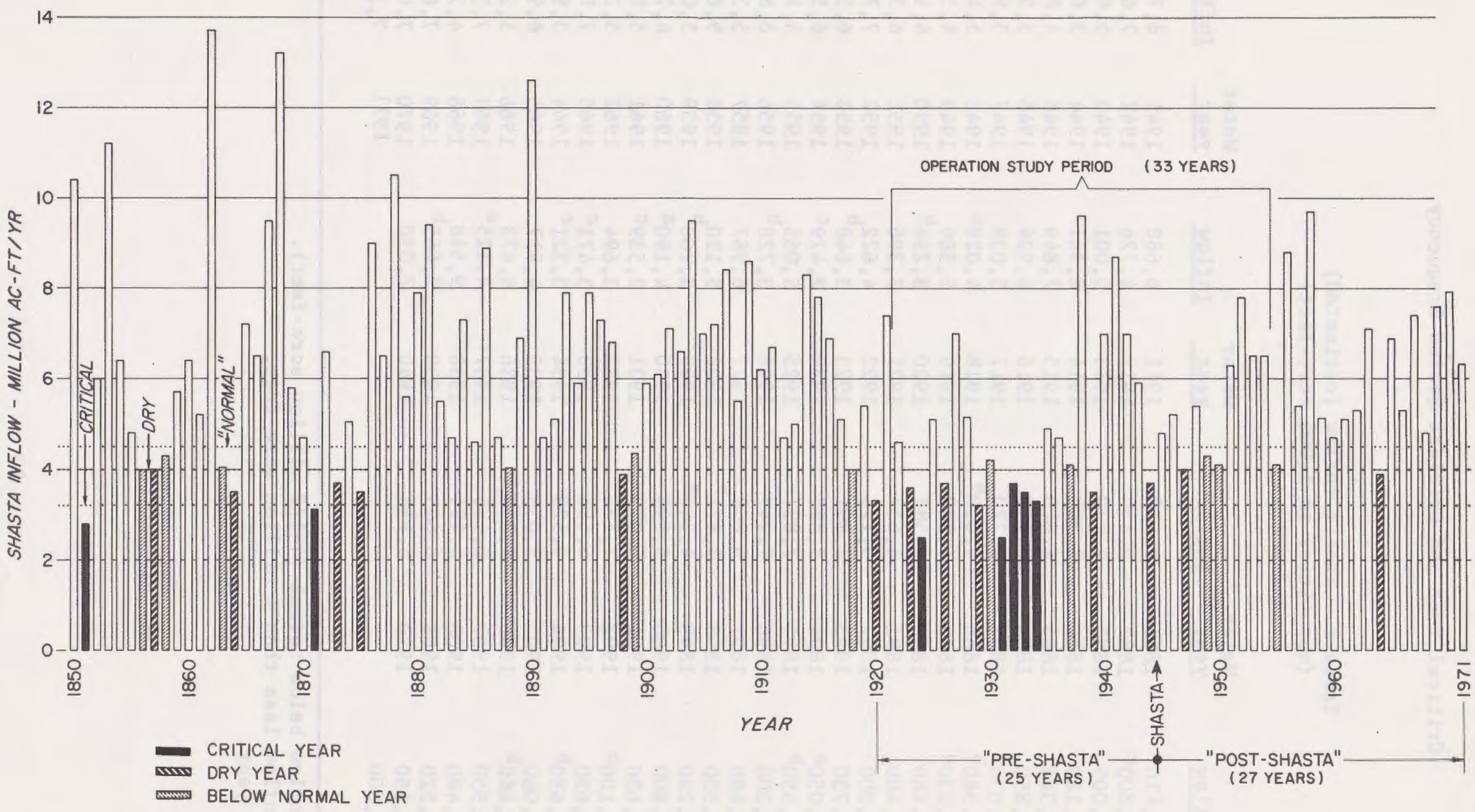
#### Statistical Procedure

Using various periods of record, frequency studies were made of the annual inflow to Shasta Lake. The period of record chosen for analysis influences the evaluation of a critical year. From 1878 through 1888 and from 1891 through 1895, the U.S. Weather Bureau had recorded gage heights of the Sacramento River at Red Bluff. The first streamflow records on the Sacramento River were collected by the U.S. Geological Survey near Red Bluff beginning in 1895. The record of a recording gage on the Sacramento River at Kennett, a short distance upstream from the Shasta Dam site, is continuous from 1926, when it was established, until 1943 when Shasta Dam was constructed. Since 1943, to compute the flow of the Sacramento River into Shasta Lake, records of Shasta operations have been used.

Annual flow at the Shasta Dam site was estimated, using precipitation and streamflow records at Red Bluff and Kennett. The estimated or measured flow at Shasta Dam site for the period 1850 through 1971, is graphically represented in figure 1, and listed in table 2.

Estimates covering the period 1922 through 1971, based on Shasta operational records and measured flows at Kennett, are considered the most reliable. The estimates for the period 1895 through 1921, based on a correlation with flows at Red Bluff, are considered

FIGURE 1



SHASTA INFLOW (1850-1971)

Table 2. Shasta inflow (estimated)
(quantities in 1,000 acre-feet)

| Water year | Inflow | Water year | Inflow | Water year | Inflow | Water year | Inflow |
|---|---|---|---|---|---|---|---|
| 1850 | 10,410 | 1881 | 9,420 | 1911 | 6,668 | 1941 | 8,716 |
| 1851 | 2,800[c] | 1882 | 5,450 | 1912 | 4,726 | 1942 | 7,619 |
| 1852 | 6,005 | 1883 | 4,720 | 1913 | 5,001 | 1943 | 5,893 |
| 1853 | 11,180 | 1884 | 7,300 | 1914 | 8,361 | 1944 | 3,688[b] |
| 1854 | 6,380 | 1885 | 4,610 | 1915 | 7,849 | 1945 | 4,859 |
| 1855 | 4,850 | 1886 | 8,900 | 1916 | 6,924 | 1946 | 5,905 |
| 1856 | 4,030[a] | 1887 | 4,720 | 1917 | 5,039 | 1947 | 3,909[b] |
| 1857 | 3,980[b] | 1888 | 4,030[a] | 1918 | 4,028[a] | 1948 | 5,415 |
| 1858 | 4,230[a] | 1889 | 6,880 | 1919 | 5,389 | 1949 | 4,317[a] |
| 1859 | 5,660 | 1890 | 12,582 | 1920 | 3,294[b] | 1950 | 4,133[a] |
| 1860 | 6,400 | 1891 | 4,637 | 1921 | 7,396 | 1951 | 6,315 |
| 1861 | 5,200 | 1892 | 5,118 | 1922 | 4,622 | 1952 | 7,785 |
| 1862 | 13,730 | 1893 | 7,891 | 1923 | 3,648[b] | 1953 | 6,540 |
| 1863 | 4,050[a] | 1894 | 5,895 | 1924 | 2,479[c] | 1954 | 6,541 |
| 1864 | 3,550[b] | 1895 | 7,837 | 1925 | 5,065 | 1955 | 4,113[a] |
| 1865 | 7,200 | 1896 | 7,247 | 1926 | 3,728[b] | 1956 | 8,832 |
| 1866 | 6,480 | 1897 | 6,858 | 1927 | 6,987 | 1957 | 5,369 |
| 1867 | 9,530 | 1898 | 3,871[b] | 1928 | 5,120 | 1958 | 9,698 |
| 1868 | 13,230 | 1899 | 4,340[a] | 1929 | 3,208[b] | 1959 | 5,037 |
| 1869 | 5,800 | 1900 | 5,896 | 1930 | 4,190[a] | 1960 | 4,733 |
| 1870 | 4,680 | 1901 | 6,073 | 1931 | 2,539[c] | 1961 | 5,073 |
| 1871 | 3,100[c] | 1902 | 7,122 | 1932 | 3,694 | 1962 | 5,261 |
| 1872 | 6,650 | 1903 | 6,586 | 1933 | 3,471[c] | 1963 | 7,002 |
| 1873 | 3,680[b] | 1904 | 9,523 | 1934 | 3,321[c] | 1964 | 3,905[b] |
| 1874 | 5,060 | 1905 | 7,038 | 1935 | 4,917 | 1965 | 6,963 |
| 1875 | 3,460[b] | 1906 | 7,259 | 1936 | 4,673 | 1966 | 5,299 |
| 1876 | 8,950 | 1907 | 8,486 | 1937 | 4,125[a] | 1967 | 7,334 |
| 1877 | 6,480 | 1908 | 5,494 | 1938 | 9,548 | 1968 | 4,772 |
| 1878 | 10,520 | 1909 | 8,605 | 1939 | 3,465[b] | 1969 | 7,667 |
| 1879 | 5,650 | 1910 | 6,156 | 1940 | 7,030 | 1970 | 7,902 |
| 1880 | 7,800 | | | | | 1971 | 7,328 |

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[a] Shasta inflow below normal (4-1/2 million acre-feet).
[b] Shasta inflow less than 4 million acre-feet.
[c] Critical year.

somewhat less reliable. For the period 1872 through 1895, flows at Shasta were estimated by correlation to flows at Red Bluff, estimated from the recorded gage heights. Estimates prior to 1872, made by correlation with available precipitation records, are considered the least reliable.

Table 3 gives the various periods analyzed in the frequency studies of annual inflows to Shasta Lake, together with the corresponding statistical information. Three of the periods studied indicate that an annual inflow to Shasta Lake of less than 3.2 million acre-feet could be expected to occur about 5 percent of the time. The studies also indicate annual inflow of less than 4 million acre-feet could be expected to occur about 16 percent of the time. The study of the period 1922 through 1971 gives similar results, with inflows of less than 3.2 million and 4 million acre-feet occurring somewhat more frequently.

The period 1922 through 1971 is considered adequate for use in estimating the frequency of the critical year because the 1922-71 data are considered reliable, and the statistics are similar to those of the longer periods.

For the period 1922 through 1971, the frequency of a critical year is about 9 percent, or an average of 9 critical years during a 100-year period.

## Monte Carlo Procedure

The second method used to evaluate the frequency of the critical year was the Monte Carlo procedure. The 50 years of record from 1922 through 1971 were randomly interchanged to produce a new sequence of events. Each year was assumed to have an equal chance of occurrence and would occur at any time, i.e., a year of critical hydrologic conditions could occur several years in succession.

The basic assumption of the Monte Carlo procedure is that each event is independent. Although there is some evidence of a base flow for Shasta, the slight tendency towards serial correlation, or the possibility of effects carrying over from one year to the next, was not considered to be significant.

Using the Monte Carlo procedure, a sequence of 10,000 years of Shasta inflow was generated from the 50-year record. The sequence was then divided into 100 events, each 100 years in length. Analysis of each event to determine the number of critical years

Table 3. Shasta inflow statistics

| Period | No. of years | Mean inflow | Log mean inflow | Standard deviation | Skew coefficient | Percent of time annual flow (acre-feet) is less than | |
|---|---|---|---|---|---|---|---|
| | | (1,000 acre-feet) | | | | 3,200,000 | 4,000,000 |
| | | | | | | (percent) | |
| 1850-1971 | 122 | 6,040 | 5,700 | 0.1530 | 0.0813 | 5.0 | 16.0 |
| 1872-1971 | 100 | 5,973 | 5,667 | 0.1429 | -0.1414 | 4.5 | 14.0 |
| 1895-1971 | 77 | 5,804 | 5,524 | 0.1400 | -0.3110 | 6.0 | 17.0 |
| 1922-1971 | 50 | 5,477 | 5,189 | 0.1451 | -0.0653 | 7.5 | 21.0 |
| 1872-1921 | 50 | 6,469 | 6,189 | 0.1312 | -0.056 | 1.8 | 7.0 |
| 1922-1954 | 33 | 5,074 | 4,795 | 0.1474 | 0.1197 | 12.0 | 31.0 |

that occurred showed the number of critical years ranged from none to 13, and averaged about 7 critical years for the 100 years.

The analysis of the sequences produced using the Monte Carlo procedures raises some question as to the adequacy of the criteria used to define the critical year.

It became apparent in determining the number of critical years in the synthetic events, that sequence was very important in the designation of a critical year. Numerous examples of how sequence affects the number of critical years were observed in the generated data. For example, if year 1931 followed 1934, only 1931 would be defined as critical. If, however, year 1934 followed 1931, both water years would be defined as critical.

The effect of still another sequence would be:

| Water year | Shasta inflow | Deficiencies below 4,000,000 acre-feet | Accumulated deficiencies | Type of year |
|---|---|---|---|---|
| 1931-32 | 3,690,000 | 310,000 | 310,000 | Noncritical |
| 1932-33 | 3,470,000 | 530,000 | 840,000 | Critical |
| 1933-34 | 3,320,000 | 680,000 | 1,520,000 | Critical |
| 1930-31 | 2,540,000 | 1,460,000 | 2,980,000 | Critical |

The sequence produces only three critical years, while the sequence presented on table 2 would produce four critical years. If inflow in water years 1932 or 1933 had been 40,000 acre-feet greater, only two years would be defined as "critical" in the sequence shown above.

In these examples, the supply is the same as that experienced in the 1931 through 1934 historic period. However, if only 3 years are defined as critical and a full supply is delivered during the noncritical year, the supply available for the remaining years would be inadequate.

## CRITICAL DRY PERIOD

The critical period of a reservoir or water supply system is influenced by many factors including reservoir storage capacity, system demand, demand patterns, operational rules and policies, and system inflow. A project which provides annual regulation on a single stream would probably have a critical period corresponding to the single driest year of record. For a complex system such as the Central Valley Project, where the ratio of storage to annual runoff approaches unity, the critical period is likely to be several successive years of subnormal flows. As more storage is added, the duration of the critical period is lengthened and short-period arrangements of years become less significant.

In the Sacramento and Trinity River basins, where the Central Valley Project derives the major portion of its supply, the historic drought during the water years 1929 through 1934 comprises the critical period, although for the Trinity basin alone, it approaches a 17-year carryover period. The evaluation of Central Valley Project firm yield and dependable power capabilities is based on an operation study through this critical period. A rigorous mathematical definition of the probability of occurrence of the critical period has not been made.

The critical dry period is to water supply studies what the standard project flood is to flood control studies. While the elements of both events can be very well defined, the present state of the art precludes anything but a general statement of the frequency of the events.

Past work done by the Bureau and others indicates that the frequency of the 6-year critical period falls in the range of once in 100 years to once in 400 years. This estimate was based primarily on an analysis of the flows of the Sacramento River.

## USE OF SYNTHETIC HYDROLOGY

The frequency of water shortages of various magnitudes is more important than the frequency of the dry period. Conventional analysis of water systems is based on the capability of the system during the most critical periods in a historic sequence of events.

It has been suggested that the historical dry period is too severe to use as the basis of a yield determination for the Central

Valley Project. Using the next driest historical period as the control, a cursory study indicated that the CVP yield could be increased by about 1 million acre-feet.

This determination of yield, while interesting, does not provide a valid alternative without further analysis. No evaluation of the risk is associated with the estimate, and valid data on the system are ignored.

The potential for a much more meaningful evaluation exists in the use of synthetic hydrology.

Synthetic hydrology is a method of expanding the data of the historic sequence. Synthetic hydrology or data generation is a method of manufacturing numbers which have properties similar to the historic data. The technique of data generation, usually used in conjunction with a computer program which has access to an infinite number of random numbers, permits the user to create any number of hydrologic sequences. To insure that the synthetic traces are acceptable for studying the behavior of a basin operation, the hydrologic sequences are constructed to maintain the statistical properties of the historic data.

Each synthetic trace used produces an estimate of a property of the basin's behavior. With a sufficient number of traces, the resulting estimates can be ranked and statistically analyzed. The data generation method can then produce enough values to establish probability distributions of quantities instead of only one value using historic data.

The capabilities of a large, complex water resources system such as the CVP system can be mathematically described. The physical features and processes can be defined by mathematical formula and logic which simulate the flow of water through the basin. Once the system operation is duplicated and accepted as an accurate reflection of the real system, hydrologic inputs can be analyzed through the model to gain information about the system.

Historic records of streamflows can be used, but they suffer some drawbacks. One of these is that a historic trace will never again repeat itself. To some, the use of well-known hydrologic data set, which realistically reflects all influencing factors, outweighs the certain fact that the set will not recur. Some historic traces are too short to permit study of long-term system properties or to represent rare events. A fixed system operation with a given set of hydrology will always produce a single number for a random quantity. With a single historic trace, for example, the size of reservoir required to assure a specified supply has a single answer, but in reality, a drought or critical period more severe than historically experienced could occur. Thus, the holdover storage to assure a given flow for a specific period is a random variable. Use of a single historic sequence can yield only one estimate, without probabilistic inferences about the quantity being studied.

Computer programs for data analysis and data generation, developed in the E&R Center of the Bureau of Reclamation in Denver, are currently being used for investigations on the Colorado River. While those programs are not directly applicable to the complex Central Valley Project, much of the work done to develop them could be used in developing similar programs for the Central Valley Project.

The use of synthetic hydrology for the CVP operation studies would be complex and would possibly require the development of new mathematical and programming procedures.

It would be advantageous to initiate synthetic hydrology studies on a small part of the Central Valley Project, such as the Trinity River, or on a less complex project, such as the Solano Project. This approach would introduce the procedures to the Mid-Pacific Region and provide an opportunity to develop an understanding of the techniques available for use on the more complex system.

# WATER USE DEFICIENCY

The yield of the Central Valley Project can vary with place of use, monthly distribution of use, and the deficiencies permitted. The impact on CVP yield of various water deficiencies for municipal, industrial, and irrigation uses has been evaluated.

## MUNICIPAL AND INDUSTRIAL DEFICIENCIES

Deficiencies that could be tolerated by users of domestic water were studied. Domestic water is that water supplied to living quarters, whether for inside or outside use.

The Southern District of the State of California Department of Water Resources (DWR) made a detailed household water use survey in a residential tract in Monterey Park, Los Angeles County, for the period March 1962 to March 1964. Average daily inside and outside water use for 12 sample homes in the tract was recorded. Data from this survey were used in an unpublished "Residential Water Use Deficiency Study," prepared for the DWR by Sidney M. Fellows in 1968, which is the basis for the analysis which follows.

The Monterey Hills tract within the city of Monterey Park in Los Angeles County was chosen for Fellows' study because adequate records of water deliveries were available and sewage discharge could be measured. The tract appeared to be of sufficient size and homogeneity to provide reliable results.

The average daily total inside and outside water use for the Monterey tract provides a water use profile of a "household" under normal water supply conditions. Outside use was distributed to lawn and plant use, separated into lawn and shrub irrigation and other uses. Outside deficiencies were demonstrated under two levels: Level 1 where no permanent damage to shrubs and lawn would occur, and level 2 where partial damage would occur.

Level 1 outside use restrictions during the summer would reduce total annual use by 5 percent. Level 2 summer restrictions reduce total annual use by 7 percent. Applying the same restrictions throughout the year would reduce total annual use by 13 and 18 percent, respectively.

For the 2-year period, inside water use in the study area was estimated at 311 gallons per household day. Average daily per capita use was estimated at 84 gallons for the same period.

## Water Use Deficiency

For analysis purposes, it was assumed that total inside use could be reduced by approximately 30 percent, with the reduction being accomplished in several ways. Home cleaning and miscellaneous would be reduced by 50 percent, total tank levels adjusted to 3 gallons from 5 (the average tank capacity), and personal and kitchen use reduced by 10 percent. The effect of these reductions would be a saving of 25 gallons per capita per day.

The total outside and inside water use restrictions as a percent of normal use for the two levels are:

| Use | Reduction of total normal use | |
|---|---|---|
| | Level 1 | Level 2 |
| | (percent) | |
| Outside | 13 | 18[a] |
| Inside | 30 | 30 |
| Total | 43 | 48 |

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[a] Some permanent damage to shrubs and lawns could occur.

When analysis of domestic water use is expanded to include all municipal supplies, it can be demonstrated that municipal supply could withstand deficiencies in normal annual usage ranging from 25 to 50 percent.

In water supply operation studies, taking a deficiency in a critical water year assures a greater firm water supply in a normal water year. For example, if 700 acre-feet of water were available to supply a requirement during the 7-year period and no deficiencies were taken, the firm water supply yield or amount guaranteed in a normal year would be 100 acre-feet (700 ÷ 7 = 100). If the deficiency criteria allows a maximum 25 percent reduction in any one critical year and 100 percent reduction during the 7-year critical period, then this same 700 acre-feet could be translated into a firm water supply yield of about 116 acre-feet (700 ÷ 6 = 116).

| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Total |
|---|---|---|---|---|---|---|---|---|
| | | (normal) | | | | | | |
| Supply (acre-feet) | 116 | 116 | 116 | 88 | 88 | 88 | 88 | 700 |

## Water Use Deficiency

Current operation studies meet municipal demands of approximately 500,000 acre-feet per year, or about 3,500,000 acre-feet during the 7-year critical period. A deficiency applied to the municipal supply of the Central Valley Project during the four critical years of the critical dry period (1928-34) would result in an additional block of water available to meet other demands during that period. Taking a 25 percent deficiency during each of the four critical years would make 500,000 acre-feet of water available for other uses. One use of the available water could include, for example, approximately 71,400 acre-feet per year (500,000 acre-feet for 7 years) to enhance fisheries in the Delta. If a 25 percent deficiency were also imposed on the additional supply, the amount of municipal supply met from the Central Valley Project could be increased by 83,300 acre-feet in normal years, and 62,500 acre-feet during critical years.

The increased amount of water available for distribution during the critical dry period would depend on the magnitude of the deficiency applied to the current municipal uses supplied by the Central Valley Project.

The potential increase in firm yield of the annual water supply is dependent on the type of use made of the water, and the deficiencies applied to that use. Figure 2 shows the potential increased yield available in normal years in the Delta for various deficiencies applied to the current CVP municipal supply, and to the potential additional supply in critical years.

## AGRICULTURAL DEFICIENCIES

The determination of the CVP yield has been based on the deficiencies established in contract negotiations. In the event of a water-deficient year, agricultural supplies take a 25 percent deficiency for that year; during the 7-year critical period, deficiencies totaling 100 percent of 1 year's supply can be tolerated.

For this study of water yield risk, the effect of increasing the deficiencies to a maximum of 50 percent in any one year and 200 percent during the 7-year critical period was investigated. With an increase of more than 300,000 acre-feet in the normal supply, the system has little or no water commencing in 1931. The results of the study indicate that the potential increase in CVP yield would be limited to approximately 300,000 acre-feet, with a 35 percent deficiency.

## Water Use Deficiency

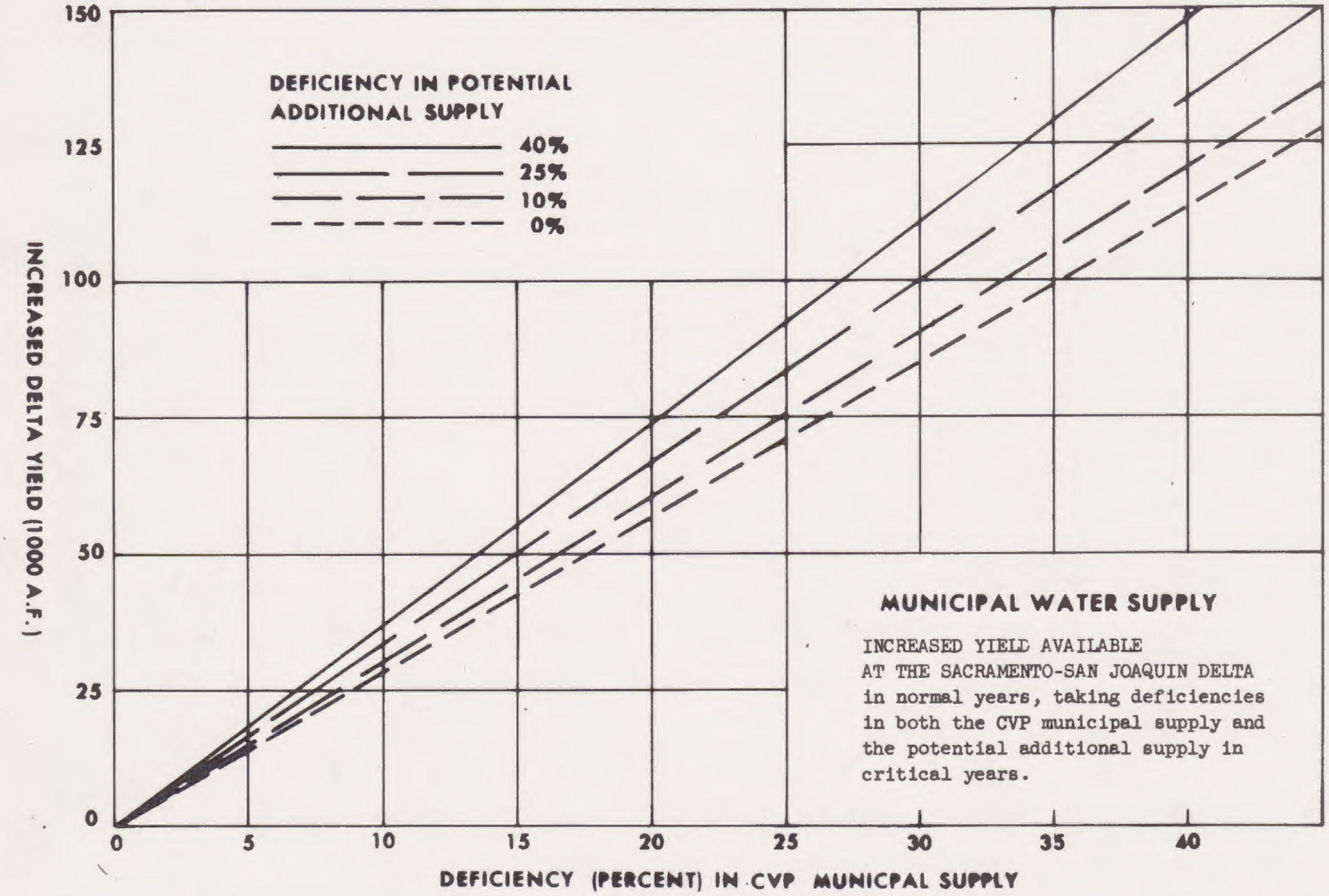
The yield determination was based on capabilities of the project during the critical dry period (1928-34). By taking 35 percent instead of 25 percent deficiencies on all CVP agricultural demands during the four years, 1931, 1932, 1933, and 1934, the supply in all other years of the study period could be increased by 300,000 acre-feet.

When an increase of 300,000 acre-feet is applied to the normal deliveries from the Central Valley Project, the critical period shifts from the 7-year period (1928-34) to a 4-year period (1928-31). All project reservoirs would reach minimum levels in 1931 and again in 1934. A normal agricultural water supply would be provided in 1928, 1929, and 1930; a deficient supply in 1931, 1932, 1933, and 1934. The increase in deficiency to agricultural supply from the Central Valley Project might not necessarily mean a corresponding reduction in water available for use on the farm during the critical period.

The potential increased yield available in normal years in the Delta for various deficiencies applied to the current CVP agricultural study, and applied to the potential additional supply in critical years, is shown in figure 3.

Other concepts such as intermittent water supplies and conjunctive use of surface water and ground water could also provide a replacement supply during critical years.

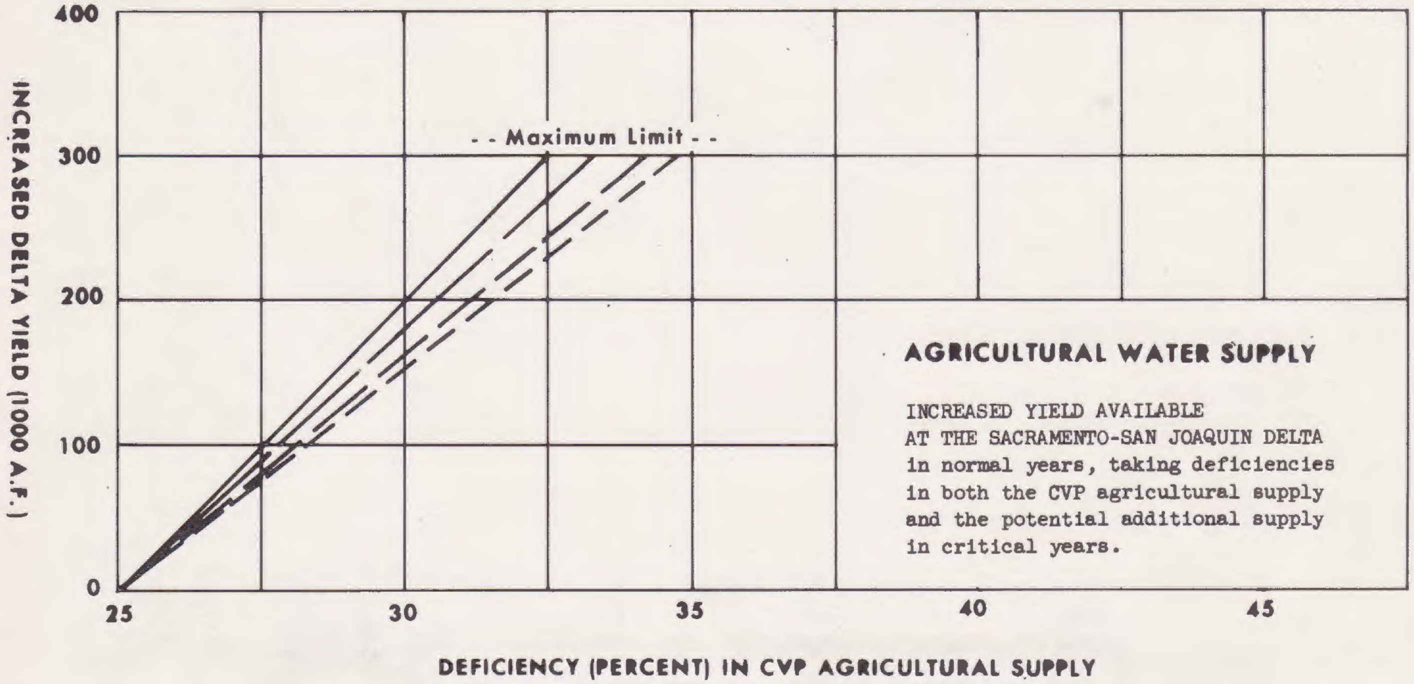
FIGURE 2



**MUNICIPAL WATER SUPPLY**

INCREASED YIELD AVAILABLE
AT THE SACRAMENTO-SAN JOAQUIN DELTA
in normal years, taking deficiencies
in both the CVP municipal supply and
the potential additional supply in
critical years.

FIGURE 3



**AGRICULTURAL WATER SUPPLY**

INCREASED YIELD AVAILABLE
AT THE SACRAMENTO-SAN JOAQUIN DELTA
in normal years, taking deficiencies
in both the CVP agricultural supply
and the potential additional supply
in critical years.

# CONCLUSIONS AND RECOMMENDATIONS

## CONCLUSIONS

1. The estimated frequency of a critical year as defined by the Shasta inflow criteria is about 8 percent, or an average of 8 critical years during any 100-year period.

2. Current methods available cannot give a definitive estimate of the critical dry period frequency, but indicate that the range is from once in 100 years to once in 400 years.

3. Municipal water users can tolerate deficiencies in normal annual usage of 25 to 40 percent, with a resultant increase in Central Valley Project yield of from 75,000 acre-feet to 150,000 acre-feet.

4. Additional information is necessary to determine the ability of industrial water users to withstand shortages in their water supplies during critical years.

5. An increase in agricultural deficiencies to 35 percent would result in an increase of approximately 300,000 acre-feet to the CVP yield with the facilities assumed in this document. Additional increases in deficiencies would not result in increased yield.

6. The use of synthetic hydrology offers the opportunity to test conclusions and operational criteria derived from historical data on different sequences of events. Synthetic hydrology can be a useful tool in evaluating the capabilities of the system and assessing the risk associated with various yields of the project.

## RECOMMENDATIONS

1. New criteria should be derived to define a critical year. Current critieria could prove ineffective in a critical period other than that experienced historically.

2. Although further analysis is indicated, serious consideration should be given to a less restrictive controlling drought period for measuring CVP accomplishments. A program to incorporate synthetic hydrology into the analysis of CVP capabilities should be established to evaluate better the risk associated with various water-short periods. This could begin with studies of the Central Valley Project, such as the Trinity River Basin, or of a less complex project such as the Solano Project.

3. Future operation studies for the determination of CVP capabilities should include consideration of greater deficiencies.

4. Additional studies should be made to determine acceptable deficiencies in industrial and agricultural supplies.

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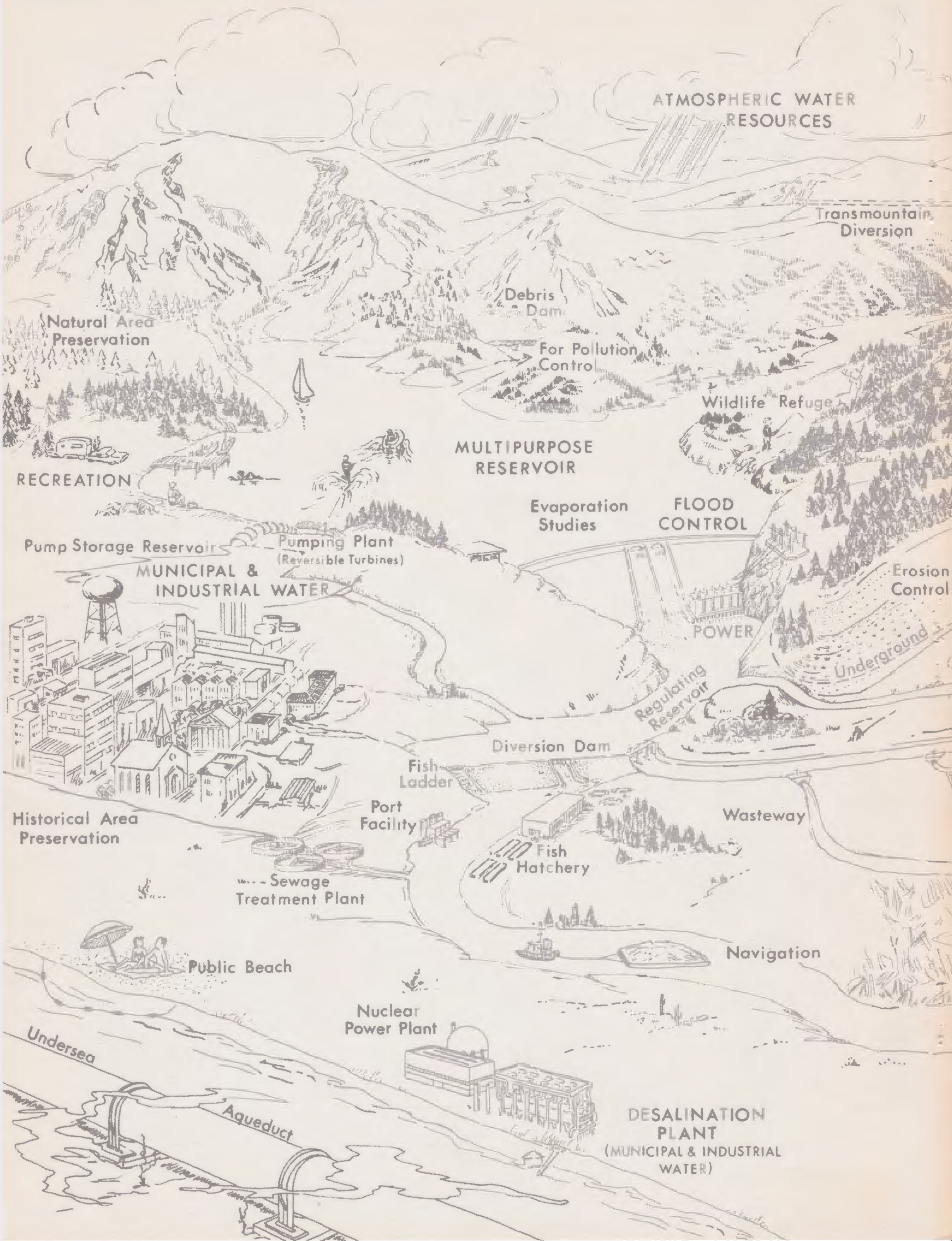
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Wildlife Refuge
MULTIPURPOSE RESERVOIR
RECREATION
Evaporation Studies
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Pump Storage Reservoir
Pumping Plant (Reversible Turbines)
MUNICIPAL & INDUSTRIAL WATER
Erosion Control
POWER
Underground
Regulating Reservoir
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Wasteway
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Sewage Treatment Plant
Public Beach
Navigation
Nuclear Power Plant
Undersea Aqueduct
DESALINATION PLANT (MUNICIPAL & INDUSTRIAL WATER)