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The Resources Agency
Department of Water Resources

BULLETIN No. 156

MATHEMATICAL SIMULATION OF SALINITY IN THE SACRAMENTO RIVER SYSTEM

AUGUST 1971

NORMAN B. LIVERMORE, JR.
Secretary for Resources
The Resources Agency

RONALD REAGAN
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ABSTRACT

The Sacramento Valley water quality model simulates mathematically the monthly flow-weighted mean electrical conductivity (EC) by reaches in the Sacramento River system. Using readily available flow and EC data, the model was developed around the system's three general types of flow: unregulated tributary inflow; reservoir impoundments and releases; and valley floor accretions or depletions. The latter was further broken down into storm-water runoff, irrigation return flow, municipal and industrial waste discharges, diversions of streamflow for beneficial use, weir spills, and unmeasured inflows and losses.

Flow and EC data for all inflows, diversions and other losses were combined in a series of equations in which mean monthly EC was weighted with quantities of flow. Model outputs were flow-weighted mean EC in micromhos, salt loading in tons and corresponding rates of streamflow in acre-feet at 12 locations in the system for each month of a selected time period.

The model was verified by comparing computed EC values with prototype values at selected river stations. Although rather large deviations occurred between computed and prototype EC values for some months, the model simulated the general pattern of EC fluctuations at the river stations. Excessive deviations generally could be attributed to specific inadequacies of prototype data.

The model was used to estimate the probable future EC at each station in the system under a projected 1990 level of development. Results showed an increase in flow-weighted average EC, but no monthly values were great enough to threaten any beneficial uses of the Sacramento River.

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FOREWORD

Selection of the most favorable management plans for California's water resources relies, in part, on careful evaluation of possible future changes in water quality. Such changes may be brought about by altered land and water use patterns, construction of dams and reservoirs, or alternative methods of reservoir operation. Foreseeing the probability of adverse water quality conditions will give planners opportunities to minimize or even eliminate some potential problems.

A computer-programmed mathematical model, which can simulate a selected indicator of water quality, is a valuable tool for estimating water quality under future conditions. A model developed by the Department of Water Resources as part of a special water quality study simulates mean monthly electrical conductivity in the Sacramento River. Electrical conductivity was selected as the water quality indicator for this study primarily because it measures total dissolved solids, or salinity, and because it can be used to estimate other mineral constituents.

The study was conducted in 1969 and 1970 with counties and local valley irrigation, reclamation, and drainage districts, all of whom assisted with costs of computer programming and operation and provided a technical advisory committee to work cooperatively with the Department.

William R. Gianelli

William R. Gianelli, Director
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ACKNOWLEDGMENTS

In July 1969 the local irrigation, drainage, and reclamation districts and the counties began collecting water samples for laboratory analyses with the Department of Water Resources. All costs for analyses of samples collected by these agencies were paid for by them. These agencies also provided funds to the Department for machine programming, program testing, and production runs.

They also organized an advisory committee which met with the Department at least once a month during the course of the study. This group acted as liaison between the Department and the various other agencies.

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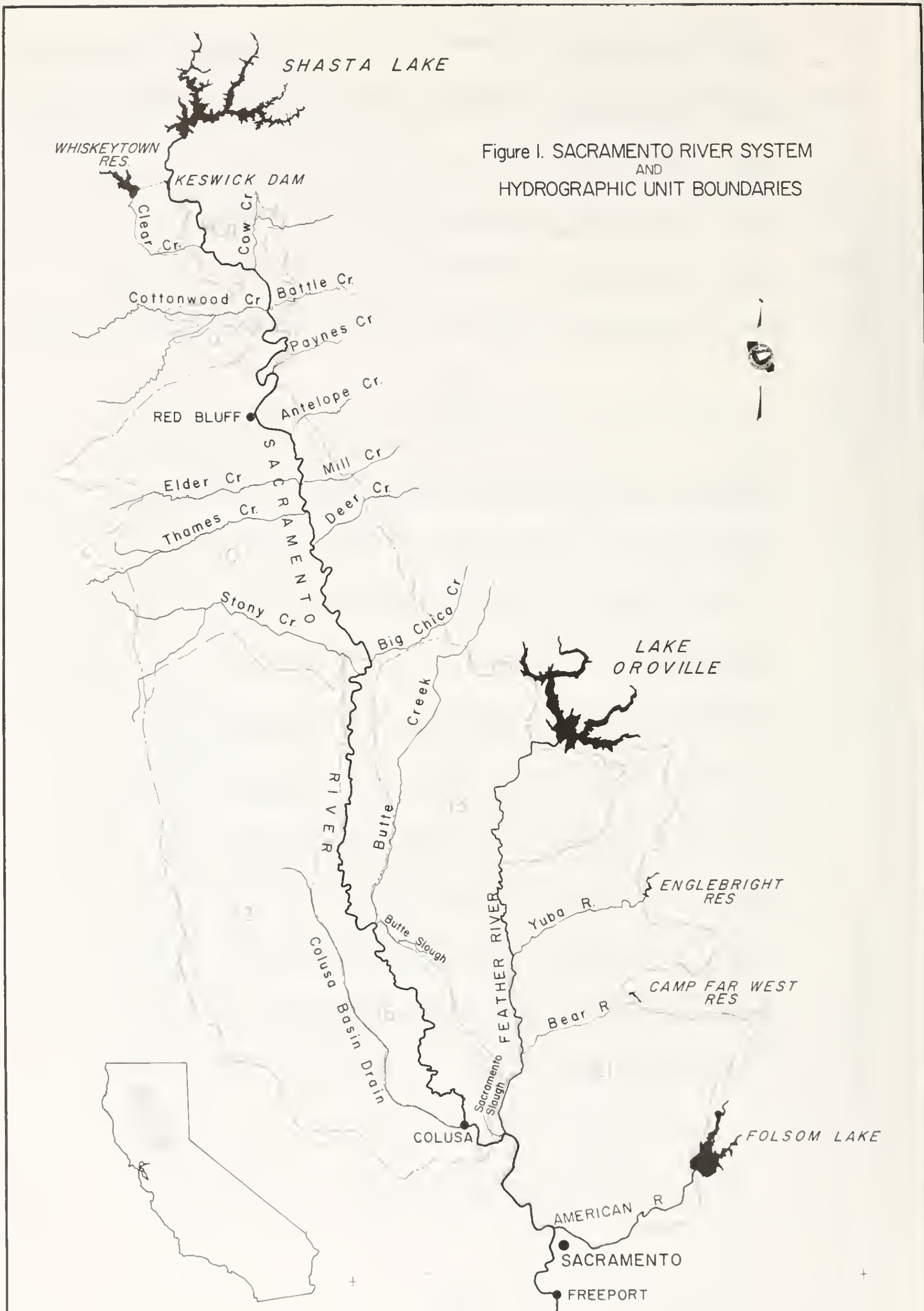

Figure I. SACRAMENTO RIVER SYSTEM AND HYDROGRAPHIC UNIT BOUNDARIES

INTRODUCTION

Systems analysis techniques employing mathematical models programmed for the digital computer provide a highly flexible means of incorporating water quality considerations in water resource planning. A model permits prompt evaluation of the probable response of a particular water quality factor in the prototype system to a change in that system.

The modeling technique was applied in a special water quality study of the Sacramento River, completed in July 1970, that was directed toward analysis of factors that influence the mineral quality of water in the river system. Its overall purposes were to provide the Department with environmental planning information; to give irrigation, reclamation, drainage districts and associations, and county governments in the Sacramento Valley the information they needed to evaluate the Central Valley Regional Water Quality Control Board's proposed water quality control policy for the Sacramento River; and to provide the Board the means to develop an adequate policy.

The mathematical model developed in this study was used to analyze present and probable future electrical conductivity at 12 stations in the river system between Keswick Reservoir and Freeport. The model permits evaluation of the effects on the river mineral quality of changes in land and water use. The development and structure of that model and illustration of its use for estimating future river salinity are described in this report.

Electrical conductivity (EC) was selected as the water quality parameter for modeling for several reasons: 1) more historical data were available for EC than for any other constituent; 2) EC as a conservative constituent of water is not changed significantly by time or biological activity; and 3) EC can be used to estimate other conservative constituents, particularly total dissolved mineral concentrations.

This study was conducted as a part of the Department's continuing role in planning for protection of water quality in water resource management planning. The model described in this report is not a final product. It is being continually updated and refined as new information becomes available. In future studies, other important water quality indicators than dissolved minerals should be evaluated by mathematical simulation of the Sacramento River system. Nonconservative nutrient and organic constituents, which cannot be simulated by this model, will be of particular importance. Consideration of these additional parameters will make possible fuller evaluation of the impact of future economic development on the quality of water in the Sacramento River.

The Department will make the model available for further use by other organizations that seek solutions to water quality problems in the Sacramento Valley. Information on the machine program can be obtained through the Statewide Planning Branch of the Division of Resources Development.

Area of Study

The area studied (Figure 1) included the entire Sacramento Valley drainage area above Freeport, about 24,000 square miles. Primary attention was focused on the valley floor where occur virtually all agricultural drainage, municipal and industrial waste discharges, and other significant factors that tend to degrade the quality of water in the Sacramento River. This report discusses: 1) the Sacramento Valley water quality model as developed in 1965; 2) the current model as used in this study; 3) computational methods and assumptions employed; 4) the hydrologic base period considered; 5) development of model inputs; 6) verification of the model; 7) estimates of 1990 mineral quality of water in the Sacramento River expressed as electrical conductivity; and 8) results of the computations.

Data Considerations

Data used to develop and operate the model were primarily those which were readily available in the Department's files and reports or in federal publications. Agricultural drainage data collected under a second part of this study were available for use as guides in assigning quantity and quality values to agricultural return flows to the Sacramento River.

As expected, available data were not fully adequate for detailed analyses of all important factors which influence the mineral quality of water in the Sacramento River system. Some hydraulic and other characteristics of the system are virtually unknown, and their determinations, if they were possible, would require detailed field investigations. For example, quantities of seepage in or out of any given reach of river have not been determined for any historic period. Yet such seepage can significantly affect mineral quality of water in the river, because seepage outflow removes salts and seepage inflow adds salts.

Data also are sketchy on the fate of minerals introduced to valley floor areas in applied surface water, rim inflows and precipitation. At certain times such minerals are retained in the soils and groundwater of the area to be leached out later. Investigation of this phenomenon could not be included within the scope of this study.

Notwithstanding data inadequacies, a usable mathematical simulation of the Sacramento Valley system was possible. Inputs were provided for all mineral sources considered significant. Where data were weak or lacking, value judgments were made.

SACRAMENTO VALLEY WATER QUALITY MODEL

In 1965 the Department developed a mathematical model for use in estimating future mineral quality of water in the Sacramento River. The model was concerned mainly with the quality of water in the State Water Project, and hence, major emphasis was placed on the quality of Sacramento Valley outflow. The study reported herein, on the other hand, is concerned with the quality of water at additional points in the river as related to the previously-mentioned water quality control policy. It was necessary, therefore, to completely restructure the model to comply with the new objectives.

The basic structure of the 1965 model[1/] is still valid, however, and a brief description of that model would be helpful in understanding the revised model used in this study. In both models, mineral concentration is expressed in terms of electrical conductivity (EC). For Sacramento River streamflow, total dissolved solids (in parts per million) is approximately equal to EC (in micromhos) x 70 percent.

The 1965 Model

The 1965 model was developed around three general categories of flow: unregulated tributary runoff; reservoir impoundments and releases; and valley floor accretions and depletions. Flow and quality data on all inflows, including natural flow, agricultural drainage, and municipal and industrial waste discharges, and on diversions are combined in a series of equations in which mean monthly EC is weighted with quantities of flow. Flow is expressed in cubic feet per second.

Unregulated Tributary Runoff

In deriving a method for estimating future quality of unregulated tributary runoff into the river system, a quality-versus-flow relationship was employed. A reasonably stable relationship exists between rate of flow and mineral concentration for natural, unregulated runoff from the mountainous watersheds bordering the Sacramento Valley. This relationship can be expressed by a mathematical equation in the form $C=aQ^b$, where "C" represents electrical conductivity; "Q", the rate of streamflow; and "a" and "b", constants characteristic of individual watersheds. Empirical

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1/ Described in detail in entry No. 27 of the bibliography, Appendix A.

C/Q relationships were developed by plotting observed values of EC against corresponding rates of flow for the headwaters of the Sacramento River and its major tributaries at gaging stations located where the natural regimen of flow has not been substantially altered by major impoundments or diversions.

Reservoir Impoundments and Releases

The natural C/Q relationship is generally upset by impoundment in a reservoir. Reservoir stratification, incomplete mixing, and varying detention times all complicate the problem of predicting mineral content of reservoir outflow. An emperical approach based on available inflow-outflow records was used to develop a computer-oriented method for deriving a quality of reservoir releases from inflow data. No general solution was derived for this problem, and each reservoir required individual treatment. The following two basic approaches were employed.

1) The quality of reservoir releases was assumed equal to the quality of water in storage, which was determined by successively mixing the flow-weighted average quality of inflow for each month with the average quality of water in storage for that month, and then allowing for a one-month detention time in the reservoir. The inflow quality was computed by the C/Q equation and the initial quality of water in storage was assumed equal to the quality of inflow for the month preceding the first month under consideration.

2) The quality of reservoir releases was assumed equal to the quality of water in storage, which was determined by the monthly running average of inflow quality, weighted according to flow, over a period of time in which the total volume of outflow during the period equaled or exceeded the volume of storage at the end of the period.

Neither of these approaches, by itself, gave acceptable answers for all months and at all reservoirs. This was shown by comparison with recorded data. In most cases, better answers resulted from a combination of the two approaches, often together with a factor to allow for unknown impoundment influences. Mathematical explanations of the two approaches are included in this report as Appendix B, "Reservoir Computational Methods".

Valley Floor Accretions and Depletions

In addition to its major measured tributaries, the Sacramento River receives local drainage and unmeasured tributary inflow as it traverses the valley floor. At the same time, various amounts of water are diverted from the river for beneficial use. The changes in water quality resulting from these factors are represented by the third part of the model. Accretions which originate in the valley floor account for a large part of these water quality changes. In the initial study, historic water quality data were assumed to represent future mineral concentration of the agricultural drainage portion of these accretions and flow quantities to be proportional to irrigated acreage drained. The remaining unmeasured accretions and depletions were accounted for by evaluating the differences in flow and water quality at existing stream gaging stations along the main stem of the river. In later studies, estimates of future accretion and depletion flow quantities were taken from actual water supply studies.

In short, the 1965 water quality model for the Sacramento River used the foregoing relationships to determine the weighted mean electrical conductivity of tributary inflow and valley floor drainage, as modified by impoundments and diversions.

The model was verified by checking its ability to reproduce historic records at key points in the watershed and at the head of the Delta. An average difference of about 10 percent was noted between computed and historic values of conductivity. Wider discrepancies were found for individual months, particularly when large fluctuations of flow occurred during the month. This difference may be related, at least in part, to the fact that computed values were based on average monthly flows, while the actual instantaneous observations of water quality that constitute the historic record may or may not represent average conditions. Nevertheless, satisfactory correlations were obtained, though it was recognized that the model could be improved by collection of additional data and refinement of empirical relationships.

The model has been used with system operation studies to evaluate water quality conditions in the Sacramento River watershed under projected 1990 development. Basic hydrology representative of both normal and critical dry periods was used and agricultural drainage, waste discharges, and other accretions were estimated for 1990 level of cultural development. Results demonstrated that, despite increased development and water usage, the mineral concentration of Sacramento River inflow to the Delta will remain well within established State Water Project contract objectives, even during the most severe dry period on record.

The Current Model

The current model, used in this study, may be viewed as an extensive refinement of the third part of the 1965 model, the part which deals with valley floor accretions and depletions. Mean monthly electrical conductivity (EC) in micromhos remains the water quality parameter. Flow in the current model is expressed in thousands of acre-feet per month.

Since only mean monthly conditions were considered, certain limitations of the model should be noted. The model does not show short-term fluctuations or instantaneous values of flow or EC which would occur at any time during a particular month. Thus, it does not indicate the dynamic effects of a large momentary slug of municipal or industrial wastes discharged into the river. Nor does the model account for time of travel of flow in the river system. But, because travel time from Keswick to Freeport is only about six days, this latter factor is not important. The model also fails to account for tidal action in the lower reach of the river, which would affect the Sacramento and Freeport stations.

For the 1965 model, the Sacramento River was divided into only two reaches between Keswick Dam and Freeport. The intermediate station was Hamilton City. Nine Sacramento River reaches below Keswick were used for the current model. Each of the two major tributaries, the Feather and the American Rivers, was considered as one reach. The current model thereby could more accurately describe the EC of water in the full Sacramento River than could the 1965 model.

The nine Sacramento River reaches below Keswick Dam were designated reaches "A" through "I". The Feather River was designated reach "J"; the American River, reach "K"; and all inflow above Keswick Dam, reach "L". The system is shown schematically on Figure 2. Reach terminals were selected on the basis of: 1) water quality checkpoints mentioned in a proposed Sacramento River water quality control policy, 2) additional checkpoints required to structure the model, and 3) availability of water quality and streamflow data.

Figure 2, page 8, shows the identification number of each source of input to the model and its location by river reach. The facing page lists each inflow and outflow designated.

Inflow sources included reservoir releases, tributary streams, agricultural drains, municipal and industrial (M&I) waste discharges, and any additional inflow and other accretions that could occur in each reach. The distinction between inputs designated as "additional inflow" and "other accretions" is explained later.

Outflow sources included diversions from the river, weir spills, and any additional losses that could occur in each reach.

Monthly flow and EC data on each source were obtained either directly from available records or estimated where recorded data were not available or where they did not apply. Flow and EC inputs for "other accretions" could be generated by the model.

A vital component of the current model was an "accretion subroutine", in which the quantities and qualities of valley floor accretions were computed for each river reach. Inputs were monthly flow quantities (in thousands of acre-feet) and mean EC values (in micromhos) of precipitation, surface water, and groundwater, plus "additional salt" (in tons) applied to the valley floor drainage area of each reach. The total inflowing salt load to the area was the sum of the products of the above flow and EC values, expressed in tons[1/], plus the tons of additional salt added by fertilizers, soil conditioners, etc.

The total of the above inflow quantities was then reduced by a depletion quantity which consisted of the consumptive use of irrigated crops and native vegetation plus soil moisture requirements. The result was the net accretion of flow to the river for each month (Figure 3). Assuming all inflowing salts were returned to the stream, the EC of net accretions was obtained by dividing the total inflowing salt load as computed above by the net accretion flow. By inspection, these EC values were then modified where they deviated significantly from known historic EC values of irrigation return flow or runoff. Final flow and EC results became input data for the "other accretions" model input source listed on the key to Figure 2. Additional study is required on the accretion portion of the model so that it will more consistently produce more realistic results of both flow and EC. The accretion subroutine is explained in more detail in "Computational Methods".

1/ 0.735 parts per million (ppm) of total dissolved solids (TDS) ≅ 1 ton of TDS per 1,000 acre-feet of water. In the Sacramento River 0.735 ppm is roughly equivalent to 1 micromho of EC. Therefore, 1 micromho was assumed equal to 1 ton of TDS per 1,000 acre-feet of water.

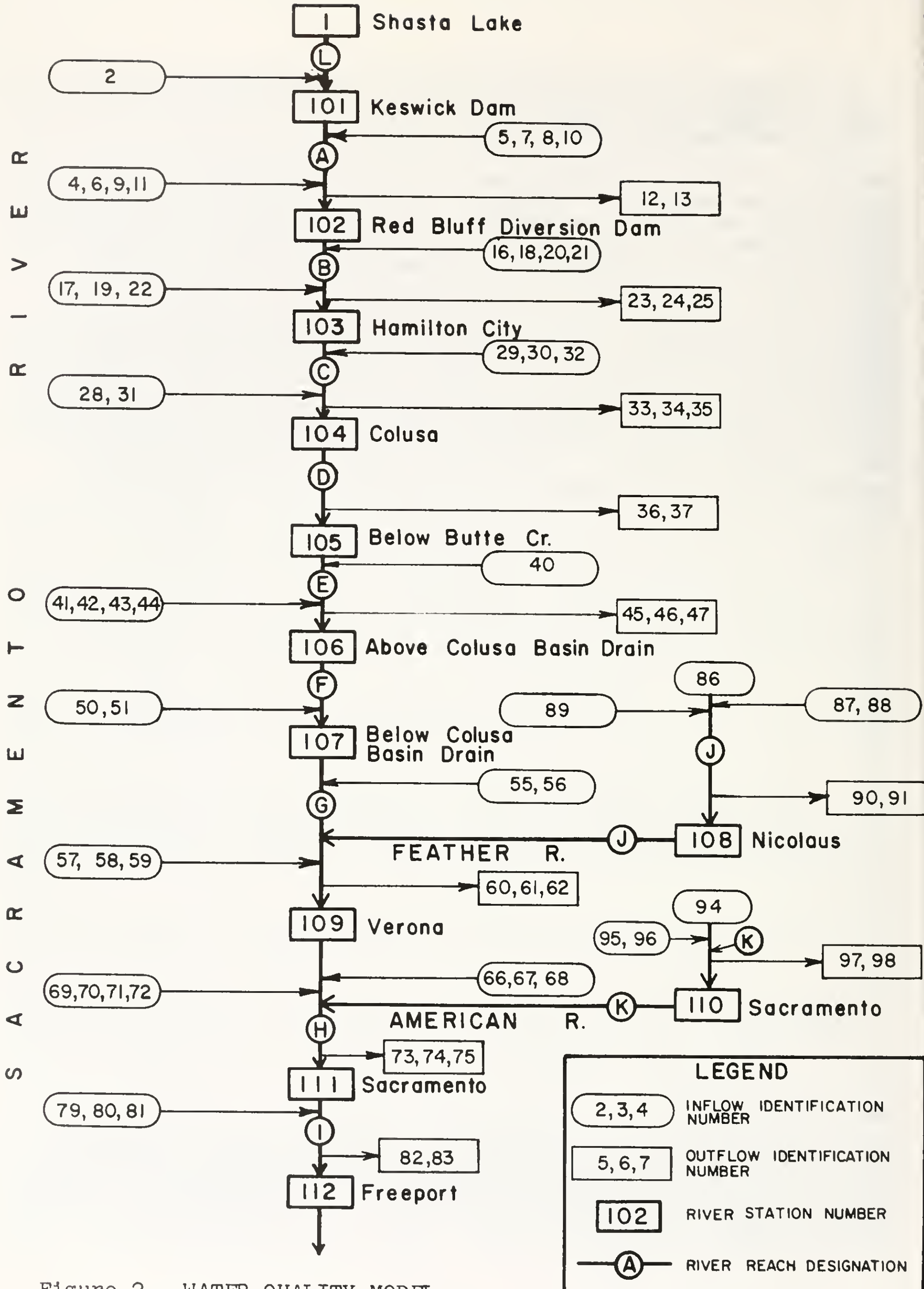


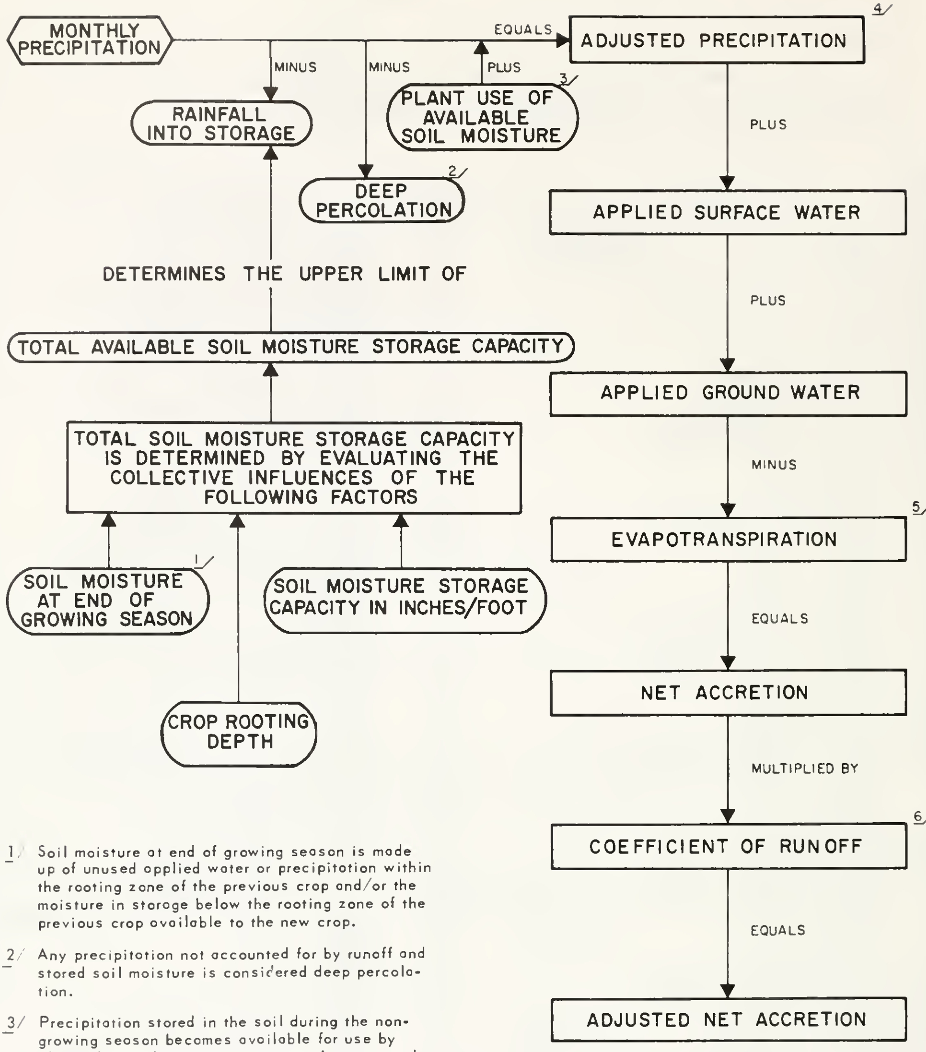
Figure 2. WATER QUALITY MODEL INPUT SOURCES

DESIGNATIONS OF INFLOW AND OUTFLOW

Key to Figure 2, "Water Quality Model Input Sources"

Number	Description	Number	Description
1	Shasta Reservoir Release	47	Additional Losses
2	Spring Creek Tunnel	50	R. D. 787(b) Drain
4	Clear Creek	51	Colusa Basin Drain
5	Cow Creek	55	Sacramento Slough
6	Cottonwood Creek	56	Natomas Cross Canal
7	Battle Creek	57	Additional Inflow
8	Paynes Creek	58	M & I Wastes
9	Redbank Creek	59	Other Accretions*
10	Additional Inflow	60	Diversions
11	Other Accretions*	61	Weir Spills
12	Diversions	62	Additional Losses
13	Additional Losses	66	R. D. 1000 Drain
16	Antelope Creek	67	Natomas Main Canal
17	Elder Creek	68	Natomas E. Main Drain
18	Mill Creek	69	Cache Creek (Eel River Diversion, Southerly Route)
19	Thomes Creek		
20	Deer Creek		
21	Additional Inflow	70	Additional Inflow
22	Other Accretions*	71	M & I Wastes
23	Diversions	72	Other Accretions*
24	Weir Spills	73	Diversions
25	Additional Losses	74	Weir Spills
28	Stony Creek (Eel River Diversion, Northerly Route)	75	Additional Losses
		79	Additional Inflow
		80	M & I Wastes
29	Big Chico Creek	81	Other Accretions*
30	Additional Inflow	82	Diversions
31	M & I Wastes	83	Additional Losses
32	Other Accretions*	86	Oroville Reservoir Release
33	Diversions	87	Yuba River
34	Weir Spills	88	Bear River
35	Additional Losses	89	Other Accretions*
36	Butte Creek	90	Diversions
37	Butte Slough	91	Additional Losses
40	R. D. 70 Drain	94	Folsom Reservoir Release
41	R. D. 108 Drain	95	M & I Wastes
42	R. D. 787(a) Drain	96	Other Accretions*
43	Additional Inflow	97	Diversions
44	Other Accretions*	98	Additional Losses
45	Diversions		
46	Weir Spills		

* Comprised of final flow and EC results.



1/ Soil moisture at end of growing season is made up of unused applied water or precipitation within the rooting zone of the previous crop and/or the moisture in storage below the rooting zone of the previous crop available to the new crop.

2/ Any precipitation not accounted for by runoff and stored soil moisture is considered deep percolation.

3/ Precipitation stored in the soil during the non-growing season becomes available for use by plants during the growing season. Amount used is added to monthly precipitation values for accretion analysis.

4/ Adjusted precipitation values are "precipitation" values used in accretion analysis and include consumptive use of precipitation in soil moisture storage.

5/ Evapotranspiration (ET) of up to eight crops plus native vegetation plus ET of precipitation in urban areas.

6/ Coefficient of runoff applied to runoff that is not related to soil moisture conditions. It may be related to precipitation intensity and occurrence, land slope, vegetative cover, and mean distance of travel for overland flow. An important consideration is lag time, since precipitation in one month may appear as runoff in the succeeding month(s).

Figure 3. DETERMINATION OF MONTHLY NET ACCRETION FLOW

COMPUTATIONAL METHODS

The mean monthly EC at each river station was assumed equal to the flow-weighted mean monthly EC of all inflows and outflows in the reach under consideration. The products of each flow and its EC were summed algebraically and divided finally by the total flow at the downstream station. This may be expressed as:

$$C_Y = (Q_X C_X + Q_{T1} C_{T1} + \text{----} Q_{Tn} C_{Tn} + Q_G C_G + Q_M C_M + Q_A C_A - Q_D C_D - Q_S C_S - Q_L C_L) / (Q_X + Q_{T1} + \text{----} Q_{Tn} + Q_G + Q_M + Q_A - Q_D - Q_S - Q_L)$$

Eq. (1)

where,

C = mean monthly EC in micromhos
Q = monthly flow in 1,000 acre-feet
Y = downstream station in reach
X = upstream station in reach
T = measured tributary
n = number of tributaries
G = estimated groundwater or other inflow not accounted for in the other model inputs
M = municipal and industrial waste discharges
A = unmeasured accretions (irrigation return flow and additional surface water runoff)
D = diversions from the river for beneficial use
S = spillage from the river over flood control weirs
L = unmeasured losses from the river

The numerator in Eq. (1) is equivalent to the total salt load (ΣSL) in tons entering the river in the reach under consideration (the product of flow in 1,000 acre-feet and EC in micromhos is approximately equal to tons of salt). The denominator in Eq. (1) is the flow (ΣQ) in the river at the downstream station in 1,000 acre-feet. Eq. (1) then may be expressed more simply as $C_Y = \Sigma SL / \Sigma Q$.

Flow quantities and EC values for item A, unmeasured accretions, in Eq. (1) were computed by the accretion subroutine. As an option, however, individual accretion values could be specified in the input data, in which case the computed values would not be used. The accretion subroutine is illustrated schematically in Figure 3 and mathematically below.

Solving for accretion flow:

$$Q_A = R(Q_P + Q_S + Q_G - Q_{ET}) \qquad \text{Eq. (2)}$$

where,

Q_A = net accretion flow in 1,000 acre-feet
R = coefficient of runoff
Q_P = adjusted precipitation in 1,000 acre-feet
Q_S = applied surface water in 1,000 acre-feet
Q_G = applied ground water in 1,000 acre-feet
Q_{ET} = evapotranspiration in 1,000 acre-feet

Solving for accretion EC:

$$C_A = F(Q_P C_P + Q_S C_S + Q_G C_G + A_S)/Q_A \qquad \text{Eq. (3)}$$

where,

C_A = EC of net accretion in micromhos
F = salt return factor
C_P, C_S, C_G = EC in micromhos of precipitation, applied surface water and applied groundwater, respectively
A_S = additional salt in tons (fertilizers, soil conditioners, etc.)

The coefficient of runoff, R, has not yet been established with any reliability for subareas of the Sacramento Valley. It was not used in the manner indicated by Eq. (2) for the 1969-70 study. Instead, storm water runoff and irrigation return flow values were modified by inspection where they deviated significantly from measured historic values.

Coefficients should be developed, however, so that the model can more rationally simulate the processes which produce storm water runoff and return flow from applied irrigation water.

The salt return factor, F, as in the case of the flow factor, R, requires additional study for its development. It is directly related to quantities of applied salts retained in the soil during the irrigation season and to quantities of salts leached from the soil during periods of heavy rainfall.

Base Period for Hydrologic Applications

The hydrologic base for the 1965 model was the period from 1953 to 1961, which covered a wide range of hydrologic conditions. For development of the current model, time and budgetary limitations restricted selection for data processing to only three hydrologic years--1965, 1961, and 1955.

The 1965 water year was chosen for preliminary development of the model's structure and for writing the computer program because it represented an approximate present level of development. Also, an expanded source of water quality data was readily available from the Department's data collection programs.

For 1965 conditions, the objective was to devise a model which would reasonably simulate the Sacramento Valley water resource system. The main concern was to develop a method for computing flow and EC of valley floor accretions.

Net accretions (and depletions) first were approximated by evaluating differences in flow and EC between the upstream and downstream stations in each reach, based on recorded values for the river stations. That method was not satisfactory, however, because net accretions did not indicate individual accretion sources, such as irrigation return flow, storm water runoff, groundwater inflow, etc. The nature of certain losses in flow, other than recorded diversions and weir spills, also could not be accounted for. A more refined accretion analysis method was required. The accretion subroutine was the result. This was used in subsequent runs of the model, with the 1961 water year as the base hydrology for further refinements.

The 1961 water year was selected because the Sacramento River Water Pollution Survey conducted at that time provided an additional source of data, including data on agricultural drains not before or since included in the Department's data collection programs.

To develop a better rationale for use in projections of flow and EC under future levels of development, flow and EC values for 1961 were first computed for each river station, using the accretion subroutine for accretions, and results were then compared with recorded values. Where deviations between computed and recorded values were excessive, adjustments were made in either valley floor inflow or losses (provided the adjustments could be justified on some rational basis or logical assumption).

The 1955 water year was used to verify the model because it was the second year for which comprehensive diversion data were available from the Trial Distribution studies of flow in the Sacramento Valley system conducted by the U. S. Bureau of Reclamation, the Department of Water Resources, and local water users. Water quality data also were available from the Department's data programs, which began systematic collection of surface and groundwater quality data in 1951. Results of the 1955 verification run are discussed under "Model Verification".

6) Net accretions (including natural salt loadings)
7) Municipal and industrial waste discharges
8) Additional inflow to the river
9) Direct diversions from the river for beneficial use
10) Spillage from the river over flood control weirs
11) Additional losses of river flow

Tables 1 and 2 are copies of machine printouts which show how the above factors were incorporated into the model. Table 1, "Analysis of Accretions for Reach from Below Colusa Basin Drain to Verona", shows those factors which were considered in the model's accretion subroutine and which contributed to valley floor accretions of both flows and salts in each reach of the river. The particular reach considered in Table 1 is Reach G, below Colusa Basin drain to Verona. Net accretions contain agricultural return flows, run-off from precipitation, or a combination of the two, depending upon the particular month under consideration.

Table 2, "Estimated 1961 Monthly Flow and Mean Conductivity in Sacramento River System, Below Colusa Basin Drain to Verona", shows all of the inflows (including previously computed accretions) and outflows which occur within the same reach. The final values are net flows and conductivities at Verona, the downstream station of the reach. Zero values are shown for Sacramento Slough and Natomas Cross Canal because these are channels for agricultural drainage or other surface water runoff, values for which, in this case, have been computed in the accretion analysis and are included in the item "other accretions". If desired, flow and EC values may be specified for these two inputs rather than computing them in the accretion analysis. In that manner, the effects on river EC of any individual agricultural drain at any point in the system can be evaluated by the model. The option of specifying accretion values is discussed further under "Net Accretions".

Precipitation

Historic monthly quantities of precipitation falling on the valley floor area of each reach were available through the Department's studies (23) of consumptive use and water requirements. In those studies, estimated average monthly rainfall was computed by multiplying measured rainfall at key stations by an appropriate index factor to yield the rainfall on the given land area in terms of thousands of acre-feet.

Precipitation quantities, before being used as inputs to the water quality model, were modified by the effects of soil moisture storage and deep percolation to groundwater. During some months, a portion of direct precipitation served to replenish soil moisture storage and/or storage in the groundwater basin, and precipitation values were adjusted by deducting those quantities. During other months, water was withdrawn from soil moisture, and precipitation values were adjusted by adding the amounts withdrawn. The latter condition was obtained generally during the irrigation season and

TABLE 1. ANALYSIS OF ACCRETIONS
FOR REACH FROM
BELOW CHD TO VERONA

1961 WATER YEAR

	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER
*** CONTRIBUTIONS TO ACCRETION ***												
PRECIPITATION												
FLOW	15	116	46	90	95	127	94	69	20	5	5	13
E.C.	100	100	100	100	100	100	100	100	100	100	100	100
SALT	1500	11600	4600	9000	9500	12700	9400	6900	2000	500	500	1300
SURFACE WATER												
FLOW	6	1	1	0	0	0	61	116	112	120	111	48
E.C.	189	195	180	180	157	167	207	268	259	247	221	197
SALT	1135	195	180	0	0	0	12611	31036	28958	29685	24564	9471
GROUND WATER												
FLOW	29	0	0	0	0	0	13	10	20	19	20	8
E.C.	900	900	900	900	900	900	900	900	900	900	900	900
SALT	26100	0	0	0	0	0	11700	9000	18000	17100	18000	7200
ADDITIONAL SALT	0	0	0	0	0	6	10	6	3	3	3	0
TOTAL SALT	28735	11795	4780	9000	9500	12706	33721	46942	48961	47288	43067	17971
DEPLETION FLOW	50	62	34	31	66	95	168	178	137	144	126	69
*** RESULTANT ACCRETION ***												
NET ACCRETIONS												
FLOW	0	55	13	59	29	32	0	17	15	0	10	0
E.C.	0	214	368	350*	328	397	0	400*	400*	0	400*	0
SALT	0	11795	4780	20650	9500	12706	0	6800	6000	0	4000	0

(*) INDICATES Q OR C VALUE SPECIFIED IN INPUT DATA. COMPUTED VALUE NOT USED.

TABLE 2. ESTIMATED 1961 MONTHLY FLOW* AND MEAN CONDUCTIVITY* IN SACRAMENTO RIVER SYSTEM
BELOW CBD TO VERONA
1961 HYDROLOGY

TRIBUTARIES AND OTHER INFLOWS	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
BELOW CHD												
FLOW	361	447	731	467	1345	1318	546	429	413	426	484	441
CONDUCTIVITY	189	195	180	180	157	167	207	268	259	247	221	197
FEATHER-NICOLAUS												
FLOW	57	157	264	180	508	489	404	281	108	40	40	32
CONDUCTIVITY	147	144	120	126	105	96	90	89	105	133	132	157
SACRAMENTO SL												
FLOW	0	0	0	0	0	0	0	0	0	0	0	0
CONDUCTIVITY	0	0	0	0	0	0	0	0	0	0	0	0
NATOMAS X CANAL												
FLOW	0	0	0	0	0	0	0	0	0	0	0	0
CONDUCTIVITY	0	0	0	0	0	0	0	0	0	0	0	0
ADDL INFLOW												
FLOW	0	0	0	0	0	0	0	0	0	0	0	45
CONDUCTIVITY	0	0	0	0	0	0	0	0	0	0	0	900
M AND I WASTES												
FLOW	0	0	0	0	0	0	0	0	0	0	0	0
CONDUCTIVITY	700	700	700	700	700	700	700	700	700	700	700	700
OTHER ACCRETIONS												
FLOW	0	55	13	59	29	32	0	17	15	0	10	0
CONDUCTIVITY	0	214	368	350	328	397	0	400	400	0	400	0
DIVERSIONS AND OTHER OUTFLOWS												
DIVERSIONS												
FLOW	0	0	0	0	0	0	7	17	15	18	19	6
CONDUCTIVITY	0	0	0	0	0	0	207	268	259	247	221	197
WEIR SPILLS												
FLOW	0	0	0	0	0	0	0	0	0	0	0	0
CONDUCTIVITY	183	184	166	180	146	153	157	200	231	237	218	257
OTHER LOSSES												
FLOW	0	0	0	0	0	0	0	0	0	0	0	0
CONDUCTIVITY	0	0	0	0	0	0	0	0	0	0	0	0
NET VALUES AT VERONA												
FLOW	418	659	1008	706	1882	1839	943	710	521	448	515	512
CONDUCTIVITY	183	184	166	180	146	153	157	200	231	237	218	257

* Monthly flow is shown in 1,000 acre-feet and mean conductivity is shown in micromhos.

often would indicate that direct precipitation had occurred when in fact it was a consumptive use of stored precipitation that had occurred earlier.

No systematic records were available on the mineral content of rainfall in the Sacramento Valley. Chemical analyses of snow on the west slope of the Sierra Nevada (13) have shown total dissolved solids ranging from less than 1 to 11 parts per million, with a mean value of about 5 ppm. In this study, EC of rainfall was initially assumed to be a constant 15 micromhos, corresponding to about 10 ppm of total dissolved solids. In later model runs, the EC value was increased from 15 to 100 micromhos to reflect the mineral pickup of rainwater as it flowed over the soil and rocks of the valley floor. This produced a more realistic result, since it corresponded more closely to that of surface water runoff into the river.

Applied Surface Water

The term "applied surface water" as used in this study refers to amounts of water diverted from the Sacramento River or its tributaries and used to irrigate crops in the area under consideration. These are not necessarily the same amounts of water per reach as those included in "diversions", which will be discussed later. Water diverted from the river in one reach may be applied for irrigation in another area which contributes return flow to a reach downstream. For example, the Glenn-Colusa Canal carries water diverted from Reach "B" and applied in Colusa Basin where drainage returns to Reach "F".

For any historic year, monthly diversion flow quantities are recorded in publications on surface water flow (16, 19). These recorded values, where applicable, were used as the basic surface water supply in accretion analyses for each reach. In some areas unmeasured amounts of surface water also are diverted from minor tributaries crossing the area. In such instances measured diversion quantities alone may be insufficient for use as the total surface water supply. Where estimated depletions in a particular area exceeded the estimated total water supply (precipitation, measured stream diversions, and estimated groundwater applications) the deficit was assumed to be made up by unmeasured diversions from minor tributaries.

The EC of applied surface water, in general, was assumed to be the same as the EC of the Sacramento River at the upstream station of the reach from which the water was diverted. For Colusa Basin, however, the average of EC's at Colusa and Hamilton City was used.

Applied Groundwater

Very little data are available on measured quantities of groundwater applied historically in the Sacramento Valley. Preliminary estimates for use in the model were provided by the Coordinated Statewide Planning Program of the Northern District office of the Department.

EC's of groundwater used in the model were the approximate areal averages of EC data gathered from wells since 1951 by the Department's groundwater quality data program (16, 17).

Additional Salts

The total quantities of salts in a given area, in addition to those occurring there naturally and those brought in by inflowing water, include "additional salts", those added by fertilizers, soil conditioners, etc. Quantities of these added salts for use as model inputs were obtained from various sources. Available publications by the University of California Experiment Stations were reviewed and additional information was obtained by interviewing farm advisors and other knowledgeable individuals.

The amounts of additional salts are minor in relation to those carried by the river and its tributary inflows. For example, in 1961 a total of 59 tons of salts were estimated to have been returned to the river from such sources as fertilizers, soil amendments, etc., during April, the month of greatest application. The total salt loading in the river at Freeport during that month was estimated at 163,300 tons. These additional salts were less than 0.04 percent of the total salts in the river. In terms of nutrients, however, fertilizers may be of much greater significance.

Depletions

Monthly depletions in water supplies to meet the consumptive demands of agricultural, urban or native lands could not be computed directly by the water quality model. A side model, programmed for digital computer, was used to make these computations. This side model was developed by the Department as part of the continuing joint DWR-USBR Central Valley operation studies (23), which developed a program commonly referred to as the C.U.-2 Program.

The C.U.-2 Program, which will simulate actual field moisture conditions, is capable of handling the lag in time between the time rainfall or irrigation water enters the soil reservoir and the time it is lost to evapotranspiration. Water stored in the soil is treated as part of the water supply in the month in which it is used. Depletions in any given month are essentially restricted to evapotranspiration.

The C.U.-2 Program, simulating the action of the soil reservoir, stores precipitation that falls in the winter months for use in the spring and summer. Applied irrigation water also is retained in the soil or released in the same manner, but no water is stored in the winter. With the C.U.-2 Program it is possible to consider the differences in rooting depth and growing seasons of various crops, the moisture retention of various soil textures, or the addition of ponding water for rice during April and May.

For this study, the C.U.-2 model was used to compute both monthly and annual depletions for eight major agricultural crops and for urban and native lands. These land uses and acreages for the selected water years are shown in Appendix C.

Net Accretions

Accretions such as storm water runoff and return flows from irrigation are computed in the accretion subroutine of the model, unless specified directly in the input data. Examples of flow and EC values of computed, as well as specified net accretions are shown on Table 1, with specified values designated by an asterisk. Final net accretion values are carried as "other accretions" for each reach, as shown on Table 2.

In the accretion subroutine, all salts applied to an area during a particular month were assumed returned to the stream that same month. This is not necessarily true; and strong evidence exists to show that, in the Sacramento Valley, some of those salts generally are retained in the area during the irrigation season and are returned to the stream when leached from the soil during periods of heavy rainfall. For that reason, the option of specifying the flow and/or EC of accretions was incorporated into the structure of the model. Whenever an accretion value is specified, the computed value will not be used as input to the model. Observable patterns of historic accretions can thereby be reproduced. During the brief period allotted to this study, a detailed analysis of these possible patterns could not be undertaken. However, available flow and EC data on return flows and runoff were indispensable guides to probable magnitudes of values specified.

Accretion flow values were specified most frequently for months of relatively heavy rainfall. For those periods, the accretion subroutine often produced net accretion flow values considerably in excess of apparent historical quantities of runoff. In the model, more realistic flow results were obtained when runoff in the Sacramento Valley floor during any one month did not exceed 30 percent of that month's total of precipitation, applied surface water, and applied groundwater. For that reason, net accretion values were limited to 30 percent of precipitation and applied water. Admittedly, this 30 percent factor was a somewhat arbitrary runoff coefficient. A more valid coefficient undoubtedly would vary, depending upon antecedent precipitation and soil moisture conditions, types of terrain, and other factors. Further refinement of the accretion analysis portion of the model should produce more valid runoff coefficients.

Municipal and Industrial Waste Discharges

The analysis of accretions (Table 1) provided flow and EC estimates of agricultural drainage and surface water runoff, but did not include estimates of municipal and industrial (M&I) wastes discharged to the river system. These wastes were treated as an individual model input, as shown on Table 2.

For the 1955-62 period covered by DWR Bulletin No. 68-62 (6), quantities of M&I wastes discharged directly to the Sacramento River and its tributaries varied from 62,330 to 79,230 acre-feet per year.1/ Since, in general the bulletin considered only individual waste discharges exceeding 500 acre-feet per year, the above total quantities could be low. For the 1955 verification run, a total of 84,000 acre-feet was used, with 60,000 acre-feet in the Sacramento-Freeport reach; 12,000 acre-feet between Sacramento and Colusa (introduced in the Verona-Sacramento reach); and 12,000 acre-feet above Colusa (introduced in the Hamilton City-Colusa reach).

EC of M&I wastes during the 1955-62 period at the City of Sacramento sewage treatment plant varied from 642 to 738 micromhos, with an average of 699 micromhos. An EC of 700, therefore, was considered representative for M&I wastes and was used as a constant throughout the system for both historic and future levels of development. Sewage treatment processes by 1990 in the Sacramento Valley were not expected to change significantly with respect to EC; therefore, a total dissolved solids in M&I wastes were assumed to remain about the same as they are now. However, nutrients and toxic materials contained in M&I wastes are more likely to adversely affect river water quality than would total dissolved solids.

Additional Inflow

In developing the current model an essential step was to make an approximate hydrologic balance between upstream and downstream stations of each reach for which recorded flow data were available. After accounting for all known or estimated inflows and outflows, significant additional inflows were needed to achieve flow balance in some reaches during parts of both the 1961 and 1965 water years.

A typical example may be observed in Table 2. September 1961 shows that an "additional inflow" of 45,000 acre-feet (TAF) was introduced (arbitrarily) in the reach below CBD to Verona. The analysis of accretions (Table 1) shows zero net accretions for September, which appears reasonable in view of the relative amounts of precipitation, applied ground and surface water, and depletion flows. The difference between recorded and computed flows at Verona was 56 TAF (523 TAF versus 467 TAF, respectively) before adding the 45 TAF additional inflow. Although the adjusted value at Verona was still less than the recorded value by 11 TAF, the new computed value at Sacramento was brought to within 4 TAF of the recorded value with no further adjustments. The relatively small difference of 4 TAF should be within the probable error of flow measurements.

After the probable amount of additional inflow has been determined, the most likely source of such inflow must be considered

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1/ Additional data on M&I waste discharge are shown in DWR Bulletin No. 111, bibliography entry No. 26.

so that an appropriate EC value can be assigned to it. On the basis of EC, these additional inflows could most often be best attributed to groundwater. Assignment of known groundwater EC values to the inflow (as was done for the 45 TAF additional inflow shown on Table 2) and operation of the model could approximately reproduce recorded EC values at the river stations.

Where hydrologic conditions are favorable, groundwater inflow undoubtedly occurs along the river. When the river stage is rising, water will be recharged into bank storage. When the stage drops, water will tend to be withdrawn from bank storage to the river. Wherever the adjacent groundwater level, whether in bank storage or in the groundwater basin, becomes higher than the surface of the river, groundwater inflow can occur. No firm criteria were developed in this study upon which to base the occurrence or quantities of groundwater inflow. Historically, the hydrologic balance served as a guide.

The EC of groundwater inflow generally was assumed to be the same as that measured in the adjacent groundwater basin. Wherever inflow appeared to be derived mainly from bank storage, EC was assumed to be considerably lower than the EC of water pumped from wells, particularly in those areas containing more highly mineralized groundwater.

Groundwater inflow from subsurface agricultural drainage can affect the quality of Sacramento River water. A recent study (15) reported by the University of California Agricultural Extension Service in Davis was an important guide in judging the probable significance of the water quality problems caused by such inflow. Its findings assisted in assigning flow and EC values to model inputs. The study estimated the extent to which future subsurface agricultural drainage will be a problem in Tehama, Glenn, Colusa, and Yolo Counties in 2020. Findings for the four-county area are summarized here.

1) Area that will need artificial subsurface drainage: 75,150 acres

2) Quantity of subsurface drainage water: 232.2 cfs (13.9 TAF per month)

3) Salinity (EC) range: 500 to 5,000 micromhos

Almost 70 percent of the above drainage, or 159.7 cfs, would enter the Colusa Basin drain at an EC ranging from 500 to 5,000 micromhos. The remaining 30 percent, or 72.5 cfs, would enter the Sacramento River at Stony Creek or above, with an EC ranging from 500 to 2,000 micromhos. The total of this drainage is small in relation to other valley floor accretions to the river, amounting to only about 6 percent of the projected agricultural drainage that would enter the river between Keswick and Knights Landing.

Diversions

Direct diversions from the river in a particular reach may not be the same as diversions for "applied surface water" in that same reach, because a portion of the diversions may be applied in the area of a different reach. For historic conditions, data on diversions of streamflow are available from state publications on surface water flow (16, 19). For future conditions, diversion quantities were related to quantities of applied surface water which would be withdrawn from the river, but not necessarily applied in a particular reach.

The EC of diversions was assumed to be the same as the EC in the river at the upstream station of each reach. For prediction model runs, the upstream EC would be the only "known" EC river value in the reach, since it would have been the final result of computations for the reach immediately upstream.

Weir Spills

Five weirs along the Sacramento River divert floodflows from the river into bypass channels. These are the Moulton, Colusa, Tisdale, Fremont, and Sacramento Weirs. Historic flow over these weirs is recorded in reports on surface water flow (16, 19, 12). As in other diversions, EC of weir spill flow is the same as that of the river at the weir location. With one exception, this is considered in the model to be the EC at the upstream station in each river reach under consideration.

The exception for determining the EC of weir spillage occurs in Reach "G", below Colusa Basin Drain (Station 107) to Verona (Station 109). In that reach, the computed EC at Station 107 could be a considerably inaccurate basis for computing the EC of outflow over Fremont Weir. That is because, under high flow conditions, Fremont Weir spillage would likely include large Feather River flows at EC values differing widely from those in the Sacramento River upstream from the weir. The EC of the Fremont Weir spill, therefore, was computed as that of the mixture of flows in the Sacramento River below CBD and the Feather River at Nicolaus.

Additional Losses

As discussed under "Additional Inflow", a hydrologic balance between upstream and downstream stations was attempted for each historic year considered. During some months, losses in river flow were detected with could not be accounted for in measured diversions. Additional losses undoubtedly do occur under certain hydrologic conditions. When the river stage is rising, water can be expected to flow from the river into bank storage and possibly as recharge to the adjacent groundwater basin or seepage onto adjacent lands.

No firm criteria or patterns for such losses were developed during the course of this study. However, observation showed that the most substantial losses usually occurred during periods of sharp increases in river flow. In the model, the EC of these losses was considered in the same manner as was the EC of diversions: equivalent to EC of the river at the appropriate upstream locations.

MODEL VERIFICATION

To verify the model, computed EC values were compared graphically and numerically with prototype values at selected river stations. Because data for comparisons were limited to only one year of record and because of uncertainties in the record itself, an involved statistical approach toward verification was not considered appropriate. Verification, therefore, was largely a matter of individual judgment guided by knowledge of the Sacramento River system, the structure of the model, and the adequacy of data used.

As discussed earlier, the 1965 water year was used for developing and programming the structure of the model; the 1961 water year, for refinements and preliminary verification; and the 1955 water year, for final verification. Several machine runs were made for 1961 until reasonable agreement was achieved between computed and measured values. Successive adjustments in flow and/or EC of certain unmeasured input data were necessary, primarily for additional inflow or additional losses.

Certain "boundary" conditions, of course, were considered fixed. These included all measured or estimated flow rates and EC values of reservoir releases, tributary inflows, diversions, precipitation, applied irrigation water, consumptive use, and municipal and industrial waste discharges. Certain other constraints were introduced, such as a maximum runoff coefficient of 30 percent and adherence to approximate historic EC values for irrigation return flow. The latter constraint was necessary because the accretion subroutine often produced results which deviated greatly from EC values observed in irrigation drains.

The same basic assumptions and rationale employed for 1961 and 1965 were used for the 1955 verification run and computed results were compared with 1955 recorded data. No adjustments were made on the basis of recorded EC data for the river stations, so that the model's probable accuracy for use in future predictions could be evaluated.

The model was balanced hydrologically, however, against recorded streamflow rates at terminal river stations in each reach to account for unmeasured accretions or depletions, such as groundwater inflow and seepage losses.

Figures 4 through 8 show comparisons between the 1955 recorded and computed EC values and recorded and computed river flow at stations where historid data are available. Although most recorded and computed flow values coincided, they were not necessarily identical, but deviations were not great enough to be perceptible on the graphs. The close correlation in flows was achieved intentionally by the hydrologic balance. Additional inflows or losses in each reach were adjusted so that the computed flows at the river stations would approximate the measured values. For future conditions, the model was balanced hydrologically by reservoir release and river flow values established in Central Valley water project operation plans.

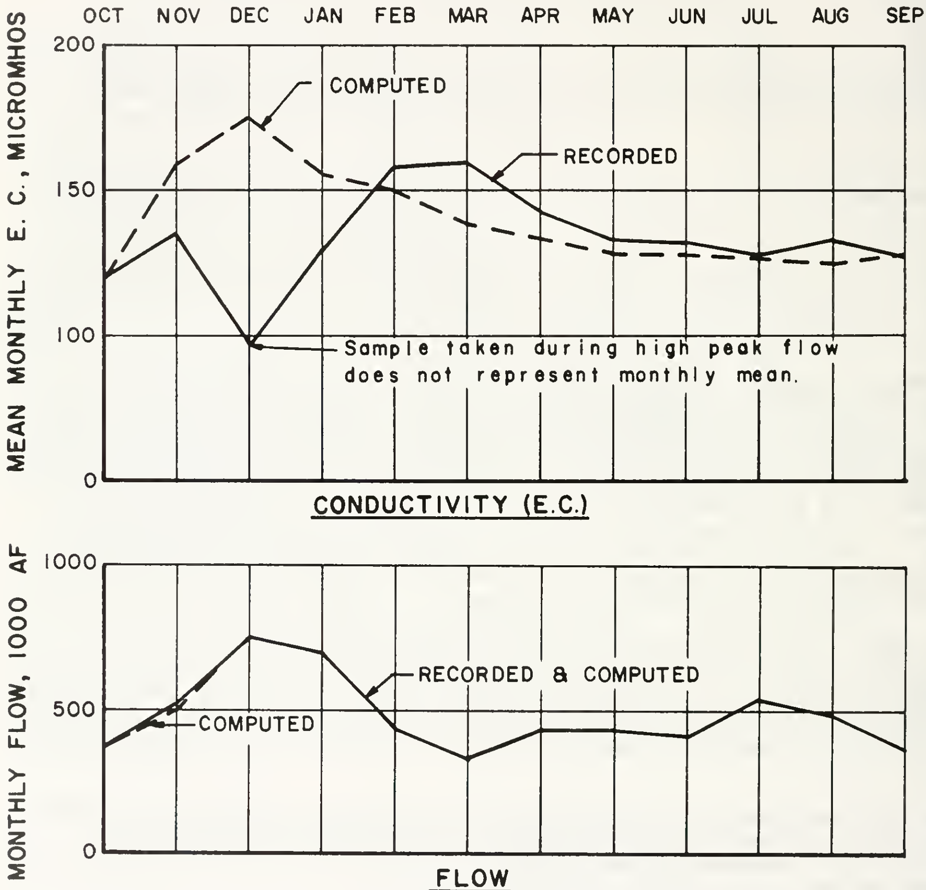

Figure 4. RECORDED AND COMPUTED FLOW AND CONDUCTIVITY, SACRAMENTO RIVER AT HAMILTON CITY, 1955 WATER YEAR

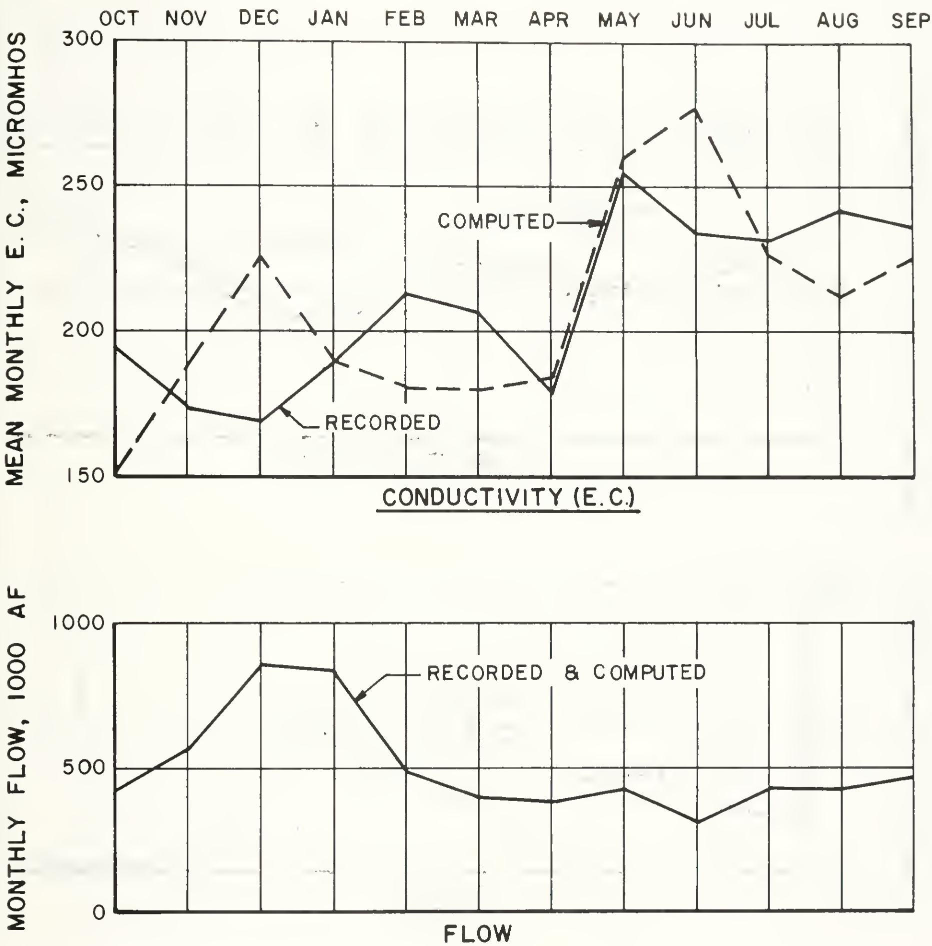

Figure 5. RECORDED AND COMPUTED FLOW AND CONDUCTIVITY, SACRAMENTO RIVER BELOW COLUSA BASIN DRAIN (KNIGHTS LANDING), 1955 WATER YEAR

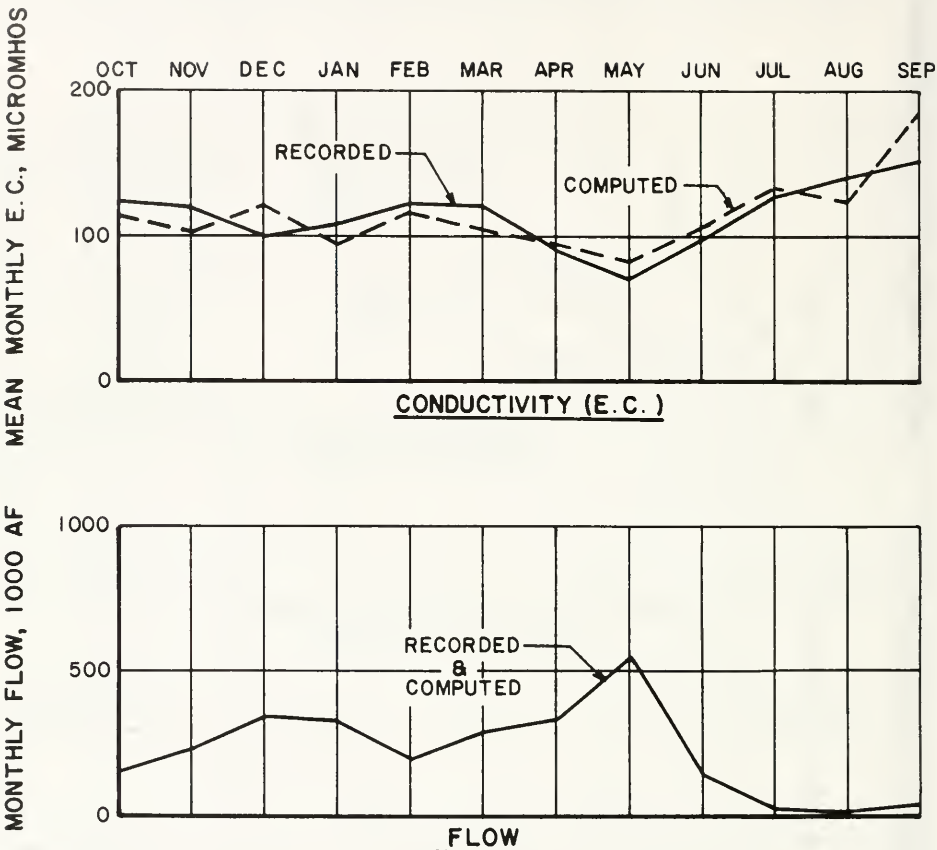

Figure 6. RECORDED AND COMPUTED FLOW AND CONDUCTIVITY, FEATHER RIVER AT NICOLAUS, 1955 WATER YEAR

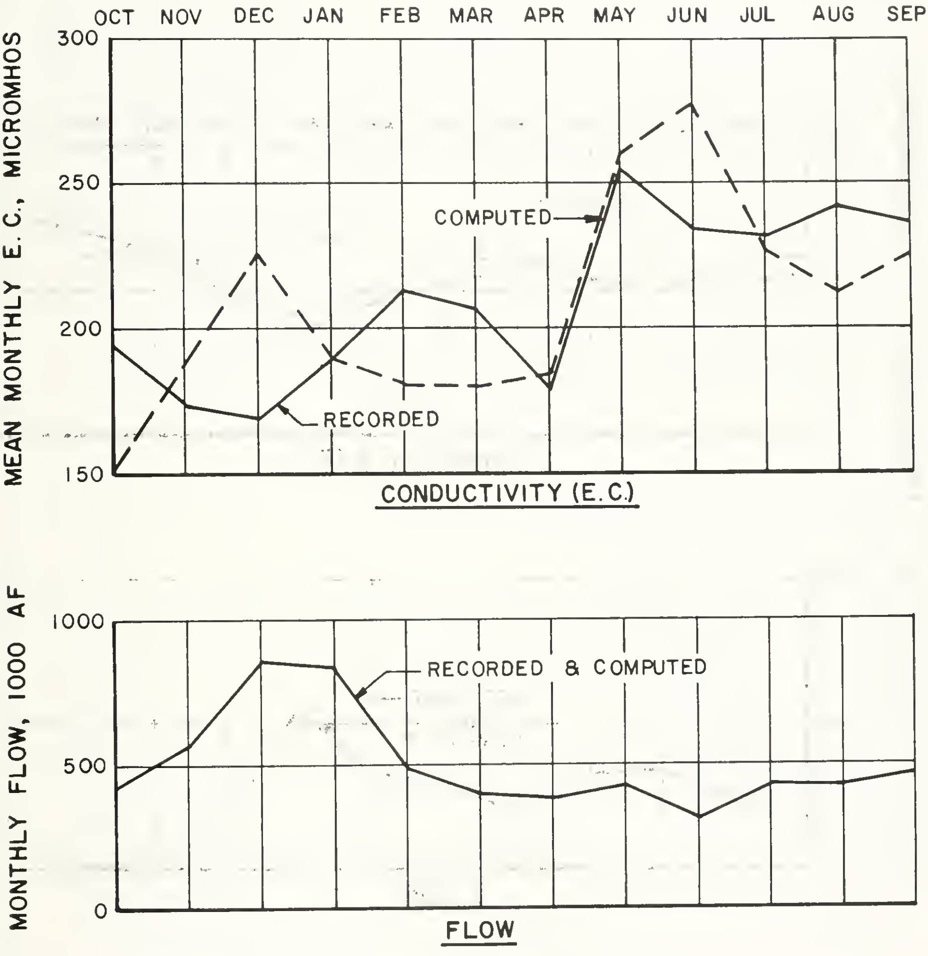

Figure 5. RECORDED AND COMPUTED FLOW AND CONDUCTIVITY, SACRAMENTO RIVER BELOW COLUSA BASIN DRAIN (KNIGHTS LANDING), 1955 WATER YEAR

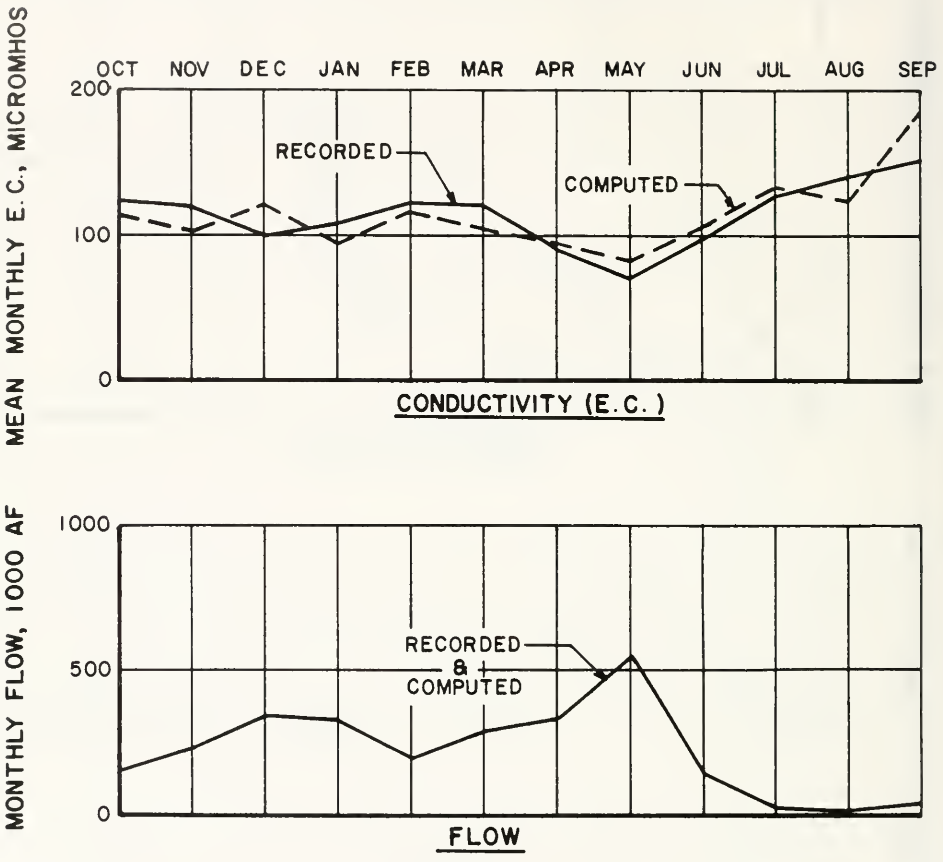

Figure 6. RECORDED AND COMPUTED FLOW AND CONDUCTIVITY, FEATHER RIVER AT NICOLAUS, 1955 WATER YEAR

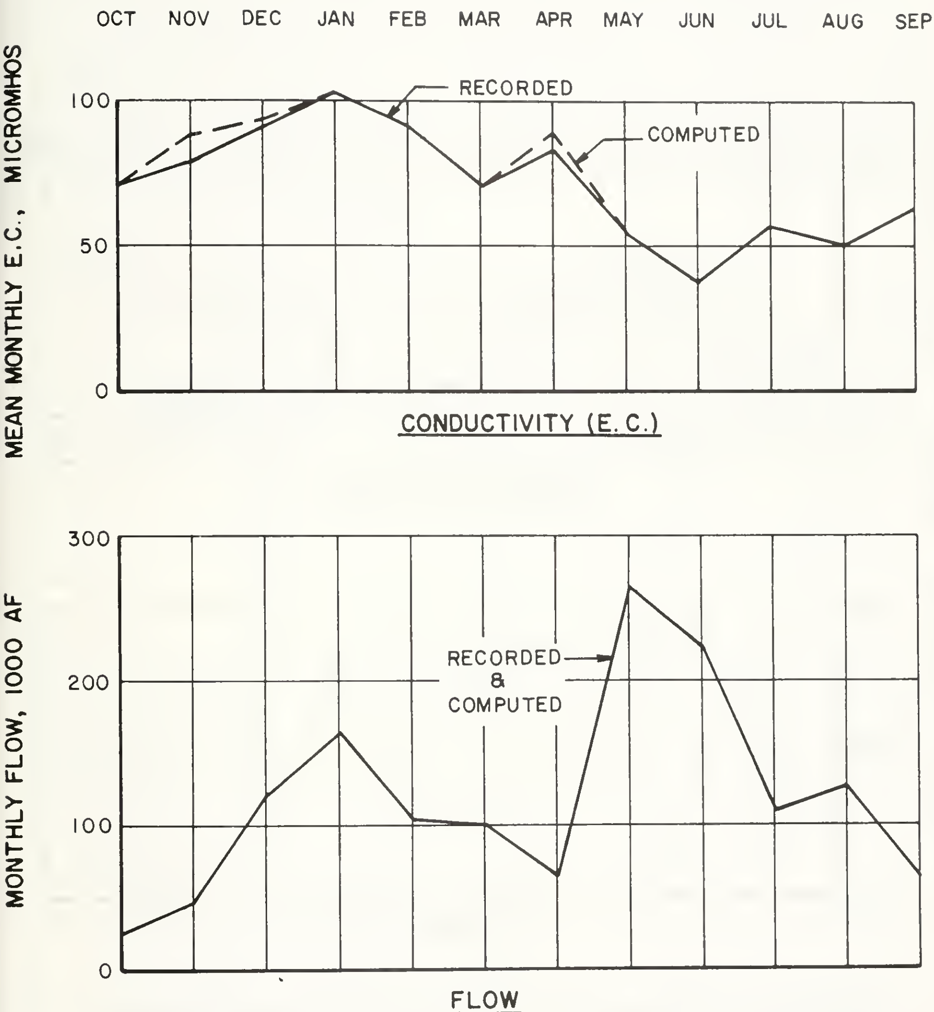

Figure 7. RECORDED AND COMPUTED FLOW AND CONDUCTIVITY, AMERICAN RIVER AT SACRAMENTO, 1955 WATER YEAR

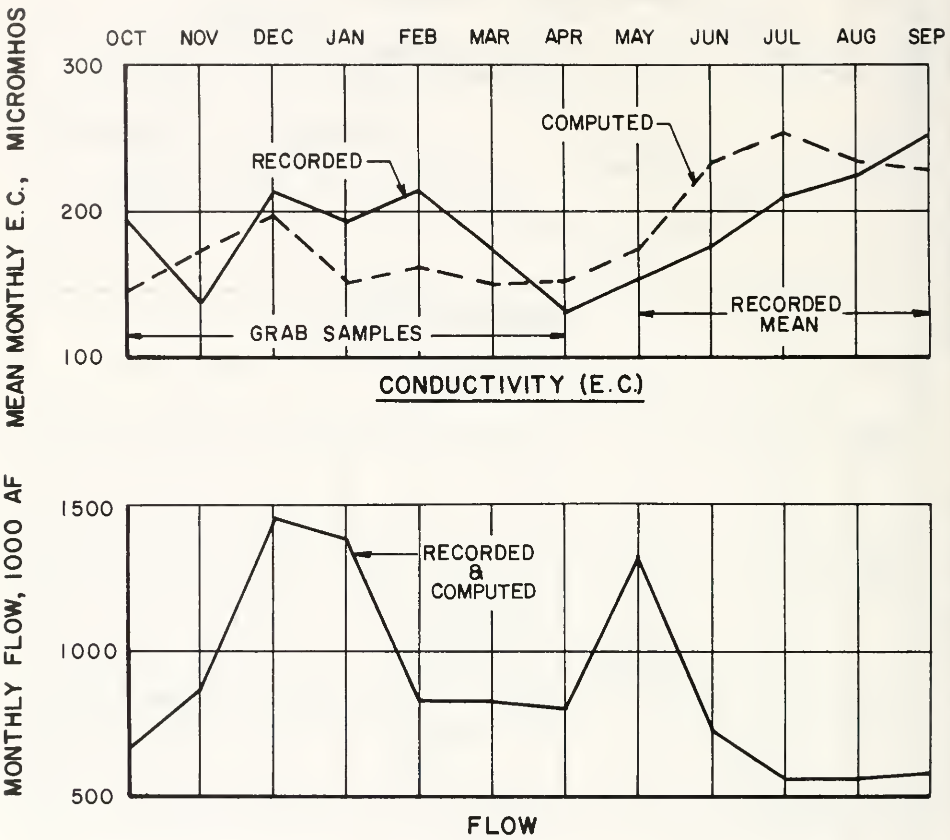

Figure 8. RECORDED AND COMPUTED FLOW AND CONDUCTIVITY, SACRAMENTO RIVER AT SACRAMENTO, 1955 WATER YEAR

Tables 3 through 5 list EC values as recorded and computed at three sites: in the Sacramento River at Hamilton City, in the Sacramento River below Colusa Basin drain, and in the Sacramento River at Sacramento. Also shown are deviations of computed values from recorded values for each month.

At Hamilton City (Table 3), the monthly average error was 13.5 percent. The recorded EC value for December, however, definitely did not represent the monthly mean, since the rate of flow when the sample was taken was two times as great as mean monthly flow in cubic feet per second (cfs). Omitting December, the monthly average error was 7.5 percent.

TABLE 3. ERROR ANALYSIS, 1955 WATER YEAR
Sacramento River at Hamilton City

Month	Conductivity in Micromhos		Deviation	
	Recorded1/	Computed	Micromhos	Percent
OCT	121	118	- 3	2.5
NOV	135	159	+24	17.8
DEC	97 2/	174	+77	79.4
JAN	130	157	+27	20.8
FEB	158	151	- 7	4.4
MAR	161	138	-23	14.3
APR	144	135	- 9	6.3
MAY	134	128	- 6	4.5
JUN	133	128	- 5	3.8
JUL	129	127	- 2	1.6
AUG	133	125	- 8	6.0
SEP	127	128	+ 1	0.8
		Total	+66	
		Average per month	+ 5.5	13.5
	Omitting December:	Total	-11	
		Revised Average per month	- 0.9	7.5

1/ Recorded values are results of grab samples (composites of 2) taken on only one day each month, and do not necessarily represent monthly mean values.

2/ Sample for December taken during peak flow (2 x monthly mean) and EC does not represent monthly mean.

TABLE 4. ERROR ANALYSIS, 1955 WATER YEAR
Sacramento River Below Colusa Basin Drain

Month	Conductivity in Micromhos		Deviation	
	Recorded	Computed	Micromhos	Percent
OCT	195	151	-44	22.6
NOV	174	188	+14	8.0
DEC	169	227	+58	34.3
JAN	189	190	+ 1	0.5
FEB	213	181	-32	15.0
MAR	207	180	-27	13.0
APR	178	184	+ 6	3.4
MAY	255	260	+ 5	2.0
JUN	233	277	+44	18.9
JUL	231	227	- 4	1.7
AUG	241	212	-29	12.0
SEP	236	225	-11	4.7
		Total	-19	
		Average per month	- 1.6	11.3

Below Colusa Basin drain (Table 4), the monthly average error was 11.3 percent, with a maximum error of 34.3 percent, occurring in December. The recorded EC values used for this station, which were derived from those published by the U. S. Geological Survey (20) for Knights Landing, were the monthly averages of daily sampling data weighted by flow. The values, therefore, should approximate the true monthly mean EC. The USGS data report notes, however, that mixing of irrigation return water with river water is not complete at the sampling site.

At Sacramento (Table 5), the monthly average error was 18.4 percent, with a maximum error of 33.7 percent for June. Recorded EC values for May through September were the monthly averages derived from USGS daily sampling data (20) and should closely approximate the flow-weighted monthly mean. The values for October through April are results of one day's grab samples and could vary considerably from monthly mean values. Furthermore, the Sacramento station was not located far enough below the confluence with the American River to allow complete mixing. For that reason, the sampling station was later relocated at Freeport.

Examination of the actual deviations in micromhos between the recorded and computed values reveals additional important

TABLE 5. ERROR ANALYSIS, 1955 WATER YEAR
Sacramento River at Sacramento

Month	Conductivity in Micromhos		Deviation	
	Recorded 1/	Computed	Micromhos	Percent
OCT	193	147	-47	23.8
NOV	136	174	+38	27.9
DEC	214	199	-15	7.0
JAN	195	152	-43	22.1
FEB	217	162	-55	25.4
MAR	176	151	-25	14.2
APR	131	152	+21	16.0
MAY	153	176	+23	15.0
JUN	175	234	+59	33.7
JUL	209	254	+45	21.5
AUG	224	233	+ 9	4.0
SEP	253	228	-25	9.9
		Total	-15	
	Average per month		- 1.3	18.4

1/ Recorded values for October through April are results of grab samples taken on only one day each month, and do not necessarily represent monthly mean values. Mean monthly flow for February was 18 percent higher than flow when sample was taken.

information. At Hamilton City, the algebraic total of monthly deviations is +66 micromhos, an average of 5.5 micromhos per month. Omitting the nonrepresentative sample for December, the total becomes -11 micromhos, an average of only -0.9 micromhos per month.

Below Colusa Basin drain and at Sacramento, near balances are achieved in algebraic totals of deviations in micromhos, being -19 and -15 micromhos, respectively. These amount to only -1.6 and -1.3 micromhos per month, respectively.

These analyses of actual deviations show that the model computed very nearly salt-balanced conditions for the year. Further investigation of the historic monthly distribution of salts in the system possibly would reveal monthly or annual patterns of salt distribution which, if incorporated in the model, would result in more accurate monthly values.

More importantly, measured EC values may not represent a complete mixture of all inflowing waters at some stream locations. Also, at those locations where only one "grab" sample was obtained per month, the relationship between measured EC and mean monthly EC was uncertain.

At the few locations where continuous conductivity recorders were in operation during the periods under consideration, errors in obtaining mean monthly EC values were minimized. Reasonably reliable data also were obtained from a few stations where samples had been collected daily.

The greatest chance for error occurred in trying to account for unmeasured valley floor accretions. For those inputs the sources were assumed and values assigned primarily on the basis of judgment. For example, if the source were assumed most likely to be groundwater inflow, an EC value corresponding to known EC of groundwater in the area was assigned.

Further refinement of the model and additional evaluation over a series of years of the more critical input values, particularly those of the major accretions, undoubtedly would produce more valid results. A more thorough statistical approach toward evaluating the relationships between computed and recorded data currently is being investigated. Additional computer runs with output for additional years would more materially aid in the statistical analysis.

The Department does plan to conduct additional verification runs of the model based on more recent data, including that for stations where conductivity recorders provide continuous EC records. These additional funds could not be made within the time available for the present study.

Although additional studies are desirable, the model appears to be conceptually valid. The 1961 and 1965 runs demonstrated that a mathematical simulation of electrical conductivity in the Sacramento River system was feasible. The 1955 verification run showed that the assumptions, coefficients and general rationale employed in developing the model were sufficiently reliable to simulate the general monthly pattern of EC at selected river stations and that approximate values of mean monthly EC could be estimated.

In many instances, flow and/or EC values of certain model inputs must be specified primarily on the basis of judgment. However, considerable (and growing) backlog of data is available as guides to judgment.

Additional Comments on Accuracy and Use of the Model

Output from the model consists of specific values of flow, EC and salt loading. These values can be expected to deviate by varying amounts from prototype values where comparisons can be made. The more important consideration is whether or not the model reasonably simulates the prototype system. If it does, the model can then be used to compare alternative systems.

In this study comparisons were made in terms of EC between two levels of cultural development. Results of the 1955 verification run indicated that the model simulated the prototype system well enough to be used for estimating the effects of a projected future level of development on EC in the Sacramento River.

The accuracy of computed results depends on the accuracy of input data. In this study input data had to be extrapolated or estimated where measured data were not available. Although certain guides to judgment were available, accuracy of those values was uncertain.

Measured streamflow and EC values used in the model generally were accepted as correct, although they are subject to the normal errors in measurement. These errors, particularly in streamflow, generally do not exceed 10 percent.

ESTIMATES OF FUTURE SALINITY OF WATER IN THE SACRAMENTO RIVER SYSTEM

Since the basic objective of the study was to develop a tool for estimating EC, or salinity, under future levels of development, the initial application of the model was placed at the 1990 level. The selection of 1990 was based on the availability of estimates (5) of anticipated levels of population growth and agricultural, municipal, and industrial development for that year. The objective was to illustrate the extent to which potential changes in any or all these areas may affect the mineral quality of the Sacramento River some 20 or more years in the future.

Water supply estimates (2) for 1990 in the Valley prepared by the Department of Water Resources and the U. S. Bureau of Reclamation provided a base hydrologic record and reservoir operation model for this study. Their estimates covered the 33-year period from (and including) 1922 through 1954, which included the years from 1928 to 1934, the most critical dry period ever recorded in the Valley. The record also covered several normal and extremely wet years. The time allotted to this study restricted evaluation of historic and probable future EC to only three of those 33 years: 1931, a critically dry year; 1936, a relatively normal year; and 1938, an extremely wet year.

The 1990 level of development, which had received the greatest attention in water supply and project operation studies in the Valley, was particularly applicable to this study because it had been used in previous water quality model runs, thereby making more input data available for the current runs.

Increased land use in the Sacramento Valley between 1961 and 1990 is illustrated below.

Land Use	1961	1990	Percent Increase
Urban acreage	148,800	239,900	61
Irrigated acreage	881,500	1,269,100	44

Detailed tabulations for these and other years used in this study are presented in Appendix C, "Present and Future Land Use". Population in the Sacramento Basin is expected to increase (5) from 932,000 in 1960 to 2,470,000 in 1990. This 165 percent growth was used as the basis for projections of municipal and industrial waste discharge quantities for 1990. Because very little quality data had been collected during 1931, 1936 and 1938, use of the model to estimate historic EC conditions for those years was required before future conditions could be assessed. Projected

1990 conditions were then superimposed upon the historic conditions to make the projected EC estimates.

The major changes in the Sacramento Valley water resource system between historic and 1990 conditions were the effects of seven major reservoirs on flow into the Sacramento River. These were Shasta Lake, Lake Oroville, Folsom Lake, Whiskeytown Reservoir, Marysville Reservoir, New Bullards Bar Reservoir, and Auburn Reservoir. Consideration also had to be given the system from the Trinity River via Clear Creek and Spring Creek Tunnels and the possibility of additional imports from the Eel River. For this study, Eel River imports were not considered, but they may be included in later computer runs.

Other significant changes were increased agricultural, municipal, and industrial development. Agricultural development is incorporated in the accretion analysis of the study, which reflects increased irrigated acreage and projected cropping patterns (see Appendix C). Waste discharges from municipal and industrial development were considered separately in the model and estimates of future quantities were based primarily upon the Department's population projections for use in water supply studies.

Figures 9 through 14 illustrate historic and projected 1990 flow and EC at Colusa and Freeport, two key stations on the Sacramento River. Figure 15 summarizes projected 1990 results for the three hydrologic conditions for the Sacramento River station at Freeport.

Tables 6 through 11 are copies of computer printouts showing estimated monthly flow in thousands of acre-feet, mean monthly conductivity in micromhos and monthly tons of salt contained in the flow at all 10 stations on the Sacramento River and on inflow from the Feather and American Rivers. Tables 6 through 8 show computed historic values, and Tables 9 through 11 show projected 1990 values for each of the three historic hydrologic conditions. Historic flow values shown for "Keswick Out" in the tables were the natural flows that occurred at the Shasta Dam site.

As indicated earlier under the heading "Model Verification", the absolute values computed by the model in some months may deviate substantially from prototype values. However, when the two levels of development are compared by means of computed values for each level, the degree of difference of change between the two levels should be reliably reflected by the model.

Discussion of Results

This section compares historic and projected EC values for each of the three water years considered. These comparisons should provide some indication of the degree of change which may be expected at the 1990 level of development. The data are shown in Tables 6 through 11.

1931 Hydrology

As mentioned earlier, 1931 was one of the driest years on record for the Sacramento Valley. The year's total outflow at Sacramento was about 41 percent of that which occurred in 1936, approximately a normal water year (Tables 6 and 7). Flow values shown on the tables do not include overflows into Yolo Bypass. During a dry year, when lesser amounts of water are available for dilution, higher than normal concentrations of dissolved minerals are expected in river flows.

In 1931 maximum computed EC at Freeport was 584 micromhos, occurring in August (Table 6). Projecting 1931 hydrologic conditions to the year 1990 shows a marked decrease in maximum EC to 362 micromhos, in April (Table 9). The August 1990 value dropped to 259 micromhos. The reasons for these changes are apparent in view of the respective flow values for each level of development. In 1931, flow in August at Freeport was only 33,000 acre-feet; projected flow for August 1990 is 259,000 acre-feet. On the other hand, flow in April 1931 was 492,000 acre-feet; projected flow for April 1990 is 362,000 acre-feet.

The flow-weighted yearly average EC at Freeport, however, was 171 micromhos in 1931 and a projected value of 221 micromhos in 1990. This is an increase of about 30 percent. However, the projected overall mineral quality is still quite good and does not approach the historic extremes.

The predicted EC values for all stations (Table 9) indicate total dissolved solids concentrations well below the recommended limit of 500 parts per million TDS for drinking water set by the U. S. Public Health Service. In terms of EC, that limit represents about 700 micromhos. The computed values are even farther below established criteria for irrigation water. In a water supply, however, the greater the margin of dissolved mineral concentrations under limiting criteria for beneficial uses, the more suitable is the water for reuse. Also, as mineral concentrations increase, more water is needed to remove salts from a basin and maintain a favorable salt balance.

1936 Hydrology

Water year 1936 is considered a normal year in terms of Sacramento Valley outflow. In historic 1936 maximum EC at Freeport was estimated at 333 micromhos, occurring in August (Table 7). The projected 1990 maximum EC at Freeport based on 1936 hydrology was 239 micromhos, occurring in June (Table 10).

The flow-weighted average EC for the year at Freeport for 1936 was 128 micromhos. The projected 1990 flow-weighted annual average, based on 1936 hydrology, was 188 micromhos, an increase of 47 percent (Tables 6 and 10). As indicated in projections based on 1931, the overall mineral quality for 1990 is quite good. The more highly regulated river flows tend to smooth out quality fluctuations and reduce extreme values.

1938 Hydrology

In contrast to 1931, water year 1938 was one of the wettest on record in the Sacramento Valley. Not counting weir spillage into Yolo Bypass, outflow at Freeport for 1938 exceeded that of 1936 by 60 percent (Tables 7 and 8). In historic 1938 maximum EC at Freeport was estimated to be 231 micromhos, occurring in August (Table 8). The projected 1990 maximum EC at Freeport for 1938 hydrology was 289 micromhos, also occurring in August (Table 11).

The flow-weighted 1990 average EC for the year at Freeport was 160 micromhos, an increase of 47 percent over the historic flow-weighted 1938 EC of 109 micromhos. As expected, the larger tributary inflows reduced 1938 average EC of 1931 and 1936.

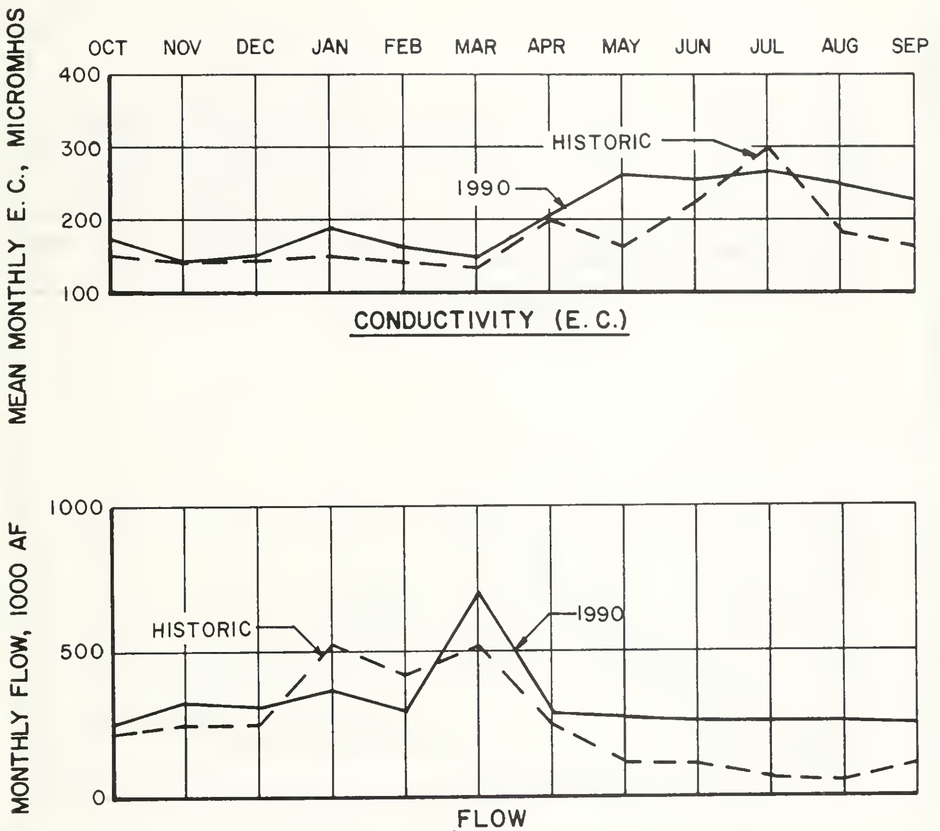

Figure 9. HISTORIC AND PROJECTED 1990 FLOW AND CONDUCTIVITY, SACRAMENTO RIVER AT COLUSA, 1931 HYDROLOGY

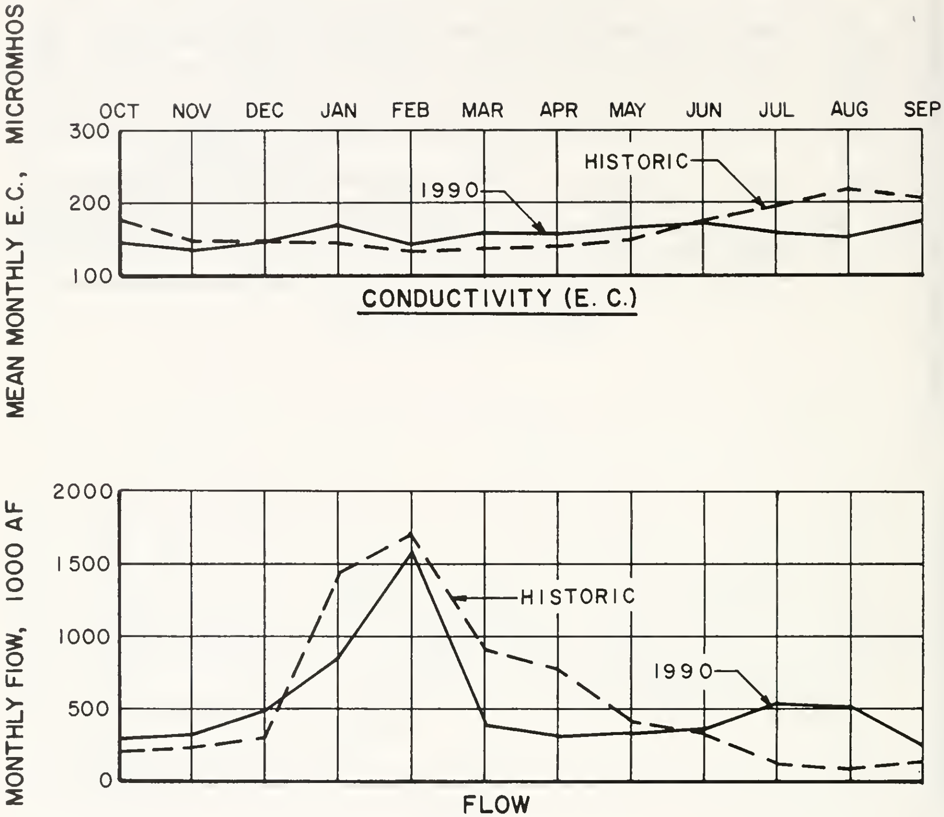

Figure 10. HISTORIC AND PROJECTED 1990 FLOW AND CONDUCTIVITY, SACRAMENTO RIVER AT COLUSA, 1936 HYDROLOGY

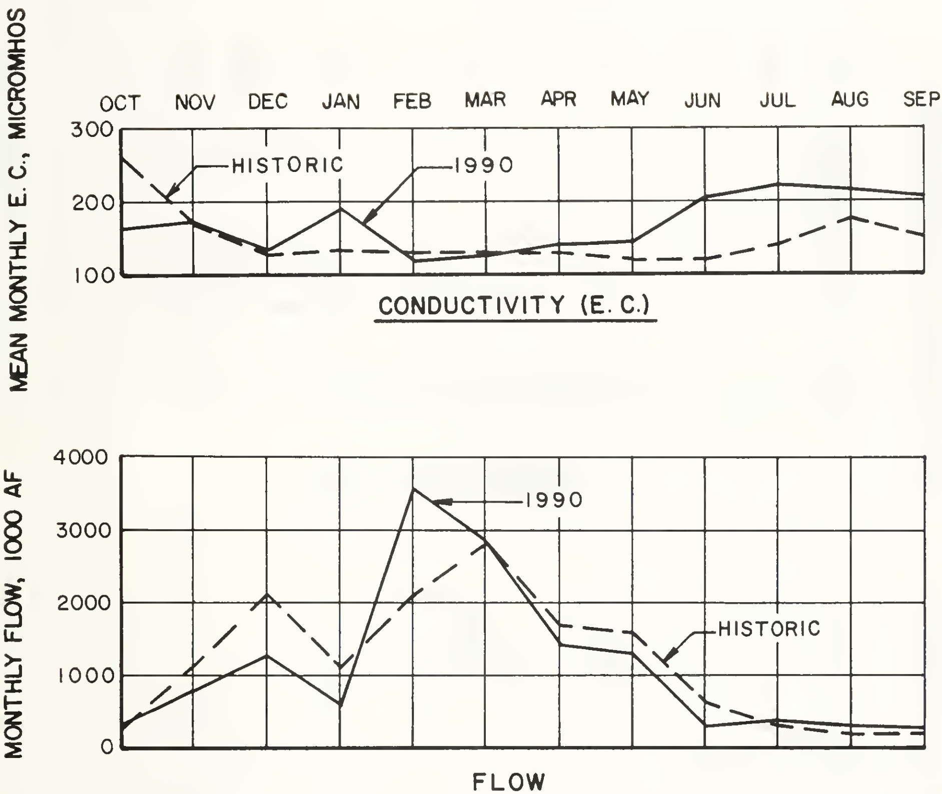

Figure 11. HISTORIC AND PROJECTED 1990 FLOW AND CONDUCTIVITY, SACRAMENTO RIVER AT COLUSA, 1938 HYDROLOGY

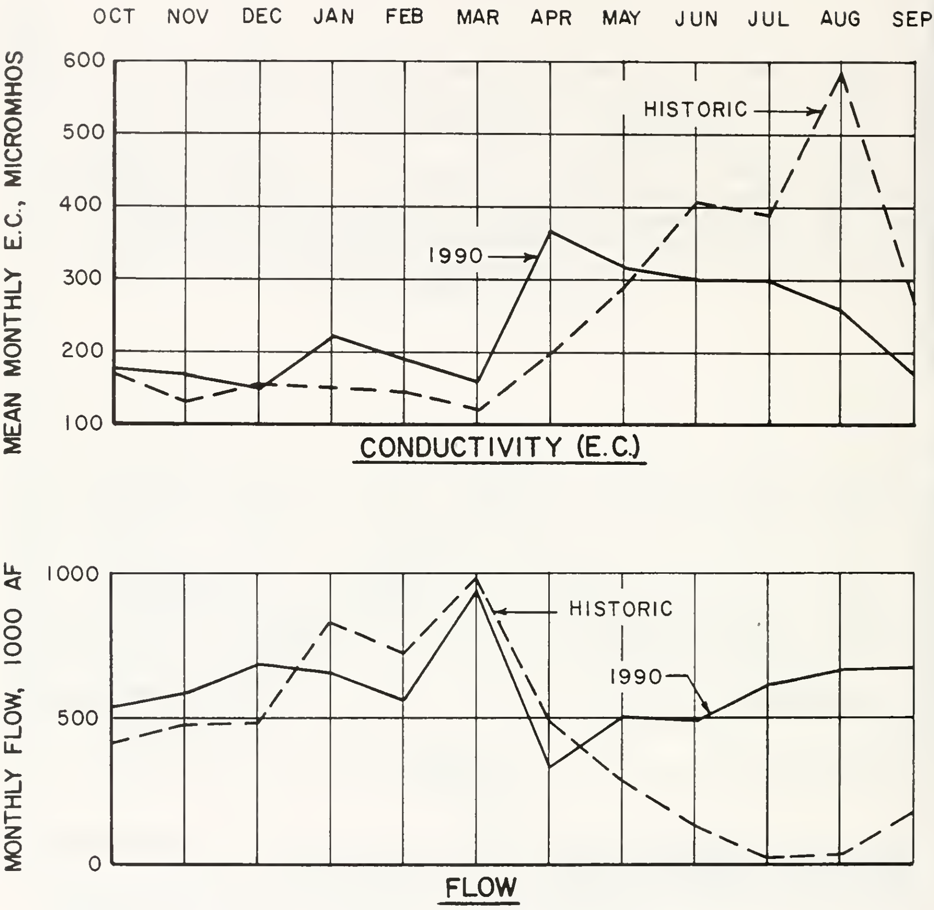

Figure 12. HISTORIC AND PROJECTED 1990 FLOW AND CONDUCTIVITY, SACRAMENTO RIVER AT FREEPORT, 1931 HYDROLOGY

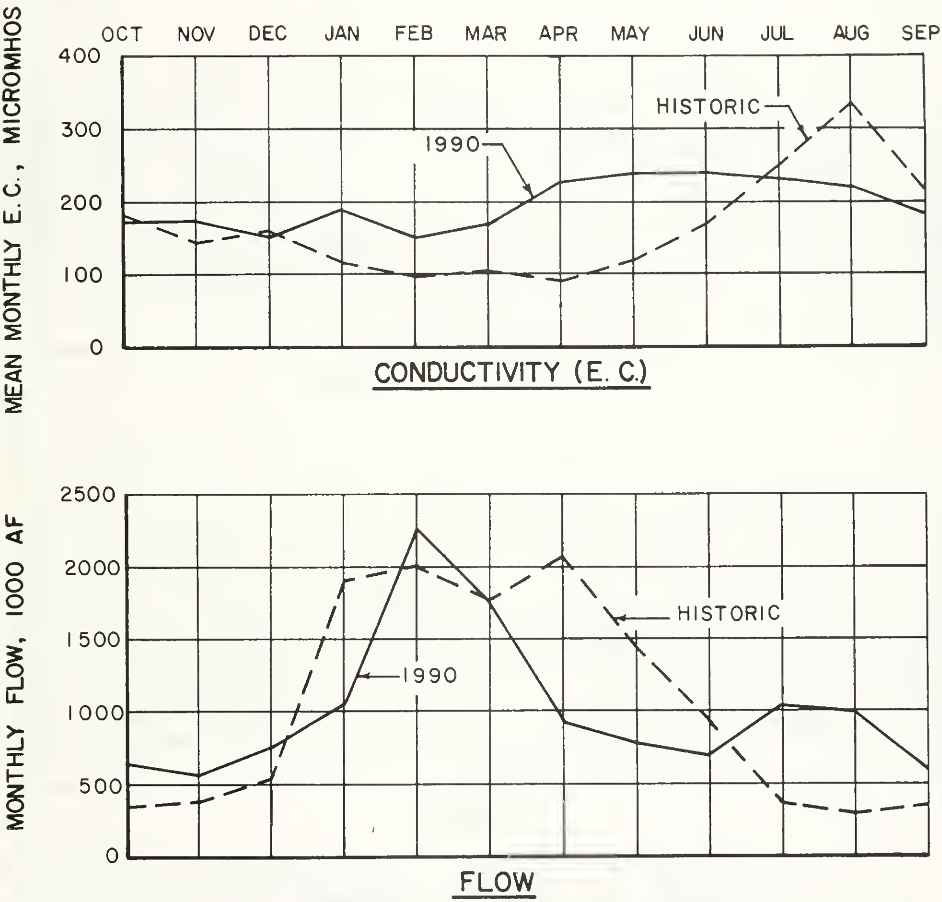

Figure 13. HISTORIC AND PROJECTED 1990 FLOW AND CONDUCTIVITY, SACRAMENTO RIVER AT FREEPORT, 1936 HYDROLOGY

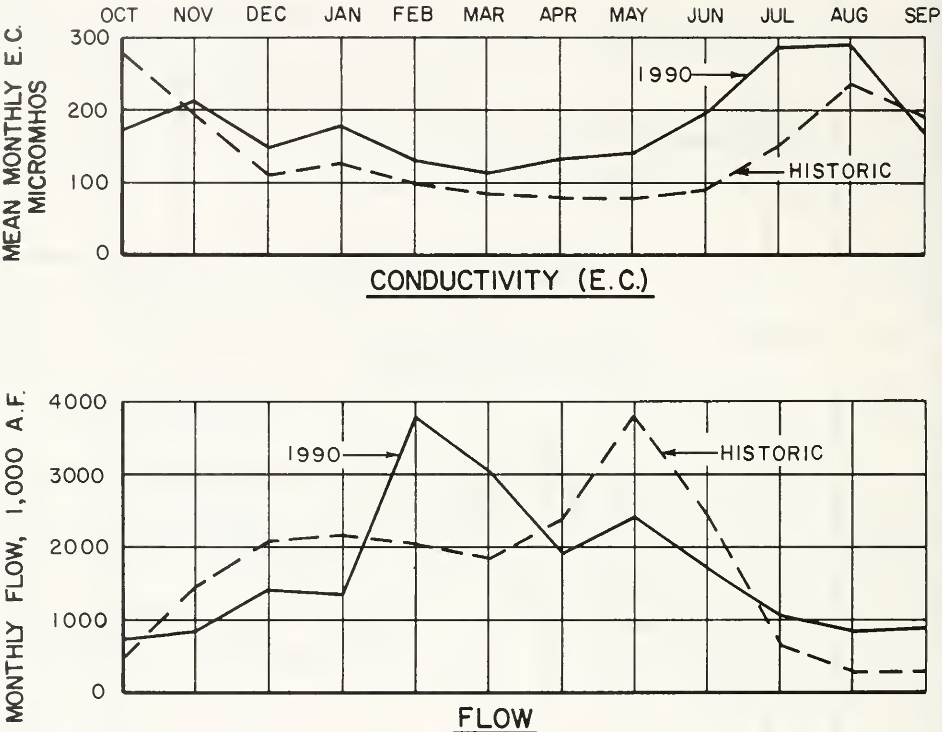

Figure 14. HISTORIC AND PROJECTED 1990 FLOW AND CONDUCTIVITY, SACRAMENTO RIVER AT FREEPORT, 1938 HYDROLOGY

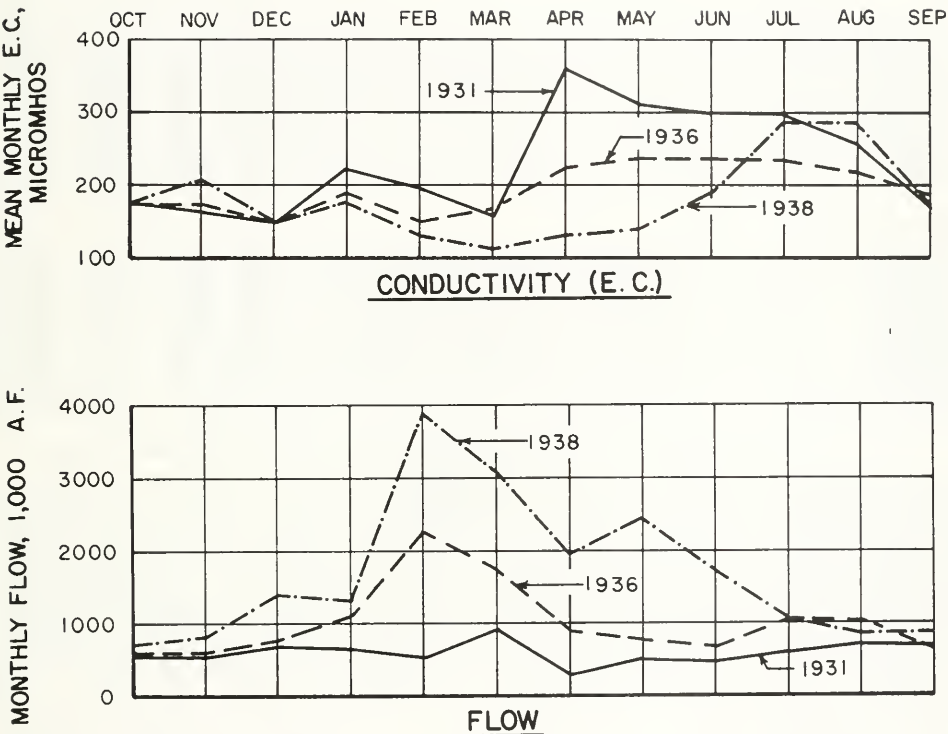

Figure 15. PROJECTED 1990 FLOW AND CONDUCTIVITY, SACRAMENTO RIVER AT FREEPORT, 1931, 1936, AND 1938 HYDROLOGY

TABLE 6. ESTIMATED 1931 MONTHLY FLOW, MEAN CONDUCTIVITY AND SALT LOADING IN SACRAMENTO RIVER SYSTEM
1931 HYDROLOGY

FLOW IN 1000 ACRE FEET

ID	STATION	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
1	KESWICK OUT	184	188	196	272	266	365	236	194	173	161	157	153	2539
2	RED BLUFF DD	208	223	224	457	373	446	278	216	187	161	159	157	3091
3	HAMILTON CTY	210	244	244	547	416	514	230	158	112	69	79	116	2939
4	COLUSA	216	248	246	525	424	520	248	112	101	60	56	107	2863
5	BEL BUTTE CR	229	250	256	539	439	559	273	156	125	79	74	136	3115
6	ABOVE CBD	227	250	266	568	449	537	192	81	56	16	22	111	2775
7	BELOW CBD	236	250	266	570	449	538	217	111	81	26	42	131	2917
8	FEATHER-NIC	160	192	172	273	235	377	122	63	18	1	5	32	1650
9	VERONA	403	442	458	783	694	864	345	168	104	31	52	179	4543
10	AMERICAN-SAC	17	39	21	60	76	132	157	114	40	8	3	6	673
11	SACRAMENTO	419	475	481	834	775	982	489	286	128	12	30	178	5089
12	FREEPORT	422	478	484	837	778	979	492	289	131	15	33	181	5119

CONDUCTIVITY IN MICROMHOS

ID	STATION	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
1	KESWICK OUT	137	138	138	131	131	125	130	136	138	140	141	141	
2	RED BLUFF DD	144	138	137	152	140	127	133	143	156	152	152	148	
3	HAMILTON CTY	146	141	144	153	143	132	135	144	153	150	152	151	
4	COLUSA	152	142	144	155	145	135	200	162	222	300	184	161	
5	BEL BUTTE CR	161	142	154	153	144	140	211	250	270	346	265	185	
6	ABOVE CBD	161	142	167	172	192	140	211	250	270	346	265	185	
7	BELOW CBD	180	142	167	174	152	141	314	518	609	790	715	238	
8	FEATHER-NIC	127	105	108	114	118	111	95	152	235	1021	205	140	
9	VERONA	167	126	155	153	144	128	245	402	544	687	626	265	
10	AMERICAN-SAC	88	86	89	79	74	64	62	66	79	133	100	100	
11	SACRAMENTO	165	128	153	151	141	121	191	278	402	310	573	261	
12	FREEPORT	169	131	157	153	143	123	194	282	409	388	584	268	

SALT LOADING IN 100 TONS

ID	STATION	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
1	KESWICK OUT	252	259	262	356	348	456	307	264	239	225	221	216	3407
2	RED BLUFF DD	299	310	308	693	522	568	369	309	292	244	242	233	4388
3	HAMILTON CTY	307	343	351	835	597	680	312	227	172	104	120	176	4222
4	COLUSA	328	353	353	815	616	701	495	181	224	180	103	172	4522
5	BEL BUTTE CR	368	355	394	825	634	781	576	390	338	274	196	252	5383
6	ABOVE CBD	365	355	444	978	684	750	405	203	151	55	58	206	4654
7	BELOW CBD	424	355	444	991	684	757	681	574	493	205	300	311	6220
8	FEATHER-NIC	203	202	186	311	278	419	116	95	42	10	10	45	1918
9	VERONA	673	557	710	1198	1002	1104	844	756	565	213	326	474	8422
10	AMERICAN-SAC	15	34	19	48	56	84	97	75	32	11	3	6	478
11	SACRAMENTO	691	606	737	1261	1090	1188	934	795	515	37	172	465	8491
12	FREEPORT	712	627	758	1282	1111	1202	955	816	536	58	193	486	8735

TABLE 7. ESTIMATED 1936 MONTHLY FLOW, MEAN CONDUCTIVITY AND SALT LOADING IN SACRAMENTO RIVER SYSTEM
1936 HYDROLOGY

FLOW IN 1000 ACRE FEET

ID	STATION	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
1	KESWICK OUT	181	178	212	805	1062	562	503	343	295	202	170	160	4673
2	RED BLUFF DD	204	214	286	1426	1467	762	685	448	370	233	188	177	6660
3	HAMILTON CTY	224	233	315	1726	2084	878	788	475	372	192	142	159	7588
4	COLUSA	215	237	312	1442	1713	911	788	443	343	152	101	130	6767
5	BEL BUTTE CR	234	247	341	1646	2116	973	837	510	385	192	142	175	7798
6	ABOVE CBD	232	247	341	1445	1878	894	762	419	324	131	63	139	6895
7	BELOW CBD	235	247	341	1605	2073	904	762	429	343	141	103	177	7360
8	FEATHER-NIC	104	97	138	599	894	589	700	437	248	135	131	125	4197
9	VERONA	335	344	479	1444	1436	1348	1461	902	597	308	274	337	9265
10	AMERICAN-SAC	33	45	51	429	809	432	627	574	345	83	27	25	3490
11	SACRAMENTO	361	391	533	1902	1987	1783	2086	1467	930	371	286	357	12454
12	FREEPORT	364	394	536	1905	1990	1786	2089	1470	933	374	289	360	12490

CONDUCTIVITY IN MICROMHOS

ID	STATION	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
1	KESWICK OUT	138	139	137	120	113	122	120	124	123	135	138	139	
2	RED BLUFF DD	158	141	137	134	123	129	132	125	125	140	147	148	
3	HAMILTON CTY	170	145	142	142	125	130	134	144	169	180	200	199	
4	COLUSA	179	147	145	146	134	138	140	152	178	195	218	206	
5	BEL BUTTE CR	200	151	150	145	132	145	141	174	213	260	301	225	
6	ABOVE CBD	200	151	150	145	133	145	141	174	213	260	301	225	
7	BELOW CBD	210	151	150	146	150	149	141	184	246	298	398	246	
8	FEATHER-NIC	121	125	169	77	73	77	77	93	97	104	104	109	
9	VERONA	182	144	155	127	128	121	110	158	220	286	345	219	
10	AMERICAN-SAC	85	79	81	57	52	56	51	50	55	70	80	80	
11	SACRAMENTO	177	139	153	113	96	106	94	117	161	244	329	213	
12	FREEPORT	182	144	156	114	97	107	94	118	163	248	333	217	

SALT LOADING IN 100 TONS

ID	STATION	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
1	KESWICK OUT	250	247	290	966	1200	686	604	425	363	273	235	222	5761
2	RED BLUFF DD	322	301	392	1914	2050	983	904	561	464	326	276	264	8757
3	HAMILTON CTY	382	338	446	2445	2604	1143	1057	684	627	346	285	316	10673
4	COLUSA	385	349	451	2104	2301	1256	1104	675	612	296	221	268	10020
5	BEL BUTTE CR	467	373	510	2383	2792	1415	1182	885	821	499	427	394	12147
6	ABOVE CBD	463	373	510	2093	2496	1301	1076	727	691	340	250	313	10632
7	BELOW CBD	493	373	518	2340	3117	1351	1076	787	843	420	410	435	12154
8	FEATHER-NIC	126	121	234	461	654	456	539	408	241	140	136	136	3452
9	VERONA	610	494	744	1835	1831	1632	1614	1428	1314	879	944	739	14064
10	AMERICAN-SAC	28	36	42	246	422	240	317	289	191	58	22	20	1910
11	SACRAMENTO	640	545	814	2158	1909	1893	1951	1718	1502	906	841	760	15736
12	FREEPORT	661	566	835	2179	1930	1914	1972	1739	1523	927	962	781	15988

TABLE 8. ESTIMATED 1938 MONTHLY FLOW, MEAN CONDUCTIVITY AND SALT LOADING IN SACRAMENTO RIVER SYSTEM
1938 HYDROLOGY

FLOW IN 1000 ACRE FEET

ID	STATION	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
1	KESWICK OUT	185	720	1109	587	1531	1886	1299	984	476	301	247	273	9540
2	RED BLUFF DD	232	1167	1871	930	2599	3149	1745	1243	595	346	269	247	14389
3	HAMILTON CTY	251	1358	2476	1270	3164	3831	2180	1594	723	339	226	234	17658
4	COLUSA	237	1168	2147	1087	2896	2792	1700	1591	624	312	285	285	14144
5	BEL BUTTE CR	259	1195	2384	1277	2545	3131	1812	1748	789	368	256	246	18949
6	ABOVE CBD	256	1006	2081	1180	1841	2314	1062	1300	620	272	170	213	12337
7	BELOW CBD	264	1013	2103	1340	2421	2486	1862	1300	621	302	195	238	13345
8	FEATHER-NIC	129	418	1558	523	1526	2368	2208	2246	1092	214	81	89	12436
9	VERONA	411	1012	1941	1946	1831	1105	1453	3304	1980	514	254	257	16260
10	AMERICAN-SAC	36	80	450	154	578	823	722	1004	585	128	34	30	4424
11	SACRAMENTO	450	1441	2097	2184	2018	1894	2376	3847	2438	631	277	283	19959
12	FREEPORT	453	1444	2100	2191	2021	1897	2378	3850	2441	634	280	286	19995

CONDUCTIVITY IN MICROMHOS

ID	STATION	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	KESWICK OUT	137	109	116	119	105	114	114	108	116	127	130	132
2	RED BLUFF DD	166	140	135	135	123	124	120	116	119	133	137	139
3	HAMILTON CTY	258	166	130	133	123	123	121	107	110	124	169	141
4	COLUSA	262	168	132	139	130	130	129	115	118	135	177	151
5	BEL BUTTE CR	300	187	134	137	127	130	135	117	127	160	215	174
6	ABOVE CBD	300	187	134	137	128	131	135	117	127	160	215	174
7	BELOW CBD	347	221	149	142	128	138	135	117	128	210	290	220
8	FEATHER-NIC	144	126	73	103	77	63	64	61	70	94	130	160
9	VERONA	286	194	117	131	110	105	87	88	99	162	239	193
10	AMERICAN-SAC	84	78	56	65	54	51	51	48	51	63	78	83
11	SACRAMENTO	272	191	106	126	95	83	77	78	88	144	226	185
12	FREEPORT	275	192	107	127	96	84	78	78	89	147	231	191

SALT LOADING IN 100 TONS

ID	STATION	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
1	KESWICK OUT	253	785	1286	699	1608	2150	1481	1063	552	302	321	294	10874
2	RED BLUFF DD	388	1634	2917	1256	3182	3897	2101	1440	707	460	369	343	18291
3	HAMILTON CTY	648	2244	3218	1695	3880	4720	2542	1702	796	421	382	329	22578
4	COLUSA	822	1950	2840	1513	2710	3636	2196	1827	734	421	364	310	19123
5	BEL BUTTE CR	773	2239	3189	1744	3244	4085	2447	2052	904	590	551	442	22281
6	ABOVE CBD	767	1885	2788	1612	2374	3026	1434	1526	790	436	366	370	17375
7	BELOW CBD	915	2247	3135	1899	3092	3437	1434	1526	795	633	566	523	20197
8	FEATHER-NIC	185	515	1143	540	1181	1497	1415	1374	768	201	105	124	9049
9	VERONA	1181	1960	2279	2617	2023	1158	1444	2899	1964	831	608	495	19459
10	AMERICAN-SAC	30	62	254	100	314	420	365	483	298	81	27	25	2460
11	SACRAMENTO	1724	2796	2221	2763	1912	1568	1831	2991	2147	910	626	574	21512
12	FREEPORT	1245	2817	2242	2784	1933	1589	1952	3012	2168	931	647	545	21764

TABLE 9. ESTIMATED 1990 MONTHLY FLOW, MEAN CONDUCTIVITY AND SALT LOADING IN SACRAMENTO RIVER SYSTEM
1931 HYDROLOGY

FLOW IN 1000 ACRE FEET

ID	STATION	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
1	KESWICK OUT	243	303	280	160	171	808	379	285	263	339	338	255	3624
2	RED BLUFF DD	259	341	325	293	263	663	446	355	349	386	387	255	4322
3	HAMILTON CTY	240	349	341	388	304	732	277	237	240	236	264	243	3451
4	COLUSA	245	334	322	373	289	718	288	275	266	244	261	254	3889
5	BEL BUTTE CR	256	336	328	387	301	736	361	349	342	348	294	298	4296
6	ABOVE CBD	256	289	278	348	296	657	240	248	238	255	248	243	3556
7	BELOW CBD	270	299	282	379	257	666	380	309	317	329	280	243	4010
8	FEATHER-NIC	183	155	125	136	126	151	65	122	86	186	251	330	1918
9	VERONA	422	451	445	564	441	817	385	450	391	574	560	573	6073
10	AMERICAN-SAC	109	79	205	51	47	54	38	74	151	153	139	111	1203
11	SACRAMENTO	530	571	675	646	552	887	316	497	477	599	657	659	7066
12	FREEPORT	545	584	690	661	567	896	331	512	492	614	672	674	7240

CONDUCTIVITY IN MICROMHOS

ID	STATION	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	KESWICK OUT	129	130	135	130	132	133	134	127	135	132	134	132
2	RED BLUFF DD	135	137	139	160	146	138	145	146	163	151	152	142
3	HAMILTON CTY	162	141	146	187	156	147	285	207	272	297	254	215
4	COLUSA	174	147	151	193	164	151	206	267	254	270	253	223
5	BEL BUTTE CR	189	147	150	189	160	149	250	306	302	321	365	221
6	ABOVE CBD	189	147	150	192	160	149	250	306	302	321	345	224
7	BELOW CBD	219	163	160	250	163	159	379	423	451	451	408	221
8	FEATHER-NIC	116	116	116	120	107	99	113	104	79	119	124	129
9	VERONA	178	147	161	216	166	148	362	340	373	349	286	168
10	AMERICAN-SAC	93	88	57	68	108	96	107	92	88	94	90	93
11	SACRAMENTO	181	153	136	212	181	150	346	305	286	288	249	159
12	FREEPORT	176	167	149	223	195	159	362	317	299	298	259	171

SALT LOADING IN 100 TONS

ID	STATION	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
1	KESWICK OUT	314	394	378	209	226	809	508	363	355	446	451	335	4788
2	RED BLUFF DD	350	466	453	470	389	912	648	518	567	585	589	342	6305
3	HAMILTON CTY	390	481	499	725	474	1076	567	681	692	782	671	572	7458
4	COLUSA	425	480	487	721	474	1083	593	735	677	712	659	566	7624
5	BEL BUTTE CR	484	495	492	731	483	1096	902	1067	1032	1116	1072	570	9537
6	ABOVE CBD	485	424	417	667	411	978	600	758	718	818	855	536	7468
7	BELOW CBD	593	487	452	946	420	1059	1440	1307	1429	1484	1143	536	11297
8	FEATHER-NIC	213	179	145	189	134	150	51	127	68	221	310	474	2212
9	VERONA	738	663	714	1218	731	1209	1392	1531	1459	2002	1602	961	14219
10	AMERICAN-SAC	181	69	117	35	50	52	32	68	134	143	126	103	1029
11	SACRAMENTO	853	871	931	1367	998	1331	1093	1518	1364	1724	1635	1046	14722
12	FREEPORT	958	976	1026	1472	1183	1427	1198	1623	1469	1829	1740	1151	15973

TABLE 10. ESTIMATED 1990 MONTHLY FLOW, MEAN CONDUCTIVITY AND SALT LOADING IN SACRAMENTO RIVER SYSTEM
1938 HYDROLOGY

FLOW IN 1000 ACRE FEET

ID STATION	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
1 KESWICK OUT	332	344	363	160	816	289	242	494	542	866	866	341	5651
2 RED BLUFF DU	364	407	485	514	1182	435	412	633	657	912	882	356	7241
3 HAMILTON CTY	290	357	519	780	1488	464	366	393	440	565	559	253	6474
4 COLUSA	308	349	501	872	1593	388	319	327	357	541	515	258	6320
5 BEL BUTTE CH	307	356	510	943	1767	421	364	379	417	605	567	282	6918
6 ABOVE CBD	289	291	412	978	1767	381	238	250	271	501	476	242	6096
7 BELOW CBD	345	350	415	1077	1974	402	483	415	452	683	634	280	7430
8 FEATHER-NIC	222	172	188	467	1548	792	323	345	245	178	212	302	4994
9 VERONA	567	521	681	1188	2242	1392	728	781	652	805	780	515	10772
10 AMERICAN-SAC	91	76	123	140	355	160	80	140	259	385	346	140	2295
11 SACRAMENTO	630	565	743	1077	2279	1728	902	755	684	1048	990	588	11989
12 FREEPORT	645	580	758	1092	2294	1743	917	770	699	1063	1005	603	12169

CONDUCTIVITY IN MICROMHOS

ID STATION	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
1 KESWICK OUT	116	115	121	119	114	118	116	123	118	121	117	117	
2 RED BLUFF DU	127	121	133	163	129	134	132	127	123	125	122	126	
3 HAMILTON CTY	133	127	138	163	133	141	140	156	163	151	144	163	
4 COLUSA	146	134	143	171	143	162	159	171	177	161	153	175	
5 BEL BUTTE CH	145	133	143	178	150	157	160	223	243	216	198	194	
6 ABOVE CBD	145	133	143	178	150	157	168	223	243	218	201	194	
7 BELOW CBD	190	175	146	198	171	188	299	333	346	293	275	247	
8 FEATHER-NIC	111	115	118	115	102	93	69	82	122	135	129	110	
9 VERONA	159	156	137	183	148	149	203	241	301	297	268	172	
10 AMERICAN-SAC	70	72	66	83	83	73	77	71	63	65	72	86	
11 SACRAMENTO	161	161	140	180	145	164	215	225	229	224	212	168	
12 FREEPORT	174	175	151	187	148	168	223	235	239	231	219	181	

SALT LOADING IN 100 TONS

ID STATION	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
1 KESWICK OUT	384	395	440	191	929	336	282	609	639	1049	1013	399	6664
2 RED BLUFF DU	463	493	643	837	1521	582	546	802	805	1144	1072	451	9358
3 HAMILTON CTY	384	454	717	1278	1979	653	512	612	716	854	804	413	9368
4 COLUSA	438	467	719	1498	2277	628	508	559	632	871	787	452	9827
5 BEL BUTTE CH	446	475	728	1678	2646	662	583	846	1013	1308	1123	548	12055
6 ABOVE CBD	428	388	588	1742	2646	599	381	558	658	1093	956	470	10499
7 BELOW CBD	655	614	606	2134	3377	746	1206	1383	1563	2003	1746	691	16724
8 FEATHER-NIC	247	198	221	539	1584	736	222	284	299	240	273	333	5177
9 VERONA	902	810	825	2174	3318	2079	1476	1884	1961	2388	2087	885	20789
10 AMERICAN-SAC	64	55	81	116	295	117	62	99	164	249	249	121	1671
11 SACRAMENTO	1016	908	1039	1942	3308	2827	1948	1702	1565	2351	2096	989	21676
12 FREEPORT	1121	1013	1144	2047	3405	2932	2045	1807	1678	2456	2201	1094	22936

TABLE 11. ESTIMATED 1998 MONTHLY FLOW, MEAN CONDUCTIVITY AND SALT LOADING IN SACRAMENTO RIVER SYSTEM
1938 HYDROLOGY

FLOW IN 1000 ACRE FEET

ID STATION	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
1 KESWICK OUT	297	232	221	168	2810	887	1008	957	496	641	658	302	7869
2 RED BLUFF DD	355	636	896	434	2977	2021	1442	1314	819	693	669	329	12385
3 HAMILTON CTY	300	767	1323	639	3357	2573	1627	1427	415	427	385	272	13512
4 COLUSA	311	789	1294	598	3613	2853	1421	1302	268	369	334	282	13434
5 BEL BUTTE CR	318	822	1419	677	3810	3026	1491	1403	352	437	388	299	14442
6 ABOVE CBD	311	799	1390	636	3782	2985	1395	1295	138	249	249	244	13473
7 BELOW CBD	395	904	1515	723	4011	3119	1553	1437	314	424	483	284	15082
8 FEATHER-NIC	225	225	1190	530	1239	2098	1384	1467	911	369	363	530	10531
9 VERONA	620	758	1747	1303	3795	2777	1933	2232	1272	836	799	813	18885
10 AMERICAN-SAC	86	49	129	151	300	688	261	418	522	301	184	146	3235
11 SACRAMENTO	711	824	1393	1345	3791	3082	1933	2482	1751	986	837	871	19926
12 FREEPORT	726	839	1408	1360	3806	3097	1948	2417	1766	1001	852	886	20106

CONDUCTIVITY IN MICROMHOS

ID STATION	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
1 KESWICK OUT	116	117	122	121	114	118	116	123	117	121	117	117	
2 RED BLUFF DD	125	124	125	169	109	107	128	129	126	130	125	129	
3 HAMILTON CTY	147	172	132	185	116	116	130	136	189	216	206	197	
4 COLUSA	160	176	137	193	121	124	140	145	204	223	214	207	
5 BEL BUTTE CR	159	179	141	199	125	126	136	159	311	322	302	276	
6 ABOVE CBD	159	179	141	199	125	126	136	159	311	322	302	276	
7 BELOW CBD	192	214	159	216	138	137	170	195	534	508	465	276	
8 FEATHER-NIC	131	166	116	118	104	90	93	88	92	112	117	109	
9 VERONA	170	204	144	182	132	122	134	150	233	357	328	147	
10 AMERICAN-SAC	69	94	68	78	83	70	68	67	61	65	73	87	
11 SACRAMENTO	161	202	140	173	138	112	127	137	186	278	282	158	
12 FREEPORT	172	211	146	179	133	115	132	141	190	284	289	167	

SALT LOADING IN 100 TONS

ID STATION	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
1 KESWICK OUT	344	272	269	193	2289	1046	1165	1177	581	776	769	352	9234
2 RED BLUFF DD	443	789	1120	733	3238	2154	1858	1699	778	908	835	423	14963
3 HAMILTON CTY	441	1316	1749	1181	3902	2984	2115	1936	786	922	793	537	18683
4 COLUSA	497	1391	1774	1152	4387	3544	1992	1887	547	825	714	585	19296
5 BEL BUTTE CR	506	1474	1996	1350	4766	3823	2034	2228	1094	1406	1173	678	22526
6 ABOVE CBD	495	1433	1958	1265	4732	3775	1903	2057	429	801	753	552	20152
7 BELOW CBD	759	1932	2404	1562	5518	4269	2433	2800	1675	2153	1873	784	28361
8 FEATHER-NIC	294	373	1375	627	1289	1899	1283	1298	843	415	426	578	10700
9 VERONA	1053	1547	2518	2375	5007	3378	2581	3338	2966	2982	2622	1359	31726
10 AMERICAN-SAC	60	46	87	117	249	479	179	281	320	196	135	127	2275
11 SACRAMENTO	1146	1668	1950	2329	4939	3447	2463	3300	3258	2737	2361	1373	30973
12 FREEPORT	1251	1773	2055	2434	5044	3552	2568	3405	3383	2842	2466	1478	32233

SENSITIVITY ANALYSES

A final phase of this study was an additional series of computer runs performed to test the model's degree of response, or sensitivity, to varying magnitudes of certain input data. These additional runs were expected to provide 1) a guide to those areas where further refinement of the model might be justified and 2) an indication of the probable range of computed EC values in the river. The first step was to determine how sensitive the model was to those variables which have the widest range of probable values. As brought out by this study, those variables are the quantities and qualities of valley floor accretions. A second step was to test the sensitivity of the model to municipal and industrial waste discharges.

Valley Floor Accretions

Historically, the probable quantities of valley floor accretions, although widely variable, appeared more reliable in their determinations than did the probable qualities (EC's). Accretion quantities could be related to probable return flows from precipitation and applied irrigation water in each hydrographic area. Although accretion EC could be related to the estimated salt input of the source waters, there was no firm basis for estimating how much of these salts would be returned to the stream during any given month.

In the first sensitivity runs, therefore, accretion EC values were varied with respect to EC values used in the original computer runs. These included runs for the 1990 level of development under each of the three hydrologic conditions--1931, 1936 and 1938. The previous EC's of all major accretions in the system, those occurring in Reaches B, D, F, G and H (Figure 1), were multiplied by factors (C) of 0.5, 0.9, 1.1 and 1.5 for the three hydrologic conditions.

Figures 16 through 21 show the monthly results at Colusa and Freeport for each year with C = 0.9, 1.0 and 1.1. Figure 17, in addition, shows values for C = 0.5 and 1.5. The 0.5 and 1.5 C factors were used, not to produce a probable range of values, but to show the overall response of EC in the river to accretion EC's.

The results of the sensitivity runs with C = 0.9 and 1.1 could be viewed as a possible range of predicted EC at the river stations. This range would be based on the assumption that each accretion EC value as estimated for the original runs had a probable error of ±10 percent. A more statistically reliable range could be obtained by reexamining each individual accretion EC value as to its probable range of accuracy and then running the model, using first the low range and then the high range for each EC. Undoubtedly some of the original values are considerably more accurate than others and a blanket 10 percent probable error for each EC value is not realistic. However, a lack of time during this study prevented a more detailed evaluation.

The figures clearly display the significance of valley floor accretions during the irrigation season, which is evidenced by the wider spread between each month's values for April through September. The sharp response of the river EC, with accretion EC values varying ±50 percent (Figure 17), shows that the quality of the river can be profoundly influenced by the quality of the accretions.

The results of these runs justify additional study to more accurately evaluate both quantity and quality of valley floor accretions.

Municipal and Industrial Waste Discharges

Sensitivity runs also were made to test the effects on river quality of municipal and industrial waste discharges. In these runs, all 1990 flow quantities of M&I wastes for 1931 and 1936 hydrology as originally used were doubled. EC values were held at the constant 700 micromhos, a value based upon recorded data for the City of Sacramento sewage treatment plant that probably will not change significantly.

With the original M&I waste flows doubled, the annual flow-weighted average EC for 1931 hydrology in the Sacramento River at Freeport increased from 221 to 237 micromhos, or 7.2 percent. For 1936 hydrology, the increase was from 188 to 193 micromhos, or 2.7 percent. Results for individual months are shown in Table 12.

TABLE 12. EFFECTS OF DOUBLING MUNICIPAL AND INDUSTRIAL WASTE FLOWS ON 1990 EC, SACRAMENTO RIVER AT FREEPORT

(EC in micromhos at 25° C)

Month	Using Original M&I Waste Flows		Using 2 x Original M&I Waste Flows	
	1931	1936	1931	1936
OCT	176	174	196	182
NOV	167	175	186	183
DEC	149	151	165	158
JAN	223	187	238	192
FEB	195	148	213	150
MAR	159	168	172	171
APR	362	223	381	228
MAY	317	235	332	240
JUN	299	239	315	244
JUL	298	231	311	235
AUG	259	219	273	223
SEP	171	181	187	189

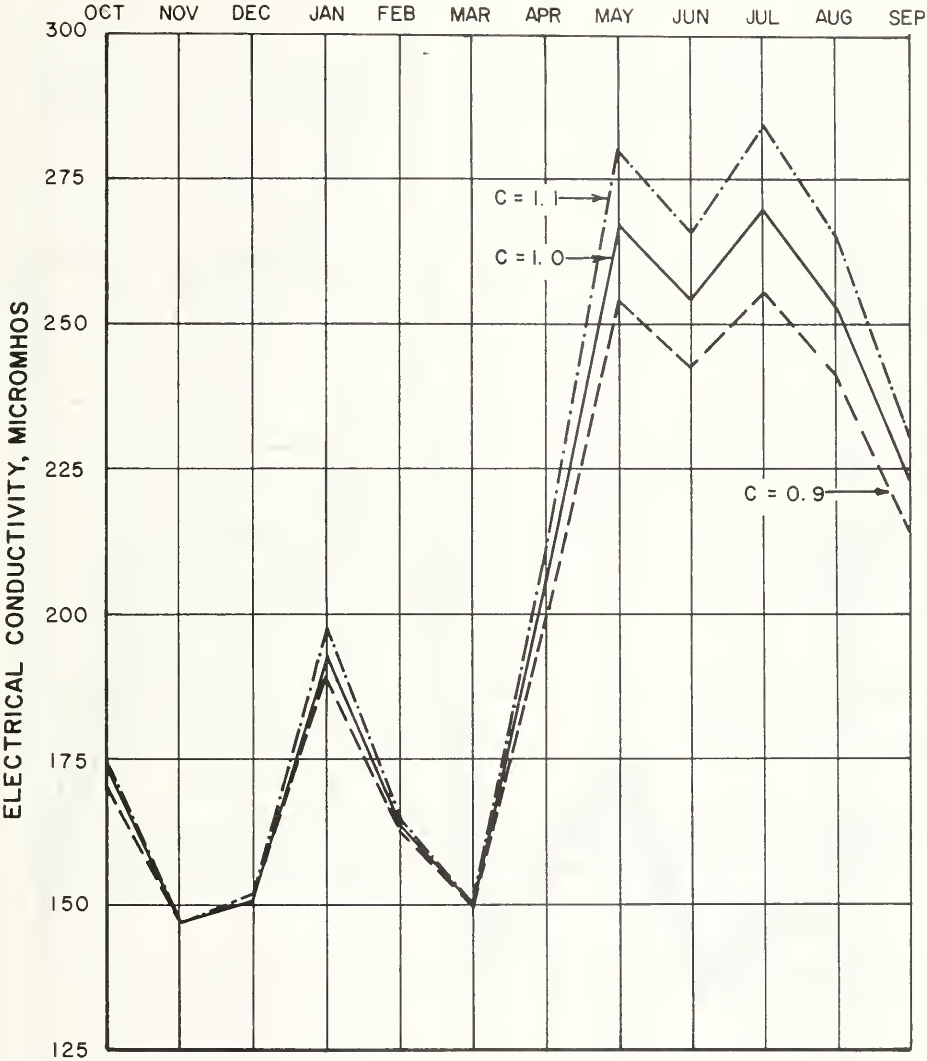

Figure 16. SENSITIVITY ANALYSIS, SACRAMENTO RIVER AT COLUSA, 1990 LEVEL, 1931 HYDROLOGY

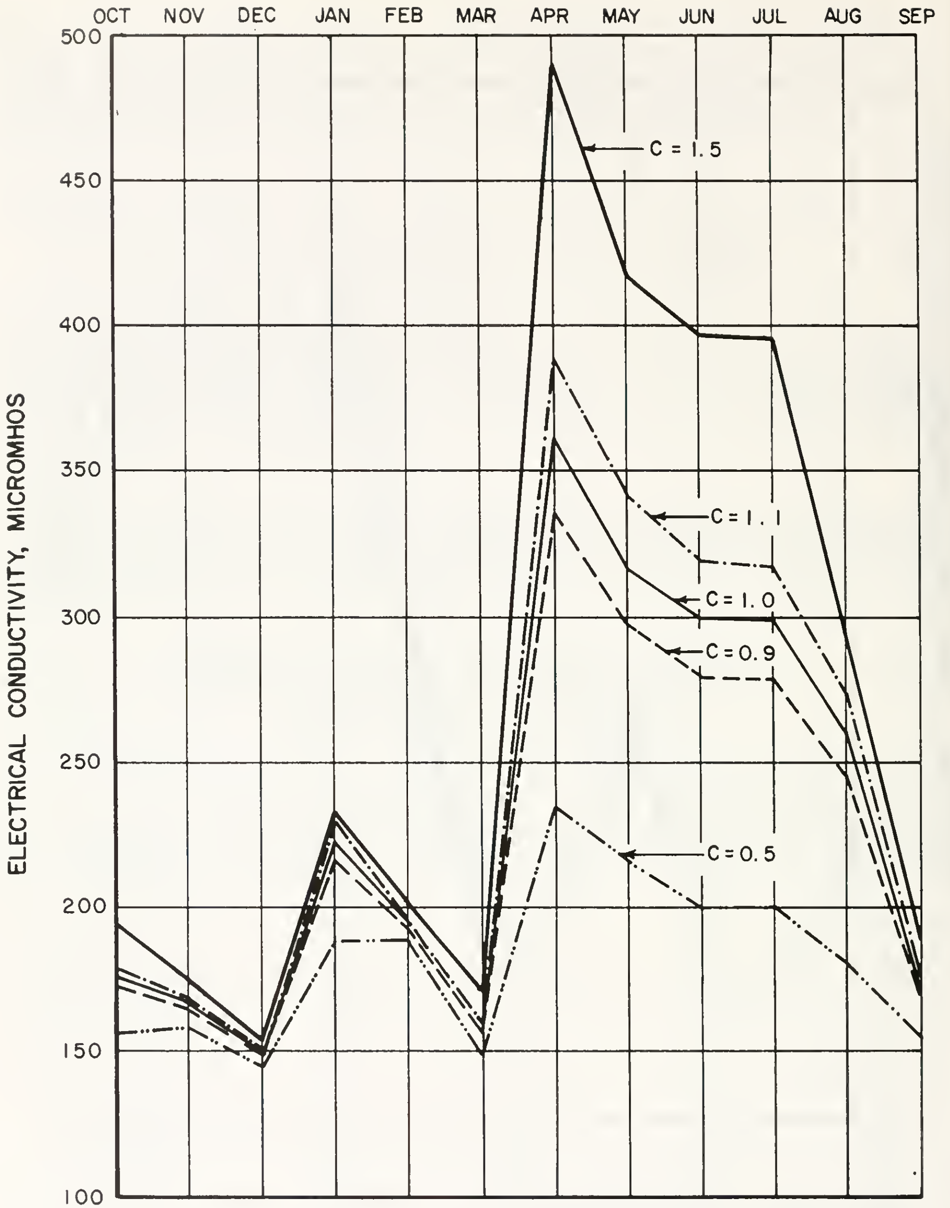

Figure 17. SENSITIVITY ANALYSIS, SACRAMENTO RIVER AT FREEPORT, 1990 LEVEL, 1931 HYDROLOGY

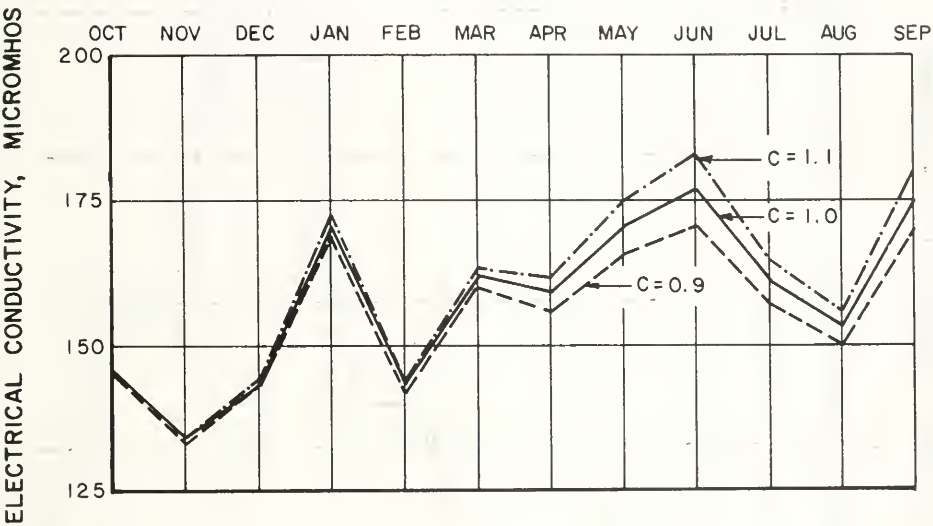

Figure 18. SENSITIVITY ANALYSIS, SACRAMENTO RIVER AT COLUSA, 1990 LEVEL, 1936 HYDROLOGY

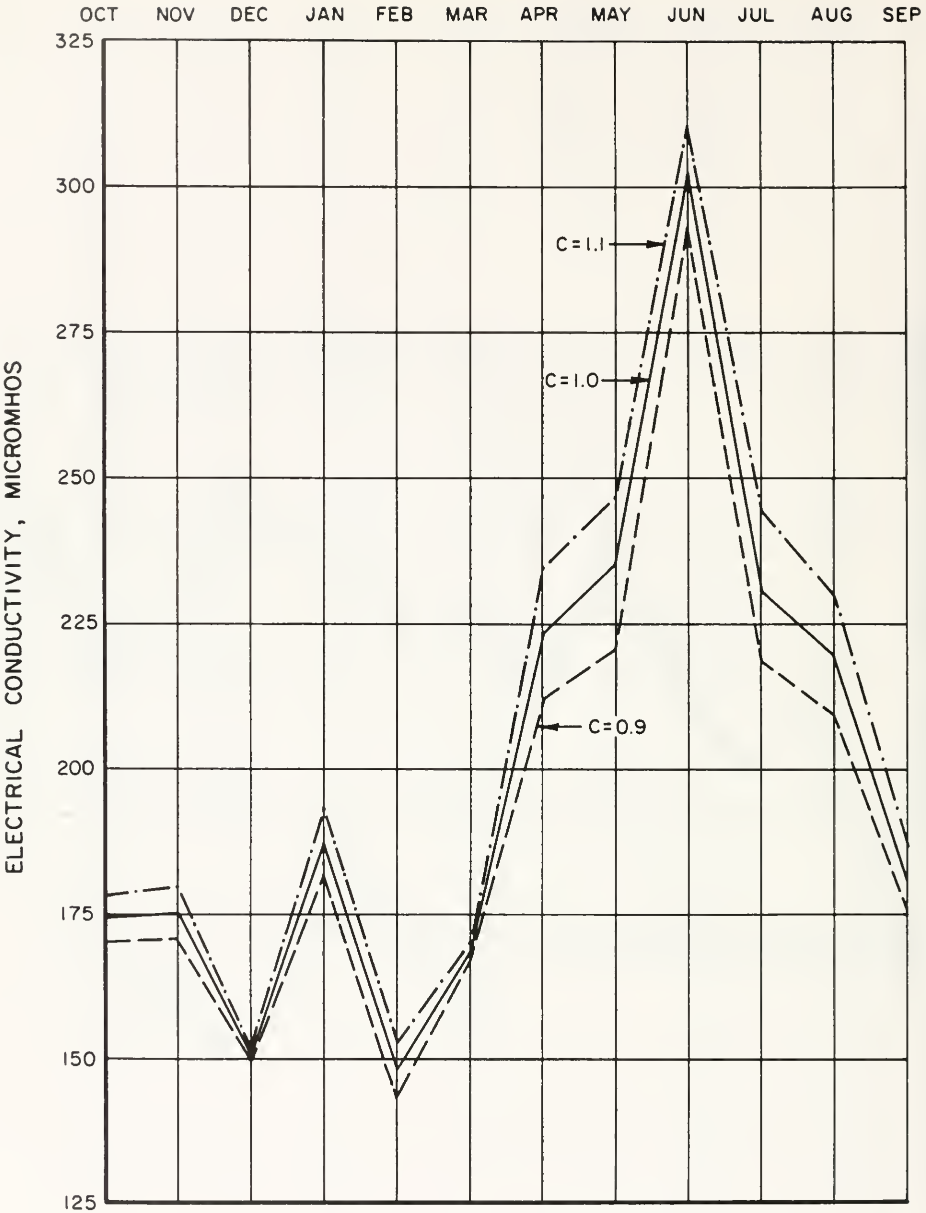

Figure 19. SENSITIVITY ANALYSIS, SACRAMENTO RIVER AT FREEPORT, 1990 LEVEL, 1936 HYDROLOGY

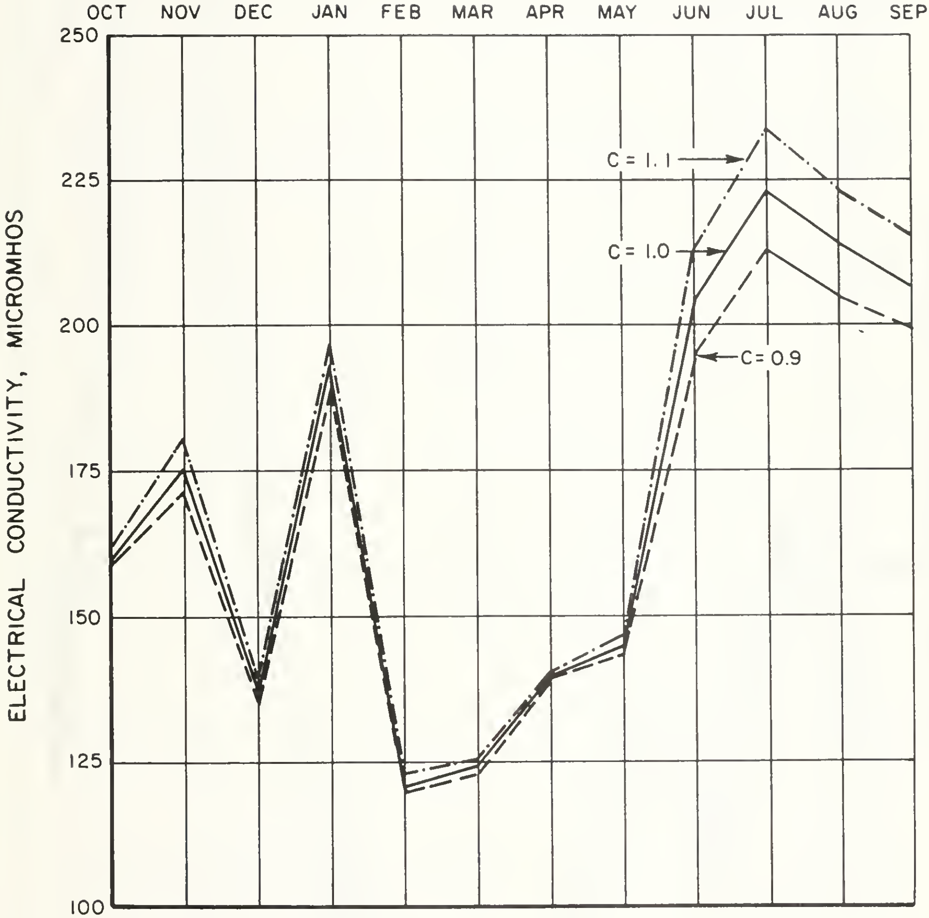

Figure 20. SENSITIVITY ANALYSIS, SACRAMENTO RIVER AT COLUSA, 1990 LEVEL, 1938 HYDROLOGY

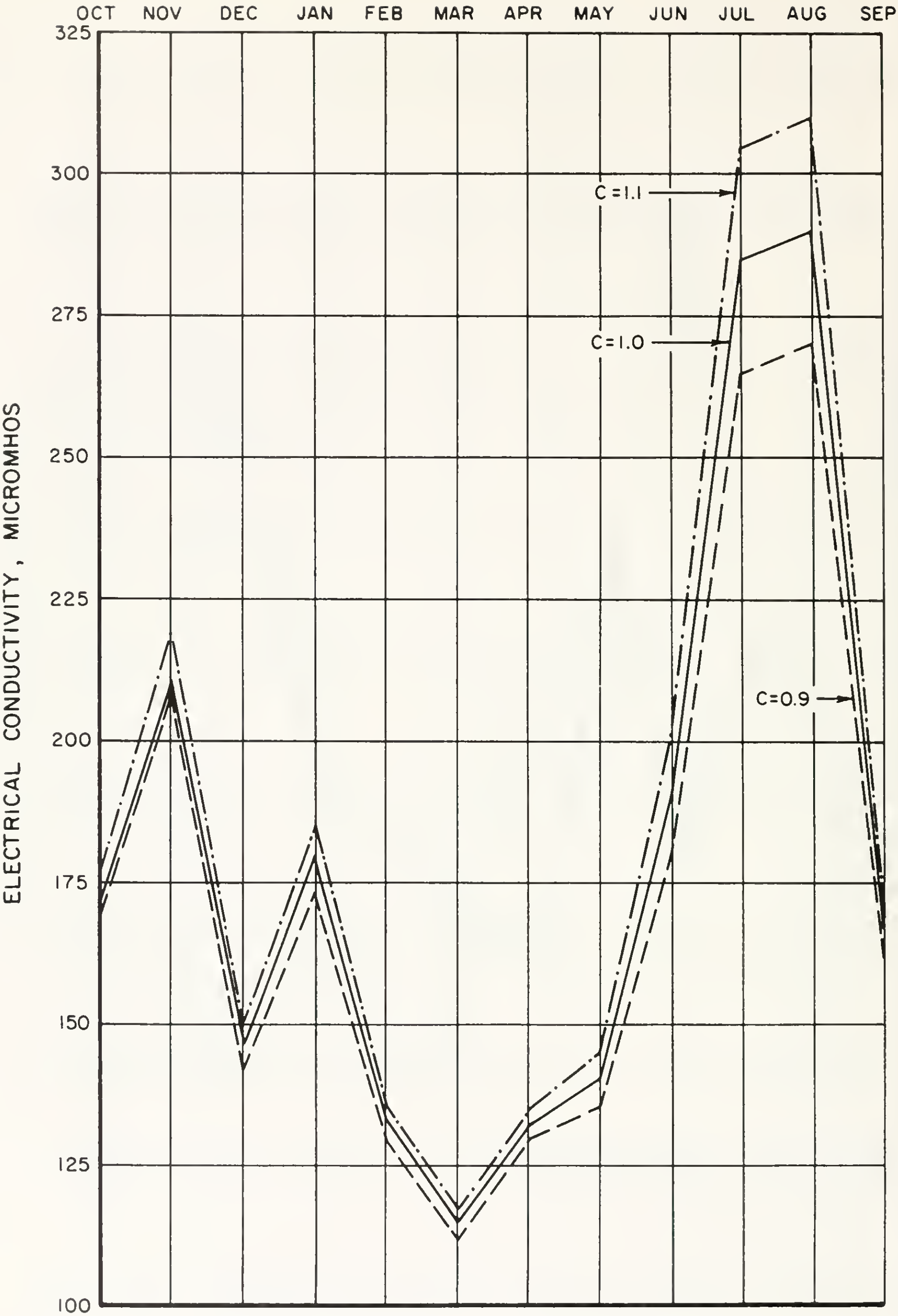

Figure 21. SENSITIVITY ANALYSIS, SACRAMENTO RIVER AT FREEPORT, 1990 LEVEL, 1938 HYDROLOGY

APPENDIXES

APPENDIX A

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(22) ____. "Surface Water Supply of the United States." Water-Supply Paper 1715, Part II. Series.

The following publications were of especial value in preparing this report.

(23) California State Department of Water Resources. "A Machine Program to Estimate Monthly Consumptive Use and Water Requirements." Office Report. November 1967.

This program is commonly referred to as the C.U.-2 Program.

(24) ______. "Estimated 1990 Mineral Quality of Water in the Sacramento River Based on Dry Period (1931-34) Hydrology." Office Report. November 1967.

(25) ______. "Predicted 1990 Mineral Quality of Water in the Sacramento River with Emphasis on the Effects of Agricultural Drainage." Office Report. November 1966.

(26) ______. "Sacramento River Water Pollution Survey." Bulletin No. 111. Appendix A, "Hydrography, Hydrology and Water Utilization and Appendix B, "Water Quality". August 1962.

(27) ______. "Water Quality Management of the State Water Project, Central Valley Portion, Part I: Sacramento Valley." Office Report. June 1965.

APPENDIX B

RESERVOIR COMPUTATIONAL METHODS

Two basic approaches were employed by the 1965 model to predict the mineral content of reservoir outflow. Earlier in this report computational methods were expressed verbally but mathematical equations were omitted for the sake of brevity. This appendix presents the mathematical equations for each approach. These are identified as Method 1 and Method 2.

Method 1

The quality of reservoir releases was assumed equal to the quality of water in storage, determined by successively mixing the flow-weighted average quality of inflow for each month with the average quality of water in storage for that month, and then allowing for a one-month flow-through time in the reservoir. The inflow quality is computed by the C/Q equation (see "The 1965 Model"), and the initial quality of water in storage is assumed equal to the quality of inflow for the month preceding the initial month of consideration.

In Method 1, a weighted average is obtained of the quality of the inflow, storage, and outflow. The quantity of the total inflow into the reservoir may be calculated from the following equation.

$$I = \Delta S + E + D + O \qquad \text{Eq. (B1)}$$

where:

- I = average monthly inflow in cfs;
- ΔS = change in end-of-month storage in cfs per month;
- E = average monthly evaporation rate in cfs;
- D = average monthly diversions out of the reservoir in cfs; and
- O = average monthly outflow in cfs.

The quality of the total inflow may be assumed equal to the weighted average of the measured (or calculated) quality of all the tributaries.

$$C_m = \frac{\sum_{j=1}^{n} (cq)_j}{\sum_{j=1}^{n} q_j} \qquad \text{Eq. (B2)}$$

where:

C_m = specific conductance (EC) of the total inflow for any month under consideration;

q = average monthly discharge of a tributary in cfs;

c = monthly EC from C/Q equation;

n = number of tributaries; and

j = any tributary

The data obtained from Equation (B2) are used as input data for Equation (B3), where it is assumed that the quality of outflow for a given month is equal to the quality of the water in storage for the previous month; that is, the outflow for one month occurred before the inflow for that month affected the quality of the water in storage.

The equation is:

$$C(1)_m = \frac{C(1)_{m-1}\ (S_{m-1} - O_m - D_m) + C_m I_m}{S_m} \qquad \text{Eq. (B3)}$$

where:

$C(1)$ = monthly specific conductance obtained from Method 1;

S = end-of-month storage in terms of flow in cfs required to produce the given storage in one month;

O = mean monthly outflow in cfs;

D = mean monthly diversions in cfs;

I = mean monthly inflow from Equation (B1);

C = average specific conductance of the total inflow from Equation (B2);

m = month of consideration; and

$m-1$ = month preceding m.

In Equation (B3) the original $C(1)_{m-1}$ value may be any reasonable, easily obtained value, since any error caused by an incorrect initial value diminishes progressively in calculations for following months.

Method 2

The quality of reservoir releases was assumed equal to the quality of water in storage, determined by the running average of mean monthly inflow quality, weighted according to flow, over a period of time in which the total volume of outflow during the period equaled or exceeded the volume of storage at the end of the period.

In Method 2 a weighted average of the inflow is averaged over a time period determined by comparing the reservoir content with the reservoir outflow. The period may be determined for each month by adding the total outflow (diversions, evaporation, and reservoir releases) for the month under consideration to the total outflow for the proper number of consecutive months which immediately precedes the month under consideration. The number of months comprising the time period should have been determined when the total volume of the monthly outflows equals, or just exceeds, the volume of water in storage at the end of the month under consideration. This procedure is expressed in the following equation.

$$S_m \leqq \sum_{i=x}^{m} (O + E + D)_i \qquad \text{Eq. (B4)}$$

where:

S = end-of-month storage in terms of the flow in cfs required to produce the given storage in one month;

O = mean monthly outflow in cfs;

E = mean monthly evaporation rate in cfs;

D = mean monthly diversions in cfs;

i = any month during the period of consideration;

m = calendar number of the month under consideration; and

x = calendar number of the month at the beginning of the period of consideration.

Equation (B4) must be solved for "x", which defines the period under consideration. Where the period under consideration spans two consecutive years, the numerical values assigned to the months in the succeeding year should be assigned a value of 12 plus their normal value; that is, January, m = 13. The quality of water in the reservoir, and consequently the quality of the outflow, may be assumed equal to the weighted average of the measured (or calculated) quality of the inflows from the tributaries during the period of consideration. The following equation is developed to calculate the specific conductance according to Method 2, the running-average method, based on outflow.

$$C(2)_m = \frac{\sum_{j=1}^{n} \sum_{i=x}^{m} (cq)_{ji}}{\sum_{j=1}^{n} \sum_{i=x}^{m} (q_j - E)_i} \qquad \text{Eq. (B5)}$$

where:

$C(2)$ = EC determined by Method 2;

c = monthly EC of a tributary, taken from the C/Q equation;

q = mean monthly flow of the tributary in cfs;

E = average monthly evaporation rate in cfs;

n = number of tributaries;

m = calendar number of the month under consideration;

x = calendar number of the month at the beginning of the period of consideration from Equation (B4);

i = any month during the period of consideration; and

j = any tributary.

APPENDIX C

HISTORIC AND FUTURE LAND USE

The current water quality model discussed in this report depends for its operation on information developed through several side models. One of these is the CU-2 model that provides basic information on the consumptive impairments of various Sacramento Valley stream systems that are created by changes in agricultural and urban land use. Land use data presented in the following tables are those that were used as input to the CU-2 model.

Land use information for water year 1955 and 1961 were developed by the Department, while that for 1931, 1936, and 1938 were synthesized by the Bureau of Reclamation, mainly from older census data. The future land use projections to the year 1990 were excerpted from file data prepared by the Department's Coordinated Statewide Planning Program.

The Department's 1955 and 1961 land use surveys were made by field personnel who mapped on 1:20,000 scale aerial photographs. The data were later transferred to 1:24,000 scale USGS quadrangle sheets where planimetric measurements of over 70 different agricultural crops and numerous related urban land uses were made.

Area numbers shown in the following tables refer to depletion study hydrographic units shown on Plate 1. Areas 15W and 15E refer to those portions of Area 15 lying west and east, respectively, of the Sacramento River.

1931 Land Use Input
(In 1000s of Acres)

Crop	Area 4	Area 10	Area 12+15W	Area 13+15E	Area 21
Pasture	20.9	19.7	21.6	17.1	29.2
Alfalfa	1.5	9.7	8.6	12.1	12.2
Sugar Beets	--	--	--	--	1.8
Field Crops	0.9	2.4	13.8	40.4	13.1
Rice	--	--	50.8	51.2	8.0
Misc. Truck	0.3	0.5	5.9	4.6	3.4
Tomatoes	--	--	--	--	2.3
Orchard	1.4	14.7	13.6	33.2	38.8
Subtotal	25.0	47.0	114.3	158.6	108.8
Urban	2.7	3.0	1.0	5.0	24.5
Native	107.3	756.4	953.8	667.7	716.0
TOTAL	135.0	806.4	1,069.1	831.3	849.3

1936 Land Use Input
(In 1000s of Acres)

Crop	Area 4	Area 10	Area 12+15W	Area 13+15E	Area 21
Pasture	20.3	19.3	25.0	19.1	25.0
Alfalfa	1.5	9.5	9.9	14.0	10.5
Sugar Beets	--	--	--	--	1.6
Field Crops	0.9	2.3	12.9	32.8	11.3
Rice	--	--	45.8	46.2	7.0
Misc. Truck	0.3	0.5	5.8	4.8	3.0
Tomatoes	--	--	--	--	2.0
Orchard	1.2	14.4	14.6	38.1	33.4
Subtotal	24.2	46.0	114.0	155.0	93.8
Urban	2.7	3.0	1.0	6.0	27.3
Native	108.1	757.4	954.1	670.3	728.2
TOTAL	135.0	806.4	1,069.1	831.3	849.3

1938 Land Use Input
(In 1000s of Acres)

Crop	Area 4	Area 10	Area 12+15W	Area 13+15E	Area 21
Pasture	19.7	19.3	26.8	19.4	23.6
Alfalfa	1.4	9.5	10.5	14.2	9.9
Sugar Beets	--	--	--	--	1.5
Field Crops	0.9	2.3	13.1	32.0	10.6
Rice	--	--	41.2	44.8	6.0
Misc. Truck	0.3	0.5	5.9	4.9	2.8
Tomatoes	--	--	--	--	1.9
Orchard	1.2	14.4	15.4	38.8	31.5
Subtotal	23.5	46.0	112.9	154.1	87.8
Urban	2.7	3.0	1.0	6.0	28.7
Native	108.8	757.4	955.2	671.2	732.8
TOTAL	135.0	806.4	1,069.1	831.3	849.3

1955 Land Use Input
(In 1000s of Acres)

Crop	Area 4	Area 10	Area 12+15W	Area 13+15E	Area 21
Pasture	21.0	41.2	52.5	43.8	54.5
Alfalfa	1.5	17.2	43.4	15.8	18.7
Sugar Beets	--	0.9	11.4	6.5	1.5
Field Crops	0.8	21.0	13.5	58.4	14.9
Rice	--	0.3	120.8	129.7	49.2
Misc. Truck	0.2	0.6	2.7	7.9	6.7
Tomatoes	--	--	4.1	5.6	2.3
Orchard	1.1	25.9	18.2	73.9	43.6
Subtotal	24.6	107.1	266.6	341.6	191.4
Urban	8.4	9.4	2.8	14.2	79.2
Native	102.0	689.9	799.7	475.5	770.1
TOTAL	135.0	806.4	1,069.1	831.3	849.3

1961 Land Use Input
(In 1000s of Acres)

Crop	Area 4	Area 10	Area 12+15W	Area 13+15E	Area 21
Pasture	22.3	54.2	54.7	29.1	62.9
Alfalfa	1.5	16.2	38.1	16.2	16.5
Sugar Beets	--	--	14.8	8.0	1.8
Field Crops	0.9	20.7	25.0	6.3	13.7
Rice	--	--	111.9	113.2	38.3
Misc. Truck	0.3	--	3.0	3.9	3.8
Tomatoes	--	--	6.3	9.5	2.6
Orchard	1.8	32.8	26.5	84.8	39.9
Subtotal	26.8	123.9	280.3	271.0	179.5
Urban	11.6	11.4	6.0	15.8	104.0
Native	96.6	671.1	782.8	544.5	565.8
TOTAL	135.0	806.4	1,069.1	831.3	849.3

1990 Land Use Input
(In 1000s of Acres)

Crop	Area 4	Area 10	Area 12+15W	Area 13+15E	Area 21
Pasture	32.0	47.8	37.1	24.3	68.2
Alfalfa	3.1	31.2	36.8	19.8	14.8
Sugar Beets	--	5.3	20.4	11.1	2.8
Field Crops	2.4	33.7	52.8	45.6	19.7
Rice	--	--	179.3	192.5	49.3
Misc. Truck	0.7	1.2	6.1	6.8	4.7
Tomatoes	0	1.4	8.3	14.8	4.1
Orchard	5.3	56.9	43.0	121.3	64.5
Subtotal	43.5	177.5	383.8	436.2	228.1
Urban	28.1	19.7	6.0	23.9	162.2
Native	63.4	609.2	679.3	371.2	459.0
TOTAL	135.0	806.4	1,069.1	831.3	849.3