SALINITY, ALKALINITY, AND DISSOLVED AND PARTICULATE ORGANIC CARBON IN THE SACRAMENTO RIVER WATER AT RIO VISTA, CALIFORNIA, AND AT OTHER LOCATIONS IN THE SACRAMENTO-SAN JOAQUIN DELTA, 1980

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Metric to Inch-Pound Conversion Table

Multiply SI units	by	to obtain inch-pound units
kilometer	0.6214	mile
meter	3.281	feet
liter	1.057	quart
cubic meter	264.2	gallon
cubic meter per second	35.31	cubic foot per second
gram	0.03527	ounce

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ABSTRACT

The salinity, alkalinity, dissolved organic carbon (DOC) and particulate organic carbon (POC) concentrations in the Sacramento River water at Rio Vista were measured every 3 to 5 days during 1980 as part of an effort to identify time-dependent variations in the composition of the fresh water flow from the Sacramento-San Joaquin Delta to San Francisco Bay. Concentration ranges were generally small compared to the seasonal range of river flow rate. Thus, transport rates to the Delta and to the Bay varied primarily as a function of flow rate. Even though the tributaries of the Sacramento River are managed by large reservoirs, winter concentration variations are similar to those that have been described in natural unregulated river systems. Because of dilution by surface runoff, salinity and alkalinity are lower when river flow increases during winter storms, whereas DOC and POC concentrations are generally higher during winter.

River flow rates and compositions during spring through mid-fall are generally the result of reservoir and water-project management practices. Releases from the major reservoirs on the Sacramento River tributaries resulted in sometimes-large variations in the salinity and alkalinity at Rio Vista. Late summer concentrations were high because of high inflow rates of agricultural waste waters. POC and DOC concentrations varied in response to small storms during spring and late-fall; concentrations were generally lowest during summer.

Fresh water inflow from the San Joaquin River increased during late summer, changing the distributions of salinity and alkalinity in the Delta. Salinity and alkalinity were highest in the east Delta during early summer. Higher flows and decreased water project demands during late summer decreased salinity and alkalinity in the east Delta, while salinity and alkalinity increased in the west Delta due to the influences of agricultural waste water inflows.

INTRODUCTION

Fresh water from the Sacramento-San Joaquin River Delta (Delta outflow) constitutes about 90 percent of the total annual fresh water flow to San Francisco Bay and accounts for most of the transport of riverine dissolved and particulate substances to the Bay (see Conomos 1979 for a summary of the hydrology of San Francisco Bay; Conomos and others 1979). Interdisciplinary field studies of the Bay estuarine system conducted by the U.S. Geological Survey during 1980 required estimates of riverine transports to the Bay and measurements of time-dependent variations in Delta outflow composition. As part of this effort, Sacramento River water was sampled every 2 to 5 days at Rio Vista and Delta waters at other locations were sampled 3 times during summer (fig. 1; appendix table A). Samples were analyzed for salinity (electrical conductance), alkalinity, and dissolved and particulate organic carbon (DOC and POC, respectively). This report presents 1) the numerical values for these analyses, 2) estimates of the transports of these substances by the Sacramento River, 3) plots of the results that illustrate seasonal variations in composition, and 4) a descriptive interpretation of the results that identifies the most probable causes for Delta outflow composition variations.

Delta Outflow Rate and Composition Estimates

The rate of Delta outflow to the Bay cannot be directly measured and, similarly, the composition of the Delta outflow cannot be determined by sampling at any one location over the entire hydrologic year. The accuracies of transport estimates are limited by the potentially large uncertainties in the Delta outflow rate and composition estimates. Estimates of Delta outflow rate are based on the river flow rates to the Delta (Delta inflow) and the sum of the consumption in the Delta and export to State and Federal water projects (total demand). The Delta outflow index (DOI) is a daily estimate prepared by the U.S. Bureau of Reclamation (USBR), that accounts for the flows of the major river systems (Sacramento and San Joaquin) and the total demand. A more accurate estimate can be prepared by adding the flows of four smaller rivers that enter the east side of the Delta (east-side rivers) and the flow that is diverted from the Sacramento River to the Yolo Bypass (fig. 1) during winter (January through March). This diversion prevents flooding in the Sacramento metropolitan area; the water returns to the Sacramento River upstream of Rio Vista. The flows from the east side rivers and Yolo Bypass were 5 and 18 percent, respectively, of the total Delta inflow during 1980. The Sacramento River flow rates given in this report include the flow rates to the Yolo Bypass. Because the flow from the Yolo Bypass to the Sacramento River is not measured, it must be assumed that the return flow is the same as the diverted flow.

According to State of California water-supply criteria, 1980 is considered a "wet" year. The total Delta inflow was $3.9 \times 10^{10} m^3$ and the total Delta outflow was $3.2 \times 10^{10} m^3$ (U.S. Geological Survey 1981a; a monthly

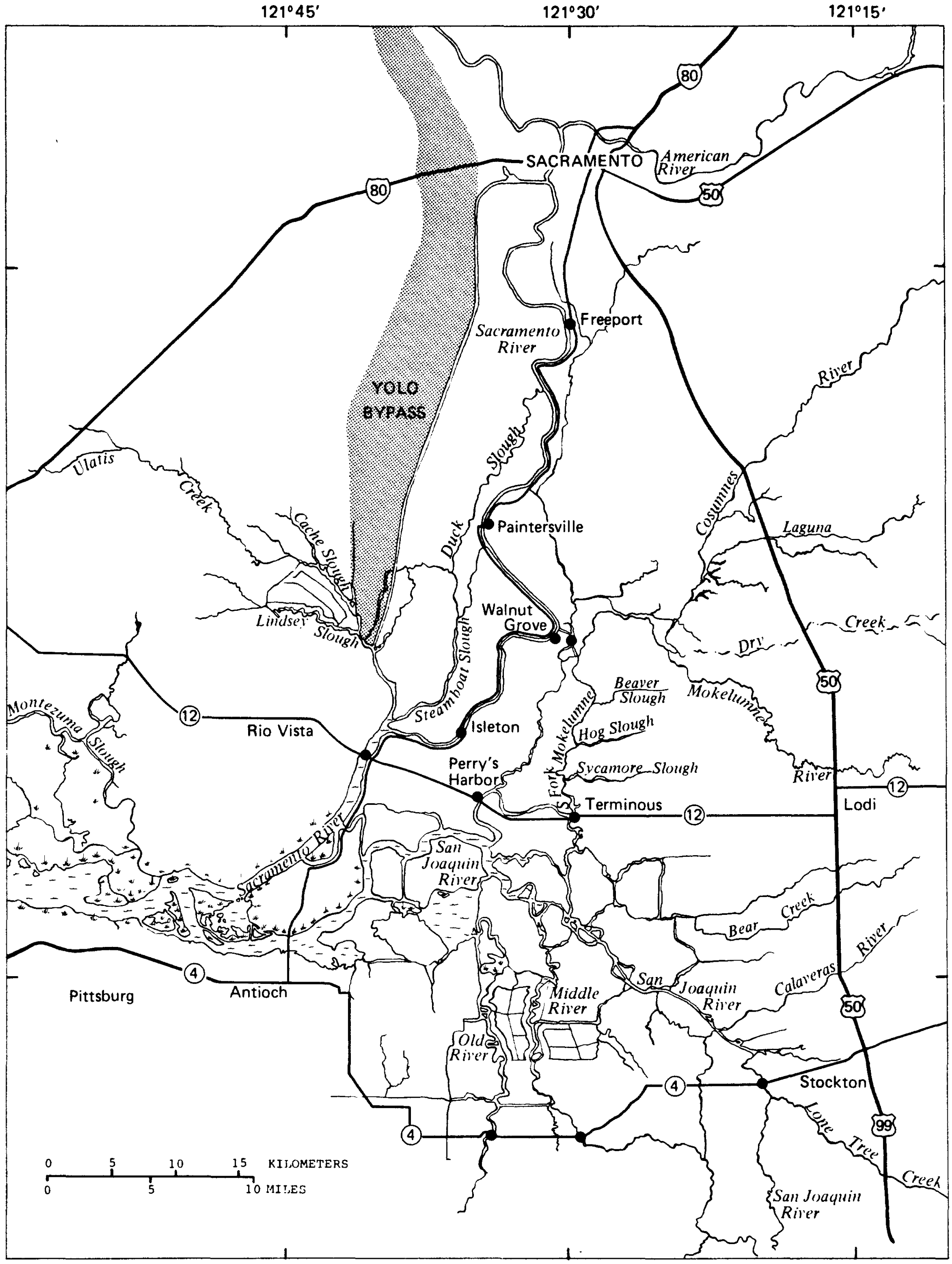

Figure 1. Sacramento-San Joaquin River Delta. Bridge sampling locations are shown by dots. Base taken from U.S.Army Map Service 1:250,000 maps numbers NJ 10-5, NJ10-6, NJ 10-8, and NJ 10-9.

summary of Delta inflows and outflows is given in appendix table B). The Sacramento River is the largest source of fresh water to the Delta, contributing 76 percent of the total Delta inflow during 1980. The second largest river, the San Joaquin, contributed only 19 percent of the 1980 Delta inflow. In addition to the significance of its large annual discharge, the Sacramento River delivers water to the west Delta and therefore contributes an even larger fraction of the flow to the Bay during most times of the year. Thus, it is probable that the composition of the Sacramento River water closely approximates the Delta outflow composition. The Rio Vista bridge was selected as the sampling location because it is downstream of where flow from the Yolo Bypass rejoins the Sacramento River and because brackish water, that is drawn into the Delta during periods of low Delta outflow, rarely extends to Rio Vista. One shortcoming of the Rio Vista location is that an undetermined fraction of the Sacramento River flow enters the Delta from distributary channels (near Walnut Grove; fig. 1) rather than from the main river channel.

Seasonal Variations in Delta Outflow Rate

Estimated daily Delta outflow rates for 1980 are shown in figure 2. Precipitation during late 1979 increased Delta outflow from typically-low fall levels to about $1000 m^3 s^{-1}$ by January 1980. The very large increases in Delta outflow during winter coincide with the occurrence of major storms (individual storm events are related to Sacramento River flow variations in the discussion). Winter Delta outflow was 74 percent of the 1980 total. By April, the Delta outflow rate had decreased to less than $1000 m^3 s^{-1}$, where it remained for the balance of the year. Some spring (April through June) variations in Delta outflow coincide with periods of precipitation, as does the small peak during December. Summer and fall variations in Delta outflow relate primarily to the management of the water projects and other factors that are treated in the discussion.

Delta outflow rate is equivalent to Delta inflow rate minus total demand. Exportation to the water projects constitutes most of the total demand. Total demand accounted for the removal of $7.1 \times 10^8 m^3$ from the Delta during 1980, 18 percent of the total Delta inflow; however, this was not equally distributed throughout the year. Total demand was only 4 percent of the Delta inflow during winter, but was more than half of the Delta inflow from July through November. Total demand exceeded 75 percent of the Delta inflow for the month of August, a volume equivalent to nearly three times the average monthly total demand during winter. Water-quality conditions in the Delta during 1980, as reported by the California Department of Water Resources (1981a), are related to circulation induced by export pumping; the effects are most evident during summer and early fall. San Joaquin River results presented here are discussed with reference to export-induced cross-Delta (north to south) circulation.

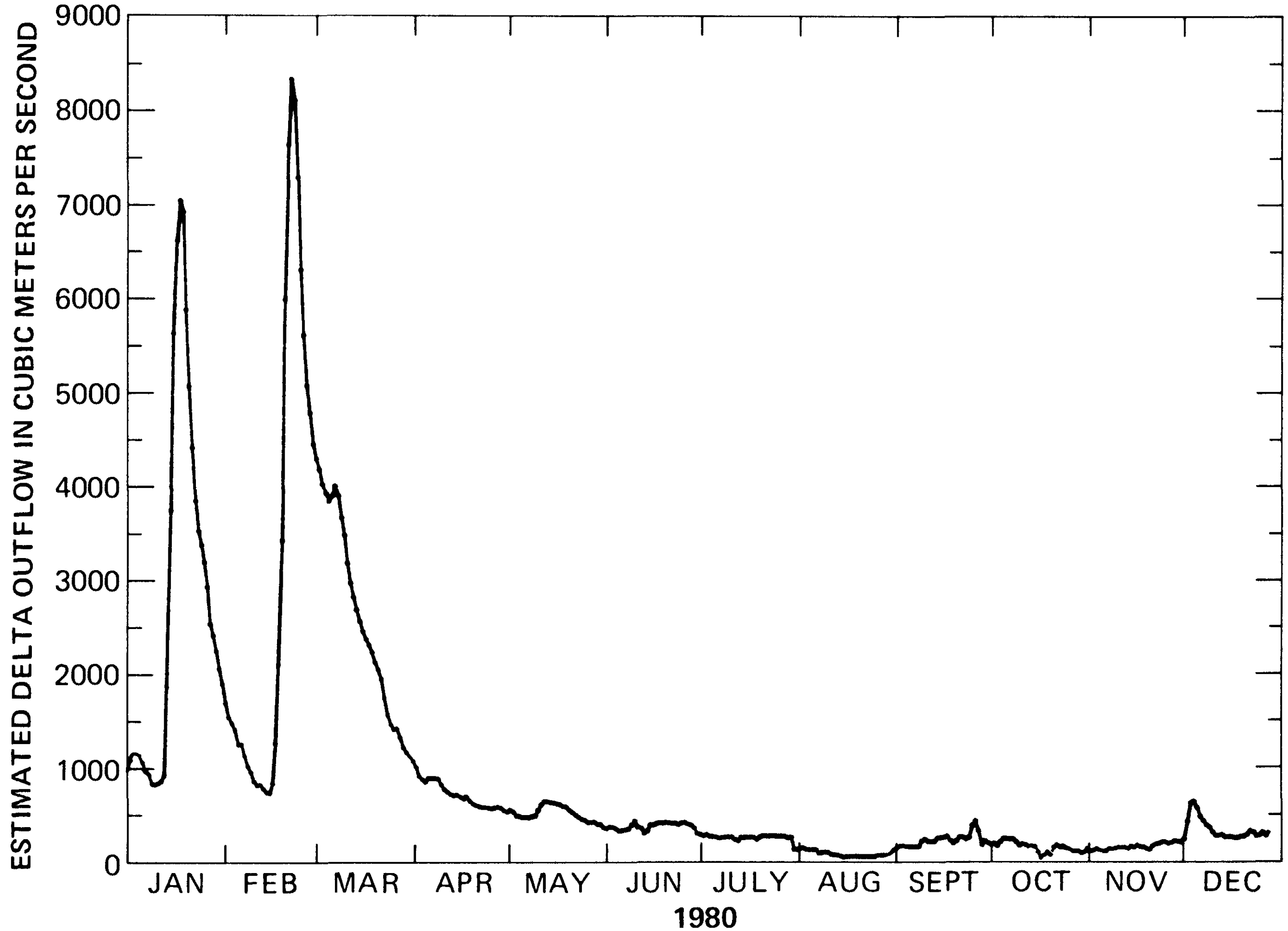

Figure 2. Average daily estimated delta outflow during 1980.

METHODS

Near-surface waters were sampled from the mid-spans of the Rio Vista bridge and other bridges in the Delta with a weighted plastic bucket. The bucket contents were poured into a 1L amber glass bottle (POC and DOC analyses) and a 1L brown plastic bottle (salinity and alkalinity analyses). POC and DOC samples that could not be filtered immediately were refrigerated in the dark. Samples taken from the Rio Vista bridge were stored for up to 10 days before filtration; other bridge samples were filtered on the same day. Additional samples were collected from the U.S. Geological Survey Research Vessel Polaris (R/V Polaris) at a location in the deep channel about 1km downstream from the Rio Vista bridge. These samples were collected with a submersible pump from the 2-m depth and were processed immediately. Locations in the Sacramento and San Joaquin Rivers were sampled from a small boat during mid-summer.

Salinity, Dissolved Solids, and Specific Conductance Methods and Calculations

Samples for salinity analysis were processed and analyzed in the same manner as those samples taken in the higher salinity waters of San Francisco Bay. Salinity is routinely measured during the Bay studies because it is a practical measure of the mixing ratio of fresh and sea waters. Salinity as defined for oceanographic and estuarine studies is not an accurate measure of the mixing ratio or dissolved-solids concentration (DS) of river or low-salinity estuarine waters. The reasons for this were discussed by Cox and others (1967), Connors and Kester (1974), and Lewis and Perkin (1978). The advantages of the salinity measurements in this study are that they relate directly to the Bay measurements and they provide a means of estimating dissolved-solids concentrations; this is described in detail below.

The conductivity ratio of each salinity sample was measured with a high-precision inductive salinometer (RS-7B, Beckman Instruments Inc.[1/]) relative to standard sea water (Instit. of Oceanog. Sciences, England). Samples and standards were contained in a thermostat-controlled water bath prior to analysis. Salinity was calculated from the conductivity ratio using the equations of Cox and others (1967), which are based on the measured chlorinities and conductivities of a set of natural water samples collected at various locations over the globe. Salinity (1.80655 x chlorinity) is related to the conductivity ratio by a fifth-order polynomial expression. The constant in the salinity-conductivity ratio equation (0.090 $^{o}/oo$) compensates for the presence of other dissolved substances when chlorinity is zero and, as such, represents the average river DS at zero chlorinity. Therefore, the negative salinities

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[1/] The mention of brand names is for identification purposes and does not constitute endorsement by the U.S. Geological Survey.

presented in this report indicate that the DS of the river water was less than the average value. Although potentially-large errors can be incurred, DS was estimated by adding 0.090 $^{o}/oo$ to the salinities. The precision of the salinity analyses is on the order of ± 0.003 $^{o}/oo$.

Specific conductance is frequently chosen as a relative measure of DS in river studies. The specific conductances of the salinity samples were estimated by the following method. Conductivity ratios were usually determined within 5°C of 25°C. Conductance at the temperature of the analysis was calculated as the product of the conductivity ratio and the conductance of the standard. The conductance of the standard and its variation with temperature were taken from the data of N. L. Brown as presented by Jaeger (1973). Specific conductances (at 25° C) were calculated by assuming that the effect of temperature on the conductance of the sample was in proportion to that of the standard, an assumption that incurs a small error. This error probably does not exceed 1 to 2 percent because the total temperature correction averaged only 6 percent of the specific conductance value.

Alkalinity, Bicarbonate Ion, and Dissolved Inorganic Carbon Methods and Calculations

Alkalinity (ALK) was determined by potentiometric titration with hydrochloric acid. Samples were titrated in a thermostat-controlled water bath. The bicarbonate endpoint was calculated by the method originally proposed by Gran (1952) and applied to sea water analyses by Dyrssen (1965). The apparatus is similar to that described by Edmond (1970), but with one important exception; the reaction-flask assembly does not include a plunger to accommodate the volume increases resulting from the titrant additions. Rather, an overflow capillary tube allows a volume equal to that of the titrant addition to be expelled from the reaction flask. This flask configuration was chosen because it eliminates the possibility of large errors resulting from pressure effects on the reference electrode junction (D. E. Hammond, University of Southern California, oral communication, 1977). The systematic error was minimized by increasing the titrant normality to 0.5N; the average value of this error for the Sacramento River samples is -0.004 meq L^{-1}. The estimated precision of the method is ± 0.006 meq L^{-1} (one standard deviation) for fresh water samples.

Bicarbonate ion concentrations were estimated from the alkalinity measurements by assuming that all of the alkalinity is attributable to bicarbonate ion. Error due to carbonate ion is negligible but the presence of a miscellaneous alkalinity fraction (Stum and Morgan 1981) would cause the estimates to be high. Dissolved inorganic carbon (DIC) refers to the bicarbonate ion concentration expressed as carbon.

Dissolved and Particulate Organic Carbon Methods

Dissolved and particulate organic carbon were determined by the method of Menzel and Vaccaro (1964; Schemel and Dedini 1979). Sample bottles (1L and 50mL glass) were cleaned with soap and water, rinsed three times with tap water, then air dried. Dried bottles and 10mL glass ampules were capped with aluminum foil and baked at 500°C for 8 hours in order to remove organic contamination. The aluminum foil caps were retained as liners for the plastic caps of the glass bottles. Glass fiber filters, sampling tubes, and purge tubes were baked at 450°C for 4 hours. Purge cones were washed in boiling distilled water then baked at 450°C for 1 hour.

Each POC sample was drawn through a glass sampling tube (inserted into the 1L glass bottle) by a peristaltic pump. The pump discharge was pressure filtered through a 25mm-diameter filtration assembly. Filtrate volume was measured with two 50mL plastic syringes attached to the discharge of the filtration assembly. Filtrate volumes ranged from about 20mL to 100mL, depending on the particle concentration; most were 100mL. Filters were folded, inserted into glass ampules, and frozen for a few hours before sealing. Oxidant (0.2g potassium persulfate) and phosphoric acid solution (10mL of 0.1N) were added to the ampule and CO_2 was purged from the solution with N_2 just before sealing with a torch.

The filtrate was discharged directly from the filter assembly into a 50mL glass bottle for DOC samples. The sample was refrigerated for a few hours before sealing. Concentrated phosphoric acid (0.1mL of 85 percent) was added to each bottle just before 10mL samples were drawn with a glass syringe that had been previously cleaned with hot chromic acid solution. Each 10mL sample was dispensed into a glass ampule containing oxidant. DOC samples were purged of CO_2 and sealed with a torch. The estimated precisions for DOC and POC analyses are $\pm$0.2mg L^{-1} and $\pm$0.1mg L^{-1}, respectively.

RESULTS

Numerical values of salinity, specific conductance, alkalinity, and dissolved and particulate organic carbon at Rio Vista are presented in appendix table C. POC results prior to mid-March were unsatisfactory due to contamination and are not given here. Appendix table D presents the results for samples collected at bridge locations in the Delta. Results from the sampling (by small boat) of the Sacramento and San Joaquin Rivers during summer are given in appendix table E.

Mean Concentration and Fluxes of Solutes and Particulate Organic Carbon at Rio Vista

Monthly flow-weighted mean concentrations of DS, ALK, DOC, and POC are presented in table 1. Annual flow-weighted mean concentrations were calculated for DS, ALK, and DOC. DS measurements made at Rio Vista by DWR (1981b) yield a

Table 1. Volume-weighted average concentrations of dissolved solids (DS), alkalinity (ALK), dissolved organic carbon (DOC), and particulate organic carbon (POC) in near-surface Sacramento River water at Rio Vista, Calif. [$g.L^{-1}$, grams per liter; $meq.L^{-1}$, milliequivalents per liter; $mg.L^{-1}$, milligrams per liter]

Month 1980	Average DS concentration ($g \cdot L^{-1}$)	Average ALK concentration ($meq \cdot L^{-1}$)	Average DOC concentration ($mg \cdot L^{-1}$)	Average POC concentration ($mg \cdot L^{-1}$)
January	0.13	1.22	7.6	---
February	0.08	1.17	4.9	---
March	0.11	1.35	3.6	---
April	0.11	1.26	2.9	0.5
May	0.10	1.10	7.0	0.6
June	0.10	1.07	4.2	0.5
July	0.09	1.01	3.7	0.4
August	0.10	1.25	2.7	0.4
September	0.12	1.53	3.3	0.3
October	0.09	1.13	2.3	0.3
November	0.10	1.15	6.0	0.3
December	0.09	1.13	9.1	0.5
Annual	0.10	1.23	5.0	---

flow-weighted mean of 103mg L^{-1}, which compares favorably with my estimate of 0.10g L^{-1}. A nine-year (1951-1960) average DS at Sacramento is 109mg L^{-1} (Irwin and Lemons 1975). These three values are less than the estimated world average for rivers of 120mg L^{-1} (Livingstone (1963). My annual flow-weighted mean alkalinity of 1.23meq L^{-1} is equivalent to a bicarbonate ion concentration of 75 mg L^{-1}, the same value as a nine-year average at Sacramento (Irwin and Lemons 1975), but it is higher than the world average of 58.4mg L^{-1} (Livingstone 1963). My flow-weighted mean DOC concentration of 5.0mg L^{-1} is the same as the median DOC value for rivers presented in a review of data from various types of watersheds (Meybeck 1980).

The ranges of the monthly flow-weighted mean concentrations of DS, ALK, and DOC are small relative to the seasonal variation of river flow rate. Therefore, river flow rate is the more significant variable determining the transports of these substances. Estimated monthly and annual fluxes of DS, DIC, DOC, and POC (monthly only) to the Delta by the Sacramento River are shown in table 2. Sixtyfive percent of the total 1980 Sacramento River flow occurred January through March. This corresponds to 66 percent of the total DS flux, 65 percent of the total DIC flux, and 70 percent of the total DOC flux. The concentrations averaged over winter (W) and spring through fall (SF) are similar for DS (W=0.11; SF= 0.99g L^{-1}) and ALK (W=1.24; SF=1.18 meq L^{-1}); however, winter DOC is significantly more concentrated than that for spring through fall (W=5.4; SF=4.5, or 3.9 mg L^{-1} if we exclude December, the month of the highest average concentration and the first significant rainfalls since July). Results from San Francisco Bay estuary also indicate that average concentrations of DOC in the Delta outflow to the Bay are higher during winter (Schemel 1981).

Sacramento River fluxes to the Delta are larger than fluxes to the Bay because of the large fraction of the Delta inflow that is consumed or exported. Fluxes to the Bay can be estimated from the average concentrations in the Sacramento River (table 1) and the estimated Delta outflows (appendix table B.)

The total dissolved carbon flux (DIC+DOC) is 19 percent of the total DS flux. Because the annual DOC flux is about one-third of the annual DIC flux, carbon transport to the Bay and ocean is dominated by bicarbonate ion. Spring through fall data show that near-surface POC is an average of only one-tenth of the total organic carbon (DOC+POC).

Other descriptions of the results are deferred to the discussion section for the sake of clarity.

DISCUSSION

California's extensive agricultural, municipal, and industrial water needs require the continuing development and management of available surface-water resources. Reservoirs operate on most of the rivers that flow to the Delta,

Table 2. Estimated monthly Sacramento River flow and fluxes of dissolved solids (DS), dissolved inorganic carbon (DIC), dissolved organic carbon (DOC), and particulate organic carbon (POC).

Month 1980	Sacramento River flow (cubic meters)	DS flux (grams)	DIC flux (grams)	DOC flux (grams)	POC flux (grams)
January	6.91×10^{9}	9.0×10^{11}	1.01×10^{11}	5.2×10^{10}	- - - -
February	6.78×10^{9}	5.4×10^{11}	0.95×10^{11}	3.3×10^{10}	- - - -
March	5.63×10^{9}	6.2×10^{11}	0.91×10^{11}	2.0×10^{10}	- - - -
April	1.64×10^{9}	1.8×10^{11}	0.25×10^{11}	0.47×10^{10}	7.7×10^{8}
May	1.18×10^{9}	1.2×10^{11}	0.16×10^{11}	0.83×10^{10}	7.2×10^{8}
June	1.30×10^{9}	1.3×10^{11}	0.20×10^{11}	0.54×10^{10}	4.7×10^{8}
July	1.35×10^{9}	1.2×10^{11}	0.16×10^{11}	0.50×10^{10}	5.4×10^{8}
August	1.12×10^{9}	1.1×10^{11}	0.17×10^{11}	0.30×10^{10}	4.0×10^{8}
September	1.12×10^{9}	1.3×10^{11}	0.21×10^{11}	0.37×10^{10}	3.8×10^{8}
October	0.83×10^{9}	0.75×10^{11}	0.11×10^{11}	0.19×10^{10}	2.7×10^{8}
November	0.73×10^{9}	0.73×10^{11}	0.10×10^{11}	0.44×10^{10}	2.0×10^{8}
December	1.22×10^{9}	1.1×10^{11}	0.17×10^{11}	1.1×10^{10}	5.6×10^{8}
Total	2.98×10^{10}	3.1×10^{12}	4.4×10^{11}	1.5×10^{11}	- - - -

primarily in order to provide water during the typically dry summer and fall. Reservoirs can presently impound a large fraction of the runoff. For example, the total reservoir capacity in the Sacramento River system is roughly equivalent to one-half of the winter 1980 Sacramento River flow to the Delta (Kahrl 1978). Although the rivers are highly managed, winter and spring flows in the rivers and from the Delta to the Bay can vary in response to the precipitation patterns.

Winter Sacramento River flows were high in response to the intensities and frequency of storms during 1980, as indicated by the precipitation at Sacramento (fig. 3). The two high-flow peaks (flood events) are clearly related to the major mid-January and mid-February storms (storm events) and smaller peaks on the shoulder of the second peak are related to smaller storm events. Flow variations as late as mid-May appear to be caused by smaller storms. The only significant precipitation between mid-May and late-November occurred during the first two days of July, but a river flow increase from this summer storm is not apparent. Late fall river flow increases again coincide with storm events. Variations in river composition would be expected to coincide with variations in flow rate that are naturally induced by precipitation and runoff (for a summary see Stumm and Morgan 1981).

River flow variations during summer and early fall are related mostly to releases from reservoirs as part of water management and water transport southward to the more-arid regions of the state. The Delta is a conveyance for water from the northern rivers to the export pumps located in the southern reach of the Delta. Because of the large fraction of the Delta inflow that is exported during summer and fall, the composition of the Delta outflow is not closely related to the Delta outflow rate; however, river composition can co-vary with river flow rate primarily because releases of impounded river waters tend to dilute ground water and waste water inflows (California Department of Water Resources 1962, 1971).

Concentration Variations at Rio Vista

Variations in the composition of Sacramento River water at Rio Vista appear to be related primarily to river flow variations and/or the occurrence of storms during most times of the year. Alkalinity and salinity concentration variations show a pattern during winter flood events that is typical for natural (unregulated) river systems (for example, the Mattole River as described by Kennedy and Malcolm 1977). The data are more complete for the second major flood event; these data are connected by dots in figure 4. River flow increases rapidly at the beginning of each storm event because of the large increase in surface runoff. Because storm (surface) runoff does not have the opportunity to penetrate the soil appreciably (and remove soluble substances), it normally decreases salt concentrations in the rivers. Lower concentrations of both salinity and alkalinity were observed at the beginning of each flood event. The fraction of subsurface water containing soil-derived salts normally

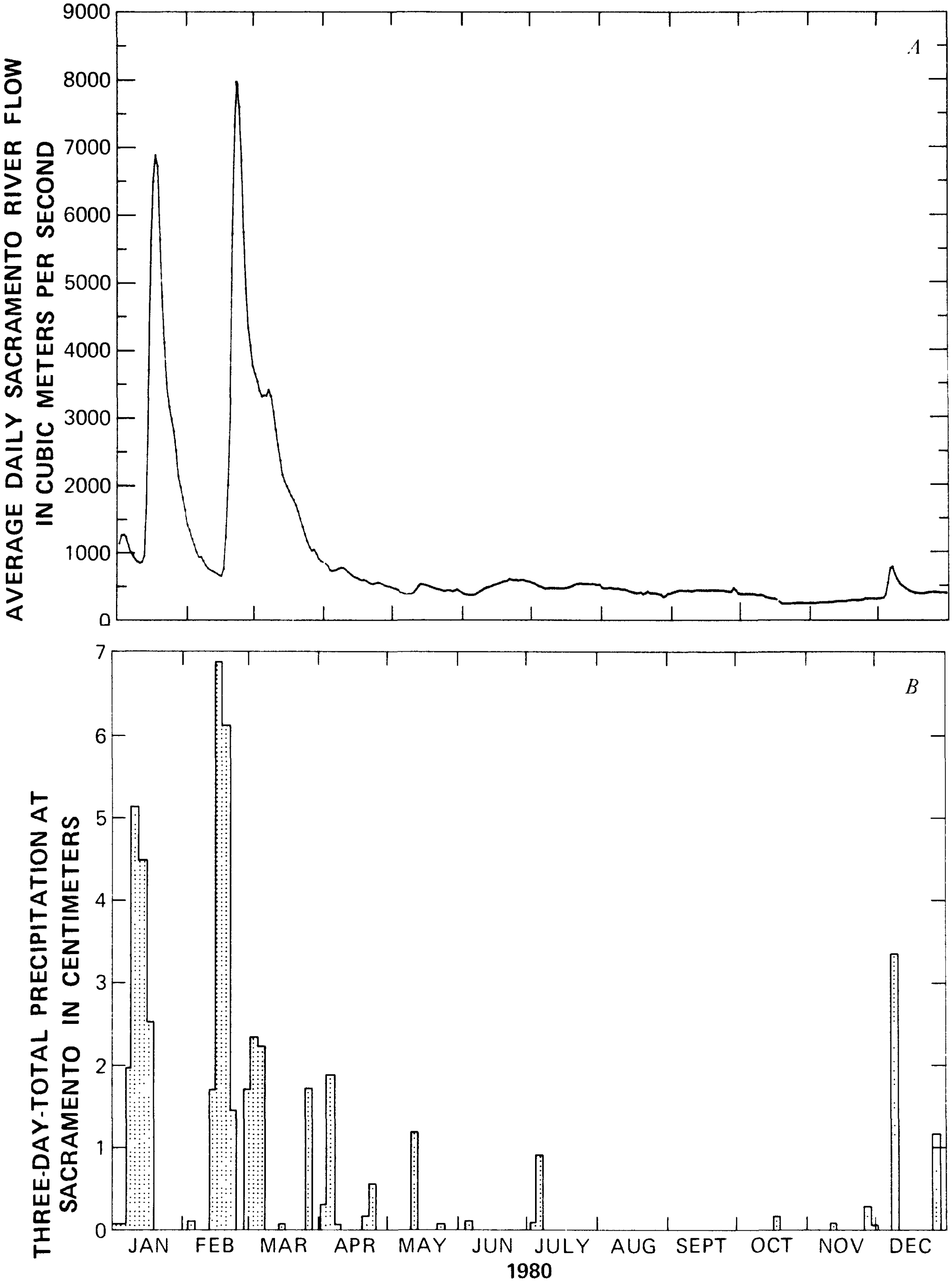

Figure 3. Average daily Sacramento River flow at Sacramento and three-day-total precipitation at Sacramento during 1980.

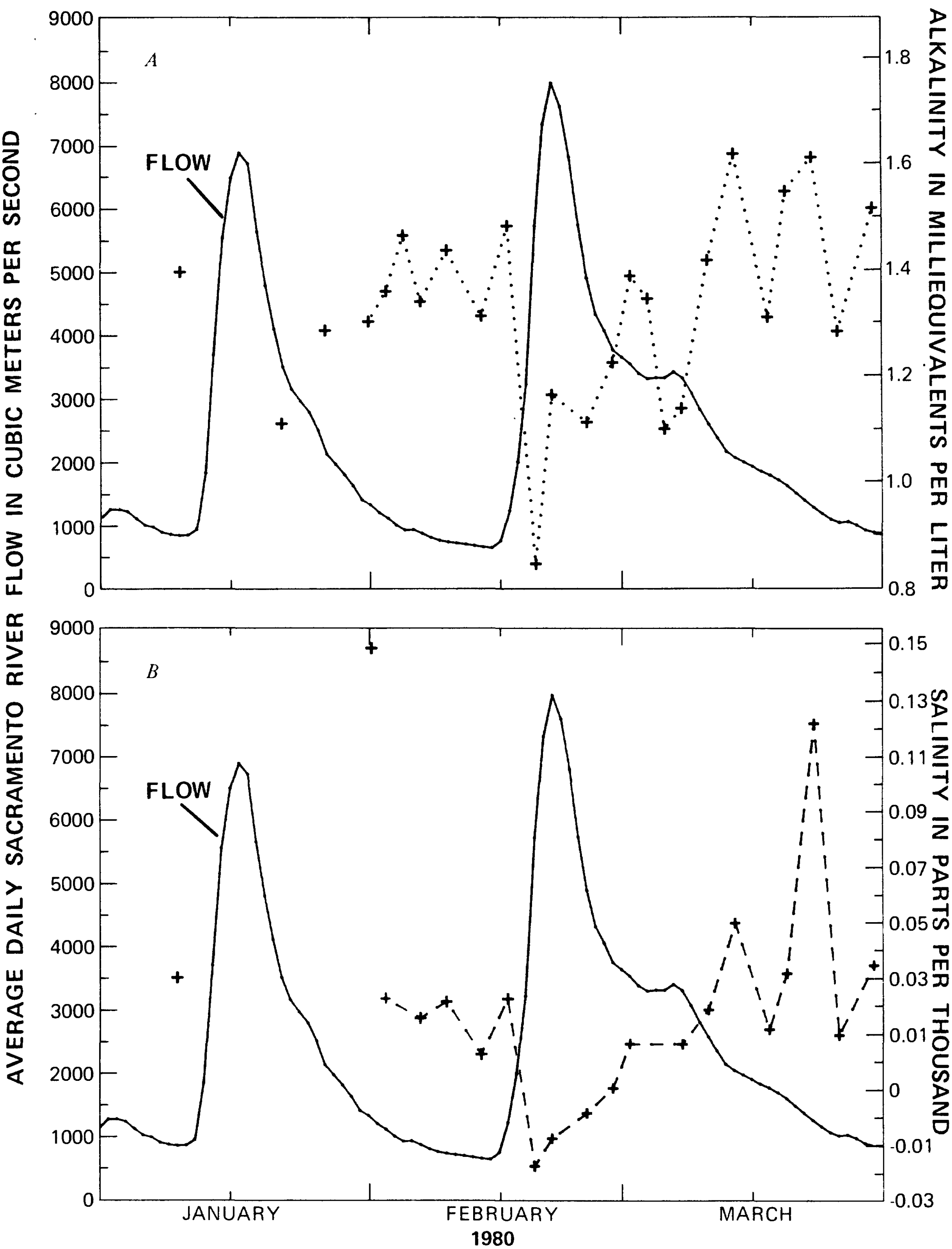

Figure 4. Average daily Sacramento River flow at Sacramento (solid line) and alkalinity (dotted line, A) and salinity (dashed line, B) at Rio Vista during winter of 1980.

increases following a storm. Alkalinity and salinity concentrations generally increased as river flow decreased following a storm event. The variations in salinity and alkalinity during March appear to be related to smaller storms and the effects of their surface runoffs. While the mid-February storm caused a near 50 percent decrease in alkalinity, the effects of the smaller storms were limited to roughly 20 percent decreases. The range of DIC concentrations is large during winter, illustrating the large errors possible when flux estimates are based on only a few measurements.

Although much smaller in magnitude than those during winter, spring through fall river flow variations are significant relative to the average flow rate (fig. 5; appendix fig. A). Flow variations of 30 to 50 percent occurred over periods of 2 to 4 weeks during spring and summer. Salinity and alkalinity appear to co-vary with flow rate, although the relation changes during the year (fig. 5). Salinity and alkalinity typically co-vary positively; salinity increases are most often accompanied by alkalinity increases. This might be expected because bicarbonate ion is typically the most abundant ion in river waters (Livingstone 1963). The salinity-alkalinity pairs correlate well (r^2=0.95, if we exclude the three highest salinity values, which do not appear to relate as well to the other measurements; appendix fig. A). The slope of the salinity-alkalinity relation (7.7 meq. g^{-1}) is much higher than that typical for the North Bay estuary (about 0.035 meq. g^{-1}). This indicates that salinity and alkalinity variations at Rio Vista during 1980 generally cannot be attributed to mixing with brackish water from the estuary.

Many factors must be considered in identifying the processes and events that cause the variations in compositions at Rio Vista during spring through fall. The effects of the various sources of water and dissolved salts in the Sacramento River system were identified in a pollution survey and a mathematical salinity model (California Department of Water Resources 1962, 1971). Relevant information from these and other reports is briefly summarized here in order to show the most-probable causes for the major variations in composition observed at Rio Vista during 1980.

Sacramento River flow to the Delta is primarily the sum of the flows from the three major tributaries of the system; The Sacramento River tributary, the Feather River, and the American River (fig. 6). Summer flows are regulated primarily by releases of water from the major reservoirs (Shasta, Oroville, and Folsom). The amount of water released from each reservoir is determined by downstream needs and available storage. The compositions of the waters from the three tributaries are different because of natural factors associated with the types and locations of the watersheds, ground water inflows, and waste water inflows from municipal, industrial and agricultural sources. The Sacramento River has typically the highest concentrations of dissolved salts, whereas the American River has the lowest concentrations. In general, the composition of water released from a major reservoir does not vary appreciably relative to the effects of salt accretions that occur as the river flows through the Sacramento Valley (California Department of Water

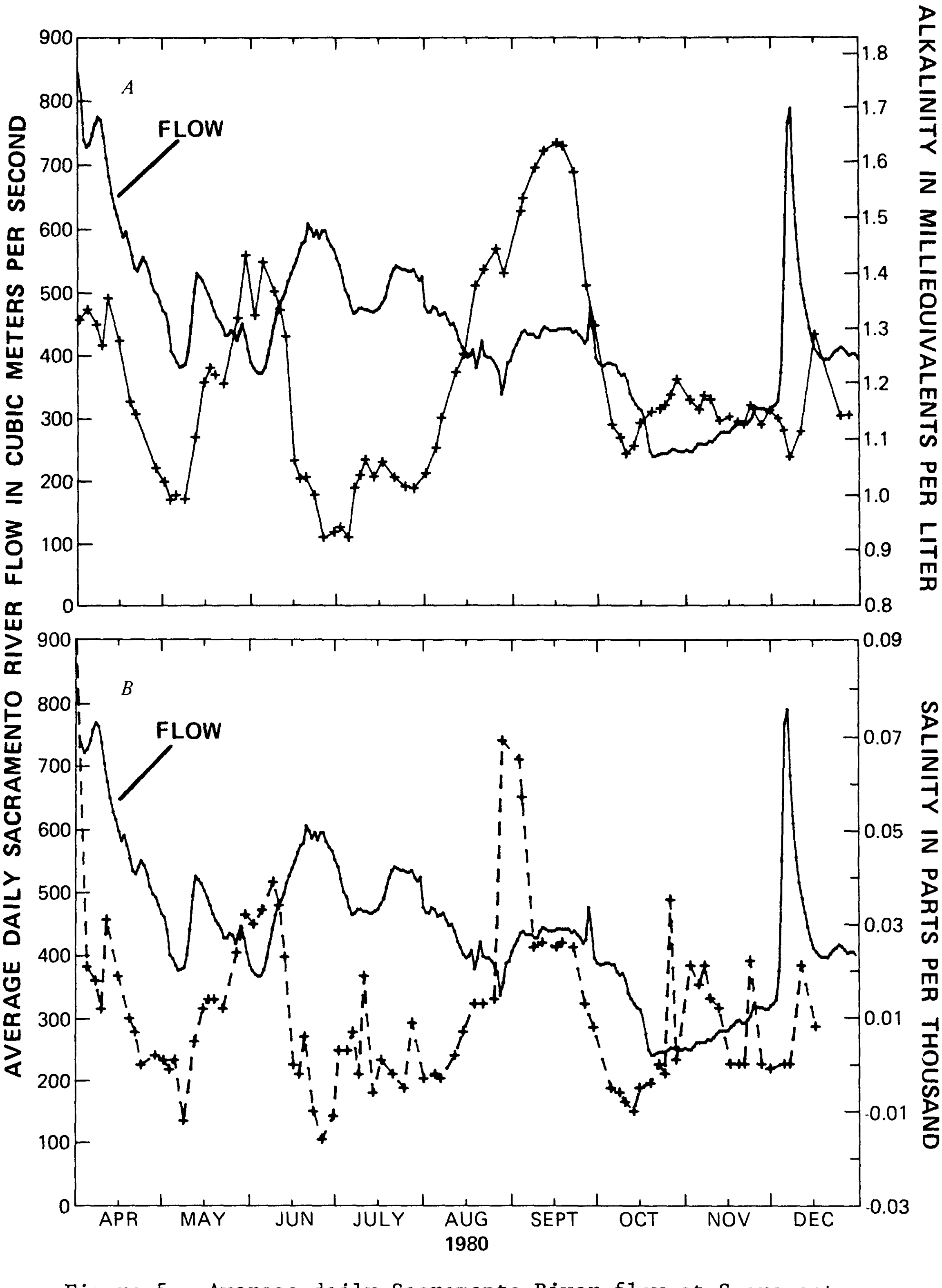

Figure 5. Average daily Sacramento River flow at Sacramento (solid line) and alkalinity (crosses, A) and salinity (crosses, B) at Rio Vista during spring through fall 1980.

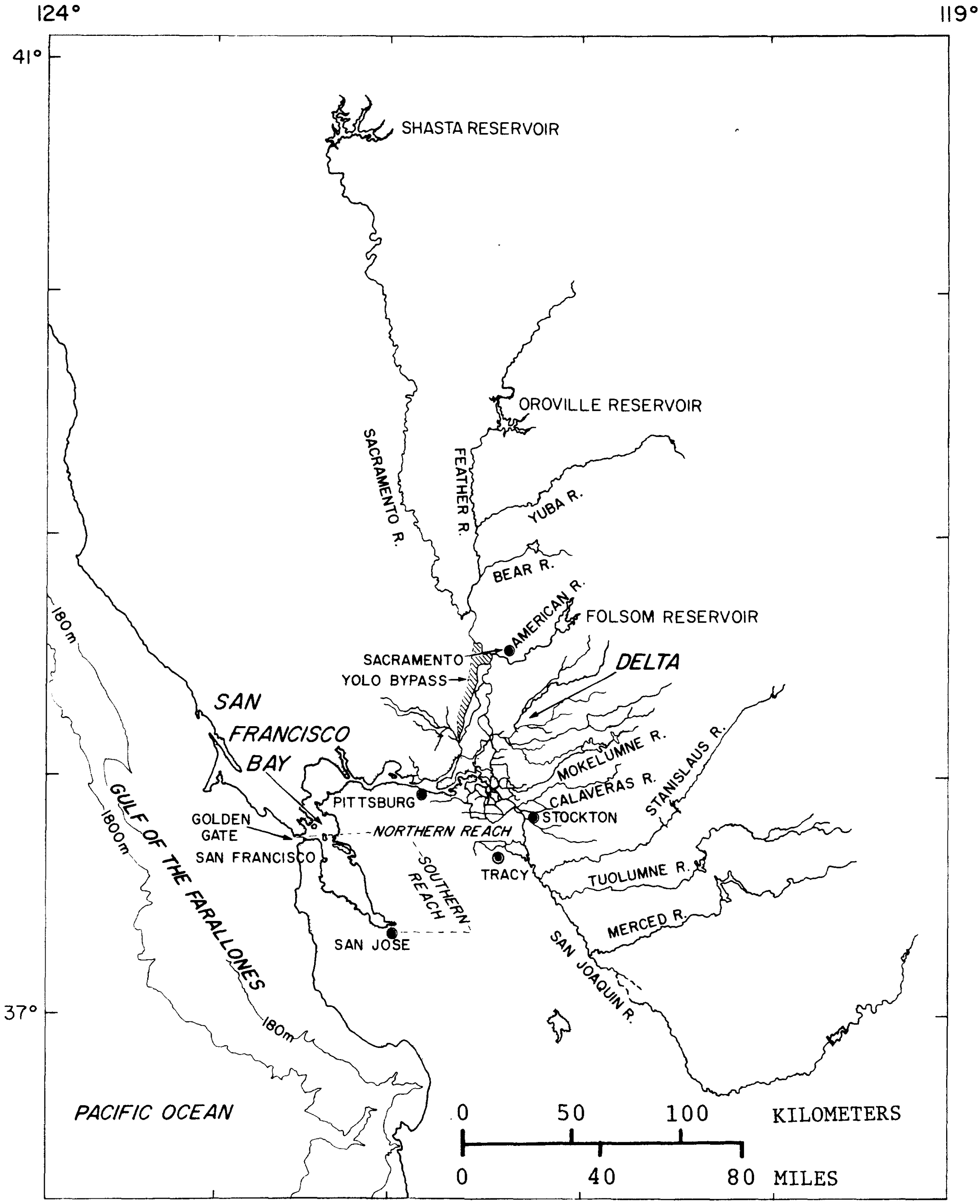

Figure 6. Major tributaries of the Sacramento and San Joaquin Rivers.

Resources 1971). The largest salt concentration increases in the Sacramento River water result from the inflow of agriculture-related waste waters; this increase is particularly large during late summer due to the highest inflow rates (California Regional Water Quality Control Board 1979; California Department of Water Resources 1962). Salinity and alkalinity measurements on the tributaries are too few in number to adequately document the seasonal variations during 1980. The effects of varying the proportions of the tributary inflows during 1980 are estimated here by using daily flow data and annual averages (not flow weighted) of the available specific conductance (SC) and alkalinity (ALK) measurements (U.S. Geological Survey 1981) as given below.

Shasta Reservoir outflow ALK and SC values averaged 47 mg L^{-1} (as $CaCO_3$)[1/] and 111 umhos cm^{-1}, respectively, during 1980. Salt accretions increased the average concentrations to 72 mg L^{-1} and 203 µmhos cm^{-1} at a location just upstream of the confluence with the Feather River, representing concentration increases of about 50 and 83 percent for ALK and SC, respectively. ALK and SC averaged 33 mg L^{-1} and 83 µmhos cm^{-1}, respectively, in the Feather River at a location just upstream of the confluence; both concentrations are less than 50 percent of the Sacramento River values. The American River joins the Sacramento River at the city of Sacramento. Because of its very low ALK (22 mg L^{-1}) and SC (53 µmhos cm^{-1}) concentrations, the American River inflow decreases the ALK and SC concentrations appreciably in the Sacramento-Feather river mixture before it reaches the Delta. The spring-summer 1980 variations in the proportions of the tributary inflows result in the predicted variations of SC and ALK in the mixture shown in figure 7.

The calculated variations in Sacramento River composition do not include the effects of seasonal variations in tributary composition. Agriculture-related waste water is the largest source of salinity, alkalinity and other substances to the Sacramento River during summer (California Department of Water Resources 1962). The rate of inflow and the effect on river composition varies with time and location. Baseline studies were conducted in the Sacra-Valley during 1976-1977 (California Regional Water Quality Control Board 1979), years of drought in California when river flows were lower than they were during 1980. Chemical analyses of monitored waste waters are made only when "indicator" concentrations exceed those during the baseline study; therefore few measurements are available for 1980. The estimates made here for 1980 are based on data from 1975 (Tanji 1981), 1976-1977 (California Regional Water Quality Control Board 1979; Merrill and others 1979), and 1980 flow data from the Glenn-Colusa irrigation district (Colusa drain).

1/U.S. Geological Survey (1981a) units are retained in order to differentiate between sources of data in this report.

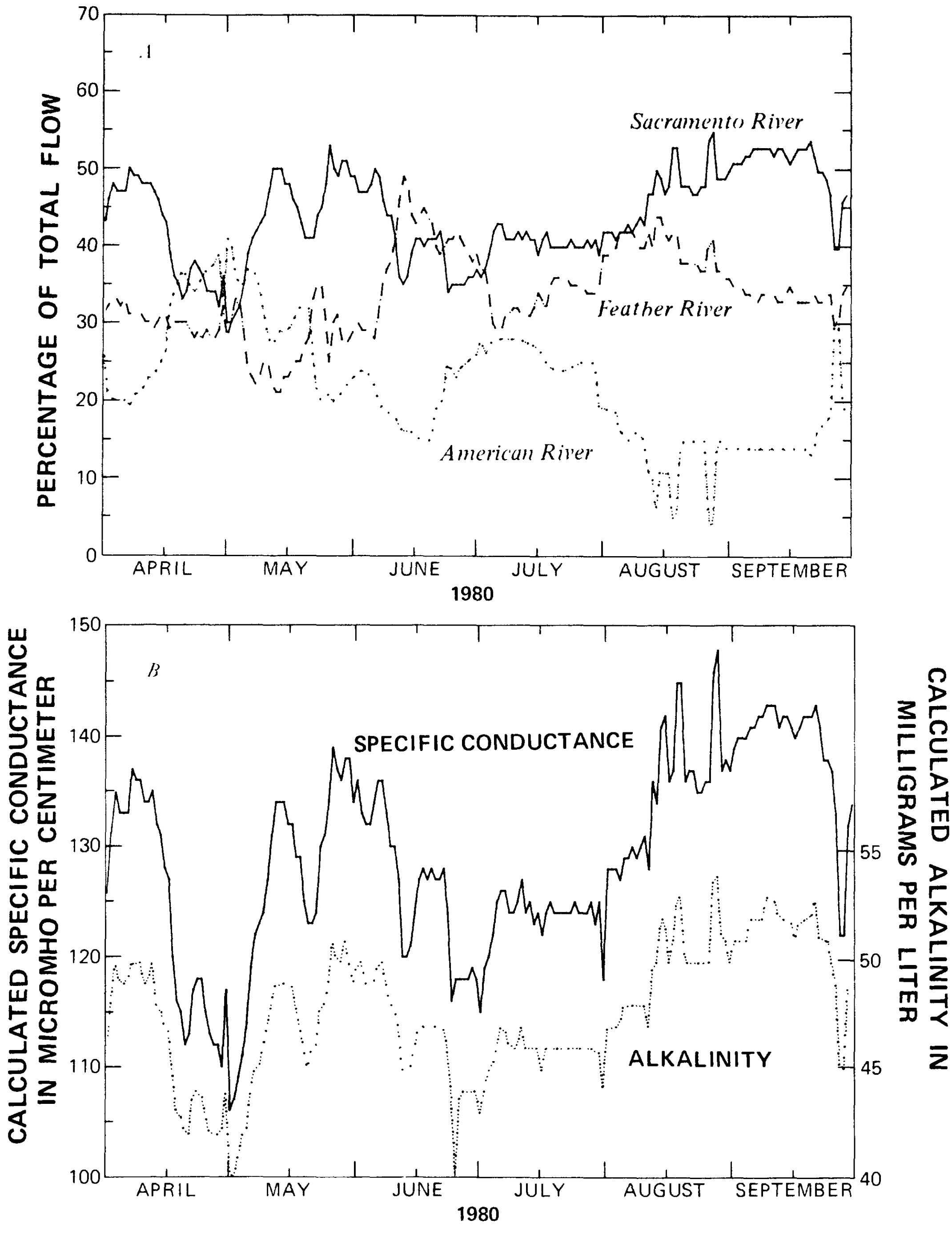

Figure 7. Sacramento River, Feather River, and American River average daily flows expressed as percentage of the total during spring through summer of 1980 (A), and specific conductance and alkalinity resulting from the mixing of the tributary rivers as calculated from their annual-average concentrations (B).

During the 1976-1977 irrigation seasons (April through September), agriculture-related waste inflows accounted for about one-tenth of the river flow, but contributed about one-third of the salt. Flow to the Sacramento River from the Colusa drain was about one-fourth of the total waste inflow. Most of the Colusa drain flow is irrigation return-flow water; about one-third of the water volume that is originally diverted from the Sacramento River is later returned with about twice the salt concentration. Data from 1976 indicate that the average salt concentration increase for waste waters in the Sacramento Valley is on the order of a factor of 4 (Merrill and others 1979). It appears that wastewater flow rates were higher during 1980 than those during the baseline study. Higher flows might be expected because some water conservation and water re-use measures that were practiced during the drought were not necessary during 1980. The Colusa drain averaged about 10 m^3s^{-1} during the baseline study, but averaged about 23 m^3s^{-1} during the 1980 irrigation season (fig. 8); however, flows during spring 1980 may include storm runoff. If other sources were proportionately higher in flow during 1980, the total inflow rate could have averaged 100 m^3s^{-1} during the irrigation season. Monthly average flow rates probably exceeded 100 m^3s^{-1} during August and September, when the larger drains have the highest flows. Because the average Sacramento River flow to the Delta during August and September of 1980 was about 420 m^3s^{-1}, it appears that agriculture-related waste water could have accounted for one-fourth of the flow.

Salinity and alkalinity concentration variations

The following paragraphs discuss the spring through fall salinity and alkalinity variations at Rio Vista. My approach is first to describe the salinity and alkalinity variations as they relate to variations in river flow (fig. 5) then to compare observed concentration variations to those predicted as a result of mixing waters from the three tributaries (mixing model; fig. 7).

River flow decreased to below 1000 m^3s^{-1} during early April. Decreasing flow rate to less than 400 m^3s^{-1} during April coincided with decreases in salinity and alkalinity. After a minimum flow was reached during early May, salinity and alkalinity increased with increasing flow until shortly after a flow maximum during mid-May. The mixing model shows salinity and alkalinity minima during early May. Therefore, it appears that increasing flow rate from the American River (exceeding those from the other tributaries during late April) was directly responsible for the lower concentrations. High flow from the American River during spring can be the result of snow melting at high elevations. Relative decreases in alkalinity and salinity are approximately 20 percent (April to May), which are about the same as the mixing model variations.

The relation of salinity and alkalinity to river flow rate reversed shortly after the flow maximum during mid-May. Salinity and alkalinity increased with decreasing flow to concentration maxima during early June,

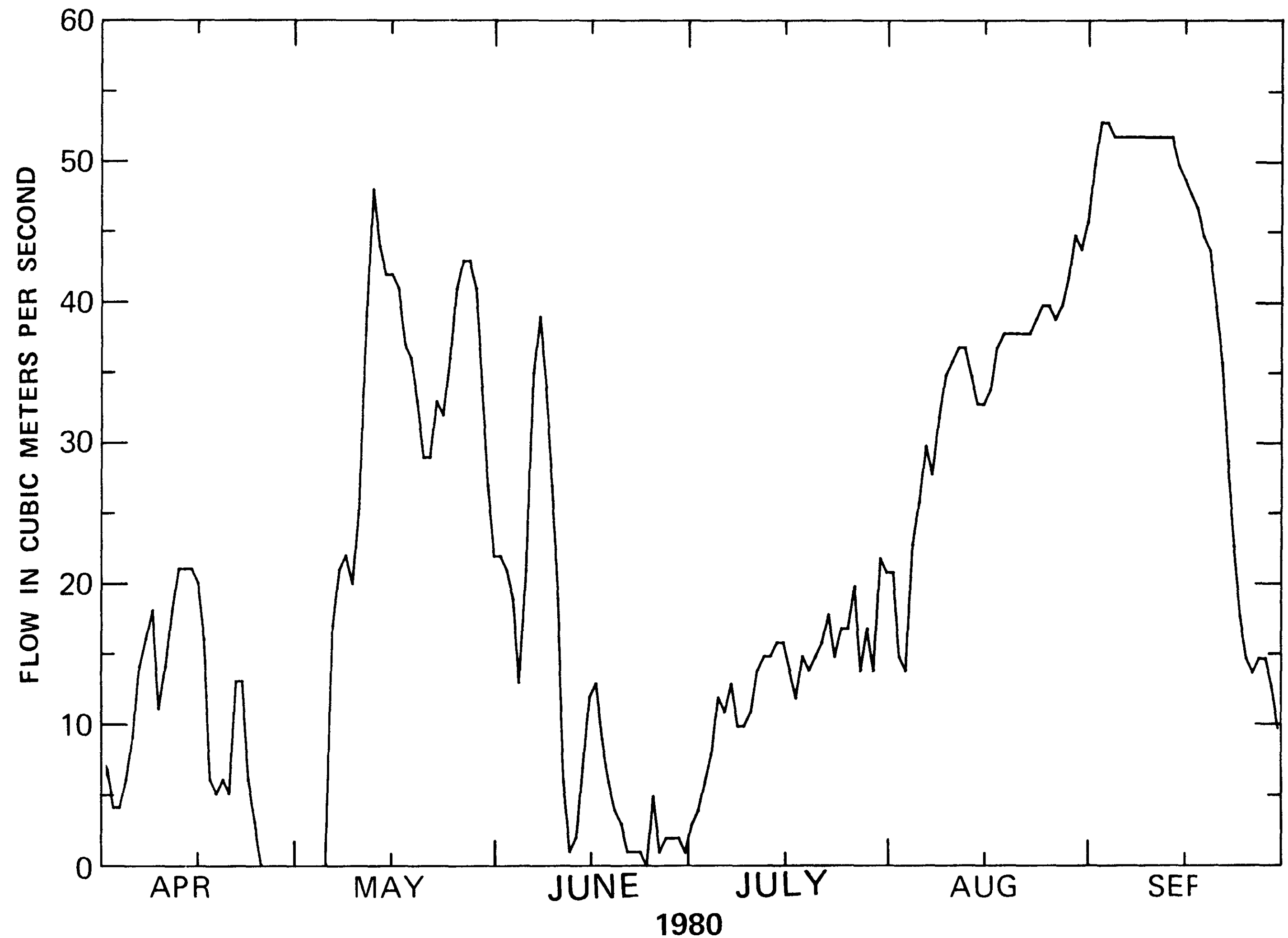

Figure 8. Average daily flow from the Glenn-Colusa Irrigation District to the Sacramento River during spring and summer 1980.

coinciding with a minimum in flow. This inverse co-variation with flow rate continued until late August. The salinity and alkalinity maxima observed during early June are also predicted by the mixing model; nearly half of the total river flow came from the Sacramento tributary. An increasing fraction and increasing flow rate from the Feather River coincided with predicted decreases in alkalinity and specific conductance during late June. Salinity and alkalinity concentration minima at Rio Vista were observed during late June. In contrast to the early May minima, the late June minima coincide with a maximum in river flow rate that is largely attributable to increased flow from the Feather River.

Low average concentrations during July appear to be related to the large fractions from the American and Feather Rivers. Concentrations increased with decreasing river flow until late-August. Increasing concentrations appear to have resulted from low American River flows and decreasing Feather River fraction. The mixing model predicts increases in specific conductance and alkalinity, but the relative variations observed at Rio Vista are about twice as large as the relative variations predicted by the mixing model. The relation of salinity and alkalinity concentration variations to river flow again reversed during late August; increasing river flow generally resulted in higher concentrations until early October, when the relation becomes unclear. The highest concentrations were observed during the period just after the positive co-variation with flow began. The mixing model does not show any of the large increases in concentrations that occurred during early September. Inflow of concentrated waste water, which increased river concentrations above the average values used in the mixing model, is indicated during August and September because the mixing model does not adequately account for the observed concentration increases. The largest increase (early August to September) coincides with the period of the highest flows from the Colusa Drain (fig. 8).

Large alkalinity and salinity concentration decreases occurred at Rio Vista from late-September into early October, generally coinciding with decreasing river flow rate. The timing of the rapid decrease coincides with the rapid decrease in flow from the Colusa drain, indicating that the reduced inflow of waste water is a major factor. However, the mixing model also predicts short-term decreases in concentrations as a result of a pulse of water from the American River.

The early December storm event increased flow and decreased alkalinity concentrations. Salinity and alkalinity concentrations increased to maxima after the maximum flow. This is possibly related to a first wash-out of salts from the watersheds since the last significant rains during spring.

Dissolved organic carbon concentration variations

Precipitation is the most important factor governing the transport of DOC from watersheds to rivers. Riverine fluxes of DOC are typically high during periods of precipitation because of both higher DOC concentrations and higher river flows (Wetzel and Otsuki 1974; Lewis and Grant 1979; Moeller and others 1979). Higher DOC concentrations are generally attributed to the mobilization of recently decomposed or leached vegetable matter. For example, DOC concentrations in some streams increase with the first autumn rains because DOC is rapidly leached from the recently-deposited leaf litter (Lock and Hynes 1976) then carried from the watershed to the stream by the storm runoff (Hobbie and Likens 1973).

The DOC data from Rio Vista show a seasonal pattern as well as a pattern related to precipitation, although the precipitation-related pattern is not as well defined as those from simple watersheds (fig. 9). The large DOC flux during winter is the result of higher concentrations and higher flow rates; concentrations were generally lower during summer and early fall than at other times of the year. The high DOC concentrations following the late-November and December storms can be attributed to the mobilization of DOC accumulated in the soils since the last significant rainfalls of spring and the products of recently-deposited material. DOC concentrations generally increased after a storm event during winter and spring, but this was not observed in all cases. DOC concentrations during and following the major mid-February flood event were generally lower than those following the smaller and less-frequent spring storms. This could be an effect of dilution during periods of extremely high runoff or indicate that most of the DOC was washed from the watersheds during earlier storms. Lower temperature during winter could also inhibit the biotic production and decomposition of DOC.

In-stream processing of DOC (biotic and abiotic processes that consume or change the composition of the DOC) is undoubtedly a factor contributing the lower DOC concentrations during summer and early fall. Higher temperatures and longer residence times in the river increase the extent of in-stream processing, removing most of the low molecular weight DOC and decreasing concentrations downsteam of the watesheds. The remaining DOC can be mostly refractory material, a less useful energy source for organisms, when optimum in-stream processing conditions prevail (Kaplan and other 1980). It appears that DOC constitutes the largest fraction of the riverine organic carbon flux to the Bay and that most is transported during winter when DOC processing is presumably at its lowest. Therefore, the winter DOC flux may constitute a large and important energy source for Bay-dwelling organisms. A fraction of the DOC can form particles or adsorb onto particles (Sholkovitz 1976), thus being deposited in the estuary. Preliminary estimates indicate that the annual DOC flux to the Bay is about the same order of magnitude as the annual phytoplankton production in the Bay (B. E. Cole, U.S. Geological Survey, oral communication 1982).

Particulate organic carbon concentration variations

Precipitation and runoff transport POC from the watershed (Hobbie and Likens 1973) and higher winter river flow rates more-efficiently suspend

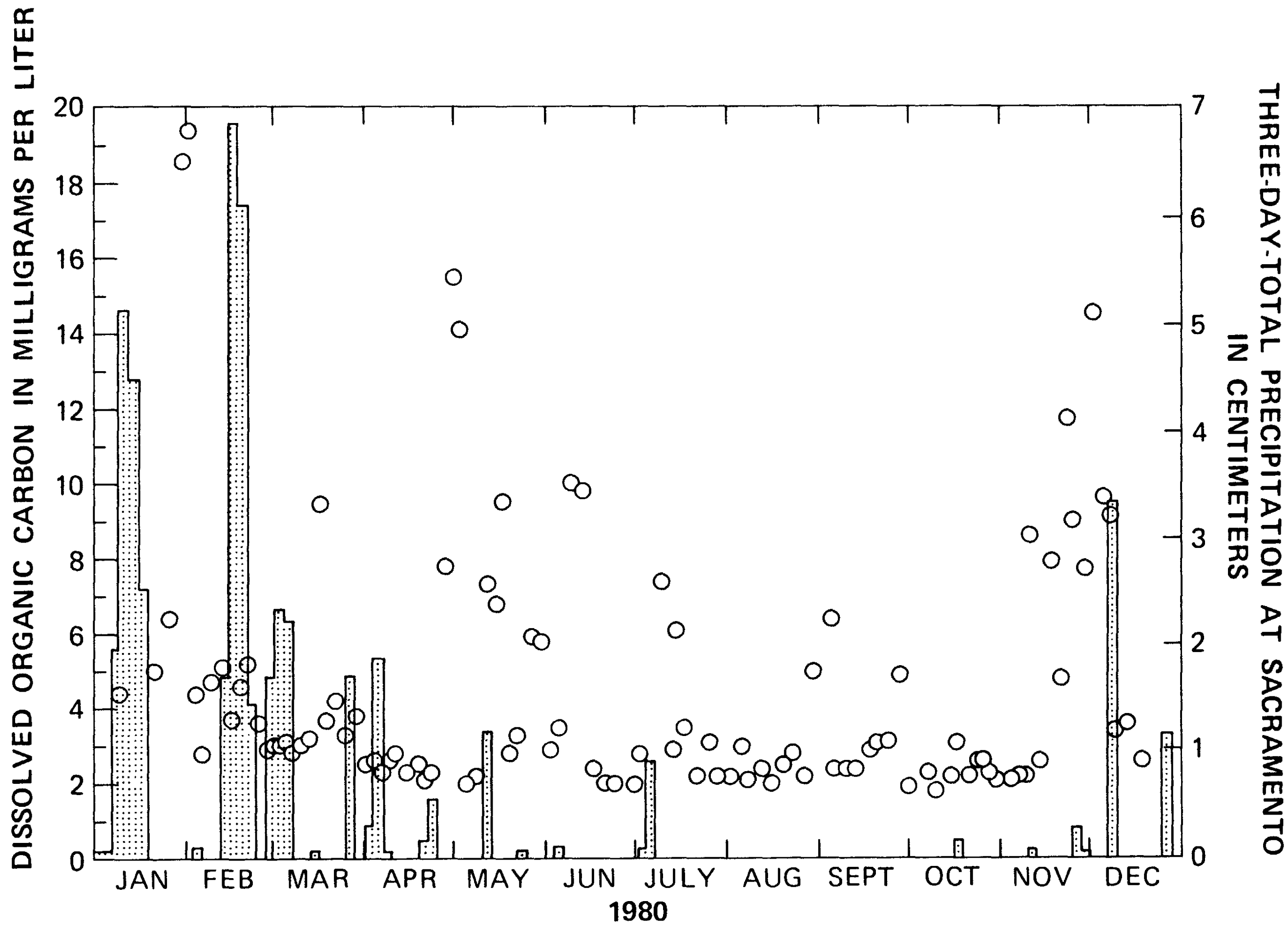

Figure 9. Dissolved organic carbon concentrations (open circles) at Rio Vista and three-day-total precipitation (bars) at Sacramento during 1980.

POC and transport it to the estuary. Suspended particulate matter (SPM) concentrations are highest in the Sacramento River during winter flood events (U.S. Geological Survey 1981a). Therefore, the SPM and POC fluxes are probably highest during winter due to both higher river flow rates and higher concentrations. Our POC flux estimates for spring through fall are probably lower than estimates of the actual fluxes because they were not calculated from depth-integrated concentrations (Nordin and Meade 1981). The POC:DOC average concentration ratio is roughly 1:10. POC concentrations probably increase relative to DOC concentrations with depth and, therefore, POC transport probably constitutes a larger fraction of the total organic carbon transport than appears to be the case from my data, particularly during winter. Thus, the 1:10 concentration ratio represents a lower limit.

Earlier data (Schemel and Dedini 1979) do not adequately show the seasonality of POC concentration in the Delta outflow because they are limited to measurements of the near-surface waters and very few samples were taken during major flood events. Winter through spring (1971-1977) POC concentrations at near-zero salinity in northern San Francisco Bay showed a median value of about 1.2 mg L^{-1} and a larger fraction of the samples exceeded 3 mg L^{-1} (the limit of the analytical range) than during summer-fall when the median value was about 1.0 mg L^{-1}. Results from 1980 (fig. 10) compare with the earlier data in that they show generally higher average concentrations during spring than during summer and fall. The high value during December followed a storm that had also increased the river flow rate. This and results from March indicate that the higher concentrations are related to storm events. The spring 1980 median value (about 0.6 mg L^{-1}) is lower than that shown by the earlier data. Similarly, the 1980 summer-fall median value is lower at about 0.3 mg L^{-1}. The lower values could indicate that POC concentrations at Rio Vista are lower than those of the Delta outflow. Higher POC concentrations in the eastern reach of the estuary can be the result of processes that resuspend particles and increase phytoplankton growth. Wind-driven resuspension might be less at Rio Vista because of the shorter fetch (the wind direction is normally perpendicular to the axis of the river at Rio Vista, but it is parallel to the axis of the upper reaches of the estuary).

Summer Distributions of Solutes in the Delta

Delta waters vary in composition as a result of variations in the river compositions and flows and the geographic location of each river inflow. Water exportation demands during summer cause a large net flow of Sacramento River water across the Delta to the Old and Middle River tributaries of the San Joaquin River then to the export pumps. Water entering the Delta via the San Joaquin River from the south-east is drawn westward through cross channels to the export pumps, reducing flow in the main San Joaquin River channel to the north. Conditions that have been attributed to the circulation pattern resulting from export pumping include a salinity increase

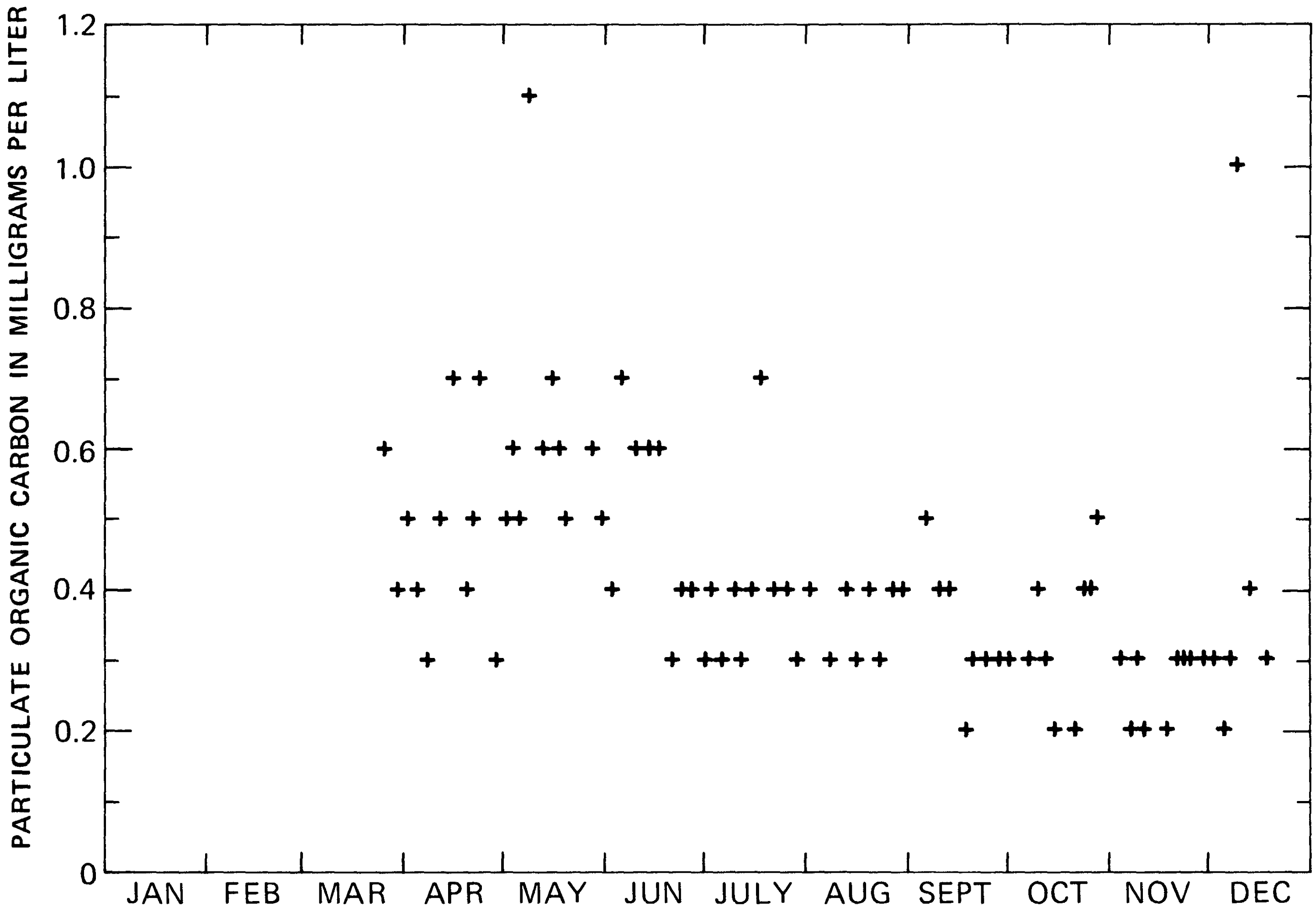

Figure 10. Particulate organic carbon concentrations at Rio Vista during 1980.

landward to the main channel of the San Joaquin River between the reach where Sacramento River water crosses the Delta and the city of Stockton (California Department of Water Resources 1981a). Flows from the San Joaquin River to the Delta are much less than those of the Sacramento River (appendix table A). In general, dissolved salt concentrations in the Sacramento River do not exceed levels that limit the usefulness of the water. Lower flow rates and larger inflows of highly concentrated waste waters (Merrill and others 1979; Tanji 1981) contribute to higher dissolved salt concentrations in the San Joaquin River flow that can limit the usefulness of the water during periods of low flow.

The bridge-sample results from June and July (appendix table D) show that waters in the eastern Delta were higher in salinity and alkalinity than western Delta waters, which were largely Sacramento River water. The small-boat sampling of the San Joaquin River during July also showed that Sacramento River water dominated the western Delta and that salinity and alkalinity rapidly increased east of the Old River and Middle River channels (fig. 11; appendix table E).

Bridge samples from September showed large changes in San Joaquin River inflow composition and a change in the distribution of salinity and alkalinity in the Delta. Salinity and alkalinity concentrations were higher in the western Delta than were previously observed; San Joaquin River alkalinity was actually less than that in the water from the Sacramento River. This change from the typical summer pattern can be attributed to greater-than-normal inflow from the San Joaquin River (fig. 12), primarily from the Tuolumne River tributary (U.S. Geological Survey 1981b). San Joaquin River flow to the Delta doubled between early- and mid-September, decreased in late September, then again increased in early October. Specific conductance in the San Joaquin River during mid-September was half the value at the beginning of the month (U.S. Geological Survey 1981b). The alkalinity distribution in the Delta was further influenced by the large late-summer increase in Sacramento River alkalinity. Delta outflow to the Bay increased during September due to the San Joaquin River flow increase and a decrease in the export pumping, including a temporary shut-down of the California Department of Water Resources pumps.

The above factors contributed to changes in the circulation patterns in the Delta as well as the spatial water composition patterns in the Delta. California Department of Water Resources reported the occurrence of a phytoplankton bloom in the western Delta during September and suggested that the most probable cause of this bloom was the change in the Delta circulation pattern (California Department of Water Resources 1981a). Although this is certainly a credible hypothesis, the large spatial and temporal changes in composition indicate that perhaps the timing and extent of the bloom are also related to chemical factors.

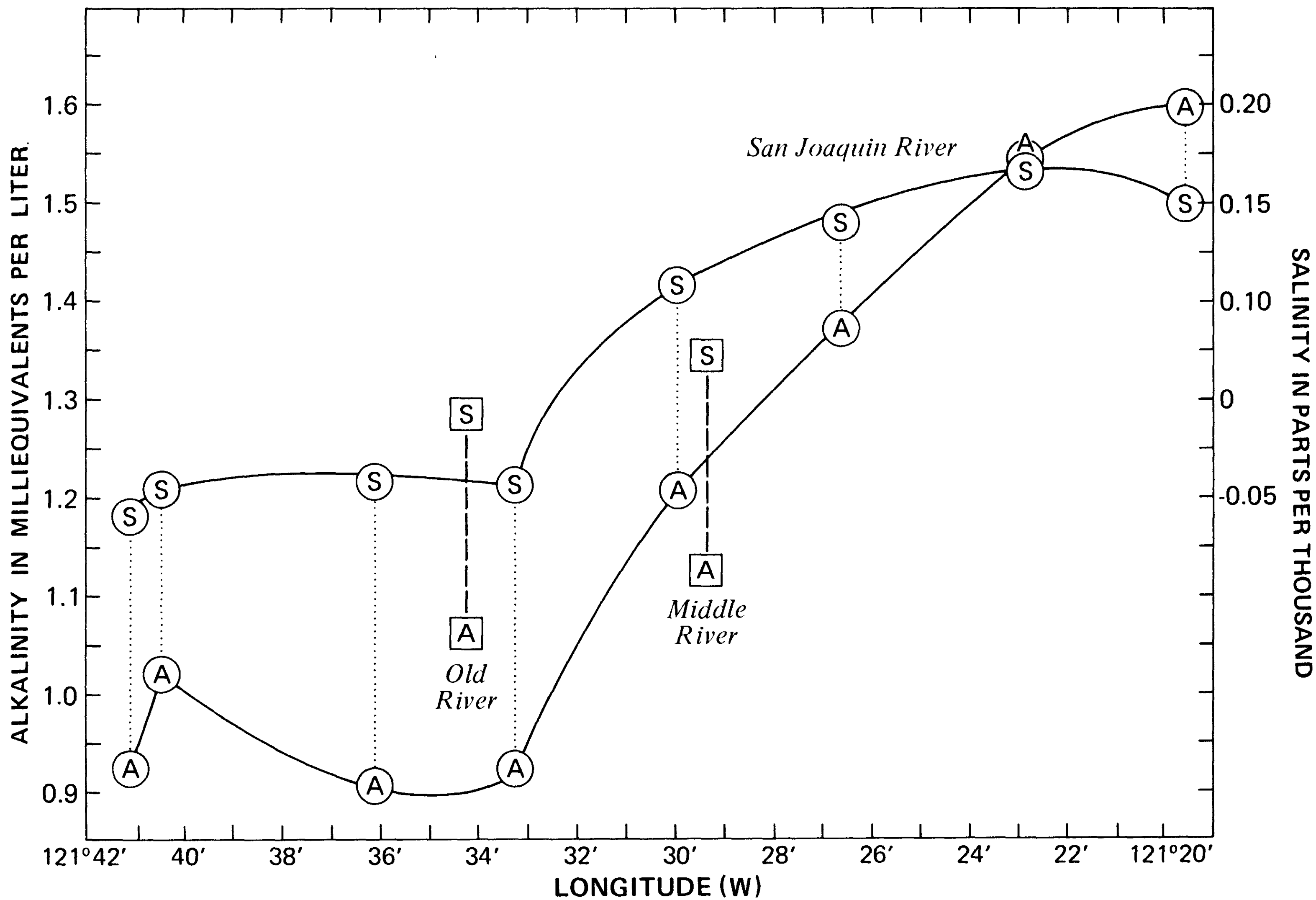

Figure 11. Salinity (S) and alkalinity (A) at locations in the main channel of the San Joaquin River (circles) and in the southern Delta (squares) during July 1980. (Consult appendix tables A, D, and E for additional location information.)

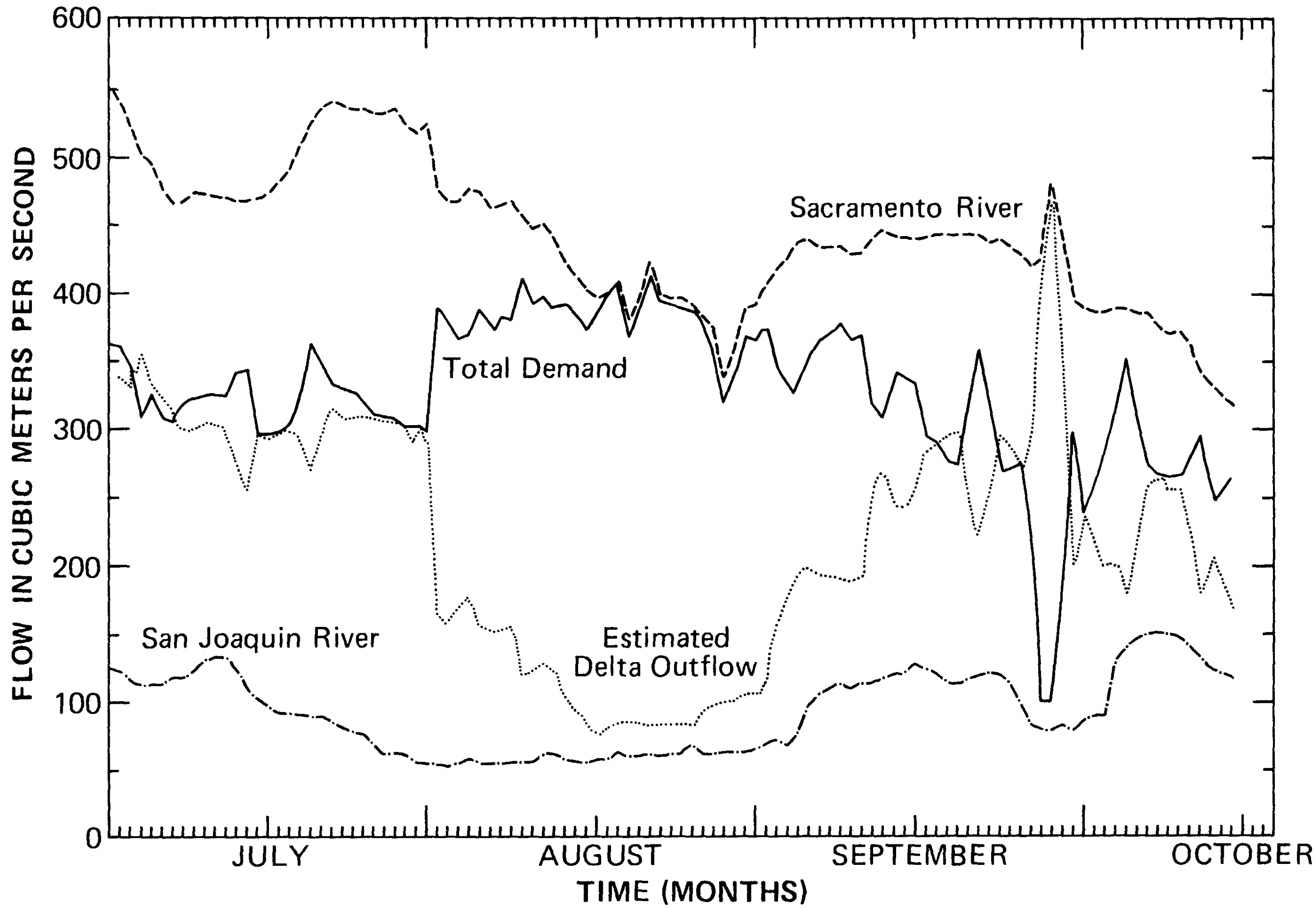

Figure 12. Average daily flows of the Sacramento and San Joaquin rivers to the Delta and estimated Delta outflow and total demand during summer 1980.

SUMMARY AND CONCLUSIONS

Seasonal and spatial variations in the composition of Delta fresh waters can be large and complex, particularly during periods of low Delta outflow, when export pumping from the Delta is more than half of the Delta inflow and reservoir releases constitute most of the flow. Winter variations in salinity and alkalinity appear to be most related to natural processes similar to those that operate in unregulated rivers, whereas spring through fall variations can be attributed to reservoir management and the inflow of waste waters. Because large variations in the concentrations of major constituents are observed in the Sacramento River, which is the major source of fresh water to San Francisco Bay, studies of the distributions of dissolved constituents in Bay waters cannot assume constant fresh water composition. For example, large variations during spring and summer occurred over periods that were much shorter than the residence time of fresh water in the estuary and, as a result, distributions of major and minor constituents in the estuary could erroneously indicate (estuarine) sources or sinks (Liss 1976; Loder and Reichard 1981).

Annual fluxes of riverine substances to the Bay are more related to the volume of Delta outflow than to large changes in composition, although the two factors can be related (as for POC and DOC). Reservoir storage and the diversion of fresh water from the Bay have increased in recent years (California Department of Water Resources 1978) and probably will continue to increase in the future, thus reducing the flow of water and fluxes of substances to the Bay. When winter flood events are reduced in magnitude, potentially important fluxes of POC and DOC to the Bay are also reduced. This is particularly important because winter DOC is probably enriched in energy-efficient compounds. The importance of the riverine organic flux as a source of food for Bay-dwelling organisms is unknown.

Higher riverine waste-derived-solute concentrations during summer indicate an increasing transport of waste-derived substances to the Bay and Delta. The effects of waste-derived substances on the Bay could be greatest during summer because substances remain longer in the estuary than they would during periods of higher Delta outflow. Future planning for waste-water management may benefit from consideration of transport and dilution processes in the Bay and the Delta. For example, waste water could be stored and then released during high flow periods.

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REFERENCES

California Department of Water Resources, 1962, Sacramento River water pollution survey: The Resources Agency of California, Bulletin No. 111, 100 p.

--- 1971, Mathematical simulation of salinity in the Sacramento River system: The Resources Agency of California, Bulletin No. 156, 72 p.

--- 1978, Delta water facilities: The Resources Agency of California, Bulletin No. 76, 119 p.

--- 1981a, Water quality conditions in the Sacramento-San Joaquin delta during 1980: Annual report to the State Water Resources Control Board, 33 p.

--- 1981b, Water quality surveillance program, 1980, Volume 1: The Resources Agency of California, 279 p.

--- 1979, Irrigation return flow monitoring, 1976 and 1977: 109 p.

Connors, D. N., and Kester, D. R., 1974, Effect of major ion variations in the marine environment on the specific gravity-conductivity-chlorinity-salinity relationship: Marine Chemistry, v. 2, p. 301-314.

Conomos, T. J., 1979, Properties and circulation of San Francisco Bay waters, in Conomos, T. J., ed., San Francisco Bay, The Urbanized Estuary: American Association for the Advancement of Science, San Francisco, California, p. 47-84.

Conomos, T. J., Smith, R. E., Peterson, D. H., Hager, S. W., and Schemel, L. E., 1979, Processes affecting the seasonal distributions of water properties in the San Francisco Bay estuarine system, in Conomos, T. J., ed., San Francisco Bay, The Urbanized Estuary: American Association for the Advancement of Science, California, p. 115-142.

Cox, R. A., Culkin, F., and Riley, J. P., 1967, The electrical conductivity/chlorinity relationship in natural sea water: Deep-Sea Research, v. 14, p. 203-220.

Dyrssen, David, 1965, A Gran titration of sea water on board Sagitta: Acta Chimica Scandia, v. 19, no. 5, p. 1265.

Edmond, J. M., 1970, High precision determination of titration alkalinity and total carbon dioxide content of sea water by potentiometric titration: Deep-Sea Research, v. 17, p. 737-750.

Gran, G., 1952, Determination of the equivalence point in potentiometric titrations. Part II: Analyst, v. 77, p. 661-671.

Hobbie, J. E., and Likens, G. E., 1973, Output of phosphorus, dissolved organic carbon, and fine particulate carbon, from Hubbard Brook watersheds: Limnology and Oceanography, v. 18, no. 5, p. 734-742.

Irwin, G. A., and Lemons, Michael, 1975, A summary of selected chemical-quality conditions in 66 California streams, 1950-1972: U.S. Geological Survey Open-File Report, 104 p.

Jaeger, J. E., 1973, The determination of salinity from conductivity, temperature, and pressure measurements, in Danielson, W. R., ed., Second S/T/D/ Conference and Workshop Proceedings: Plessey Environmental Systems, San Diego, California, p. 29-43.

Kahrl, W. L., 1978, California Water Atlas: Governor's Office of Planning and Research, 118 p.

Kaplan, L. A., Larson, R. A., and Bott, T. L., 1980, Patterns of dissolved organic carbon in transport: Limnology and Oceanography, v. 25, no. 6, p. 1034-1043.

Kennedy, V. C., and Malcolm, R. L. 1977, Geochemistry of the Mattole River of Northern California: U.S. Geological Survey Open-File Report 78-205, 324 p.

Lewis, E. L., and Perkin, R. G., 1978, Salinity: its definition and calculation: Journal of Geophysical Research, v. 83, no. CI, p. 466-478.

Lewis, W. M., Jr, and Grant, M. C., 1979, Relationships between stream discharge and yield of dissolved substances from a Colorado mountain watershed: Soil Science, v. 128, no. 6, p. 353-363.

Liss, P. S., 1976, Conservative and nonconservative behavior of dissolved constituents during estuarine mixing, in Burton, J. D., and Liss, P. S., eds., Estuarine Chemistry: Academic Press, London, p. 93-130.

Livingstone, D. A., 1963, Chemical composition of rivers and lakes. Data of Geochemistry: U.S. Geological Survey Professional Paper 440G, 64 p.

Lock, M. A., and Hynes, H. B. N., 1976, The fate of dissolved organic carbon derived from autumn-shed maple leaves (Acersaccharum) in a temperate hard-water stream: Limnology and Oceanography, v. 21, no. 3, p. 436-443.

Loder, T. C., and Reichard, R. P., 1981, The dynamics of conservative mixing in estuaries: Estuaries, v. 4, no. 1, p. 64-69.

Menzel, D. W., and Vaccaro, R. F., 1964, The measurement of dissolved and particulate carbon in sea water: Limnology and Oceanography, v. 9, p. 138-142.

Merrill, R. E., Van De Pol, R. M., and Ryley, W. E., 1979, Sources of pollution from agricultural drainage: Proceedings of the American Society of Civil Engineers, v. 105, no. IR2, p. 137-145.

Meybeck, Michel, 1981, River transport of organic carbon to the ocean, in Likens, G. E. and others, eds., Flux of organic carbon by rivers to the oceans: U.S. Department of Energy, CONF-8009140, p. 219-269.

Moeller, J. R., Minishall, G. W., Cummins, K. W., Petersen, R. C., Cushing, C. E., Sedell, J. R., Larson, R. A., and Vannote, R. L., 1979, Transport of dissolved organic carbon in streams of differing physiographic characteristics: Organic Geochemistry, v. 1, p. 139-150.

National Oceanic and Atmospheric Administration, 1980, Local climatological data, Sacramento, California, Executive Airport: Department of Commerce, Asheville, North Carolina, 12 p.

Nordin, C. F., Jr., and Meade, R. H., 1981, The flux of organic carbon to the oceans: Some hydrological considerations, in Likens, G. E. and others, eds., Flux of organic carbon by rivers to the oceans: U.S. Department of Energy, CONF-8009140, p. 173-218.

Schemel, L. E., 1981, Transport and distribution of dissolved organic and dissolved inorganic carbon in the San Francisco Bay estuarine system: Estuaries, v. 4, no. 3, p. 251-252.

Schemel, L. E., and Dedini, L. A., 1979, Particulate organic carbon in San Francisco Bay, California, 1971-1977: U.S. Geological Survey Open-File Report 79-512, 30 p.

Sholkovitz, E. R., 1976, Flocculation of dissolved organic and inorganic matter during the mixing of river water and seawater: Geochimica et Cosmochimica Acta, v. 40, p. 831-845.

Stumm, Werner, and Morgan, J. J., 1981, Aquatic Chemistry, Second ed.: John Wiley and Sons, Inc., New York, 780 p.

Tanji, K. K., 1981, California irrigation return flow case studies: Proceedings of the American Society of Civil Engineers, v. 107, no. IR2, p. 209-219.

U.S. Geological Survey, 1981a, Water Resources Data for California, v. 4: U.S. Geological Survey Water-Data Report CA-80-4, 451 p.

--- 1981b, Water Resources Data for California, v. 3: U.S. Geological Survey Water-Data Report CA-80-3, 429 p.

Wetzel, R. G., and Otsuki, Akira, 1974, Allochthonous organic carbon of a marl lake: Archiva Hydrobiologia, v. 73, no. 1, p. 31-56.

APPENDIX

Table A. Bridge sample locations.

Bridge sample locations	Lat (N.)	Long (W).	State highway
Old River (San Joaquin)	37°53.5'	121°34.2'	4
Middle River (San Joaquin)	37°53.5'	121°29.3'	4
San Joaquin River at Stockton	37°55.7'	121°19.6'	4
Mokelumne River at Terminous (Potatoe Slough).	38°06.9'	121°29.8'	12
Mokelumne River at Perrys Hbr.	38°07.5'	121°34.7'	12
Sacramento River at Rio Vista	38°09.5'	121°41.0'	12
Sacramento River at Isleton	38°10.3'	121°35.6'	160
Sacramento River at Walnut Grove.	38°14.5'	121°30.8'	160
Georgiana Slough at Walnut Grove.	38°14.3'	121°31.0'	-
Sacramento River at Paintersville	38°19.1'	121°35.0'	160
Sacramento River at Freeport	38°27.3'	121°30.0'	160

Table B. Monthly flow summary for the Sacramento-San Joaquin river Delta, 1980.

	Sacramento River		San Joaquin River		East Side Rivers			Total Demand		
	Monthly flow ($10^9 m^3$)	Percent of total delta inflow	Monthly flow ($10^9 m^3$)	Percent of total delta inflow	Monthly flow ($10^8 m^3$)	Percent total delta inflow	Total delta inflow ($10^9 m^3$)	Monthly flow ($10^8 m^3$)	Percent of total delta inflow	Estimated delta outflow ($10^9 m^3$)
January	6.9	82	0.93	11	6.0	7	8.6	4.1	5	8.2
February	6.8	79	1.3	15	5.2	6	8.6	3.8	4	8.2
March	5.6	72	1.8	23	3.5	5	7.8	3.2	4	7.5
April	1.6	65	0.75	30	1.3	5	2.5	4.7	19	2.0
May	1.2	58	0.75	36	1.3	6	2.1	5.1	25	1.6
June	1.3	72	0.39	22	1.2	7	1.8	6.6	36	1.1
July	1.4	81	0.26	15	0.7	4	1.7	8.6	51	0.8
August	1.1	85	0.16	12	0.4	3	1.3	9.9	77	0.3
September	1.1	77	0.27	19	0.5	4	1.4	7.8	55	0.7
October	0.8	71	0.29	26	0.3	3	1.1	6.6	58	0.5
November	0.7	72	0.22	23	0.5	5	1.0	5.4	57	0.4
December	1.2	85	0.20	14	0.2	1	1.4	5.2	36	0.9
total	29.7		7.32		21.1		39.3	71.0		32.1

Table C. Salinity, specific conductance, alkalinity, and dissolved and particulate organic carbon in Sacramento River water at Rio Vista, 1980.

Date	Salinity ($^{o}/oo$)	Specific Conductance (μmhos cm^{-1})	Alkalinity (meq L^{-1})	DOC (mg L^{-1})	POC (mg L^{-1})
09 JAN+	0.029	208	1.401	4.4	---
21 JAN	---	---	1.111	5.0	---
26 JAN	---	---	1.285	6.4	---
31 JAN	0.147	441	1.302	18	---
02 FEB	0.022	209	1.359	19	---
04 FEB	---	---	1.464	4.4	---
06 FEB+	0.015	196	1.339	2.8	---
09 FEB	0.021	229	1.436	4.7	---
13 FEB	0.002	201	1.311	5.1	---
16 FEB	0.022	244	1.481	3.7	---
19 FEB	-0.038	138	0.846	4.6	---
21 FEB	-0.028	162	1.165	5.2	---
25 FEB	-0.019	144	1.113	3.6	---
28 FEB	-0.010	163	1.225	2.9	---
01 MAR	0.006	196	1.391	3.0	---
03 MAR	---	---	1.348	3.0	---
05 MAR+	---	---	1.100	3.1	---
07 MAR	0.006	181	1.137	2.8	---
10 MAR	0.018	203	1.417	3.0	---
13 MAR	0.049	260	1.616	3.2	---
17 MAR	0.011	188	1.309	9.5	---
19 MAR	0.031	227	1.546	3.7	1.2
22 MAR	0.121	393	1.610	4.2	---
25 MAR	0.009	185	1.283	3.3	0.6
29 MAR	0.034	231	1.515	3.8	0.4

+ denotes sample taken from R/V Polaris.

Table C. Continued

DATE	Salinity (°/oo)	Specific Conductance (µmhos cm^{-1})	Alkalinity (meq L^{-1})	DOC (mg L^{-1})	POC (mg L^{-1})
01 APR	0.090	334	1.315	2.5	0.5
04 APR	0.021	207	1.334	2.6	0.4
07 APR	0.018	200	1.307	2.3	0.3
09 APR+	0.012	199	1.269	2.6	---
11 APR	0.031	219	1.355	2.8	0.5
15 APR	0.019	197	1.277	2.3	0.7
19 APR	0.010	179	1.167	2.5	0.4
21 APR	0.007	177	1.145	2.1	0.5
23 APR+	0.000	162	---	2.3	0.7
28 APR	0.002	164	1.048	7.8	0.3
01 MAY	0.001	160	1.023	15	0.5
03 MAY	-0.001	154	0.991	14	0.6
05 MAY	0.001	159	0.999	2.0	0.5
08 MAY+	-0.012	153	0.992	2.2	1.1
12 MAY	0.005	181	1.104	7.3	0.6
15 MAY	0.012	193	1.202	6.8	0.7
17 MAY	0.014	197	1.228	9.5	0.6
19 MAY	0.014	197	1.215	2.8	0.5
22 MAY+	0.012	193	1.199	3.3	---
27 MAY	0.024	212	1.319	5.9	0.6
30 MAY	0.032	227	1.433	5.8	0.5
02 JUN	0.030	224	1.324	2.9	0.4
05 JUN	0.033	231	1.420	3.5	0.7
09 JUN	0.039	221	1.366	10	0.6
11 JUN	0.034	213	1.333	---	---
13 JUN	0.023	193	1.284	9.8	0.6
16 JUN	0.000	161	1.062	2.4	0.6
18 JUN	-0.002	156	1.029	---	---
20 JUN	0.006	180	1.032	2.0	0.3

+ denotes sample taken from R/V Polaris.

Table C. Continued

Date	Salinity ($^o/oo$)	Specific Conductance (μmhos cm^{-1})	Alkalinity (meq L^{-1})	DOC (mg L^{-1})	POC (mg L^{-1})
23 JUN	-0.010	146	1.000	2.0	0.4
26 JUN	-0.016	135	0.923	---	0.4
30 JUN	-0.011	145	0.932	2.0	0.3
02 JUL+	0.003	176	0.941	2.8	0.4
05 JUL	0.003	176	0.923	---	0.3
07 JUL	0.007	---	1.013	---	---
09 JUL	-0.002	156	1.035	7.4	0.4
11 JUL	0.019	206	1.063	2.9	0.3
14 JUL	-0.006	156	1.033	6.1	0.4
17 JUL+	0.001	163	1.060	3.5	0.7
21 JUL	-0.002	155	1.033	2.2	0.4
25 JUL	-0.005	151	1.016	3.1	0.4
28 JUL	0.009	181	1.012	2.2	0.3
01 AUG	-0.003	154	1.038	2.2	0.4
05 AUG+	-0.002	156	1.085	3.0	---
07 AUG	-0.003	161	1.140	2.1	0.3
12 AUG	0.002	175	1.221	2.4	0.4
15 AUG	0.007	181	1.253	2.0	0.3
19 AUG	0.013	192	1.379	2.5	0.4
22 AUG	0.013	194	1.407	2.8	0.3
26 AUG	0.014	196	1.445	2.2	0.4
29 AUG	0.069	297	1.401	5.0	0.4
04 SEP+	0.065	292	1.511	6.4	---
05 SEP	0.057	276	1.535	2.4	0.5
09 SEP	0.025	215	1.588	2.4	0.4
12 SEP	0.026	219	1.618	2.4	0.4
17 SEP+	0.025	223	1.632	2.9	0.2
19 SEP	0.026	221	1.628	3.1	0.3

+ denotes sample taken from R/V Polaris.

Table C. Continued

Date	Salinity (°/oo)	Specific Conductance (µmhos cm^{-1})	Alkalinity (meq L^{-1})	DOC (mg L^{-1})	POC (mg L^{-1})
23 SEP	0.025	220	1.581	3.1	0.3
27 SEP	0.013	196	1.377	4.9	0.3
30 SEP	0.008	188	1.306	1.9	0.3
06 OCT	-0.005	162	1.126	2.3	0.3
09 OCT	-0.006	159	1.104	1.8	0.4
11 OCT	-0.008	155	1.074	---	0.3
14 OCT	-0.010	153	1.086	2.2	0.2
16 OCT+	-0.005	158	1.130	3.1	---
20 OCT	-0.004	164	1.149	2.2	0.2
23 OCT	0.000	175	1.154	2.6	0.4
25 OCT	-0.002	169	1.160	2.6	0.4
27 OCT	0.035	203	1.181	2.3	0.5
29 OCT+	0.001	172	1.207	2.1	---
03 NOV	0.021	175	1.171	2.1	0.3
06 NOV	0.017	167	1.153	2.2	0.2
08 NOV	0.021	173	1.177	2.2	0.3
10 NOV	0.014	196	1.173	8.6	0.2
13 NOV+	0.012	164	1.133	2.6	---
17 NOV	0.000	168	1.139	7.9	0.2
20 NOV	0.000	168	1.131	4.8	0.3
22 NOV	0.000	168	1.125	11.7	0.3
24 NOV	0.022	212	1.160	9.0	0.3
28 NOV	0.000	170	1.126	7.7	0.3
01 DEC	0.000	168	1.150	14	0.3
04 DEC	-0.001	167	1.138	9.6	0.2
06 DEC	0.000	167	1.114	9.1	0.3
08 DEC	0.000	167	1.066	3.4	1.0
12 DEC	0.021	210	1.113	3.6	0.4
17 DEC+	0.008	183	1.288	2.6	0.3
26 DEC	---	---	1.141	17	---
29 DEC	---	---	1.142	19	---

+ denotes sample taken from R/V Polaris.

Table D. Results from samples collected from bridges in the Sacramento-San Joaquin river Delta- 1980.

Date:	13 June				6-8 July		12 September	
Sample Location	Sal.	Alk.	DOC	POC	Sal.	Alk.	Sal.	Alk.
Old River	0.058	0.954	6.2	0.6	8/ 0.043	1.064	0.090	1.456
Middle River	0.063	0.929	4.5	0.6	8/ 0.075	1.128	0.094	1.552
San Joaquin River	0.095	1.235	6.2	1.5	8/ 0.152	1.611	0.087	1.318
Potatoe Slough	0.012	1.006	3.5	0.5	8/ -0.034	—	0.027	1.579
Mokelumne River	0.013	1.158	3.7	0.6	8/ -0.011	1.035	0.023	1.621
Isleton	0.001	1.075	3.0	0.5	6/ -0.016	0.928	—	—
Sacramento River / Rio Vista	0.023	1.284	9.8	0.6	—	—	0.026	1.618
Walnut Grove	—	—	—	—	6/ -0.012	1.015	—	—
Georgiana Slough	—	—	—	—	6/ -0.014	0.974	—	—
Paintersville	—	—	—	—	6/ -0.011	0.995	—	—
Freeport	—	—	—	—	6/ -0.009	1.042	—	—

Table E. Small boal sample locations and salinity and alkalinity measurements. (navigation aid in parenthesis)

Sample Location	Lat (N.)	Long (W.)	Sample date	Sal. (^{o}/oo)	Alk. meq L^{-1}
Sacramento Ship Channel (55G)	$38^{o}16.5'$	$121^{o}39.2'$	07 Jul	0.006	1.020
Cache Slough (49G)	$38^{o}13.7'$	$121^{o}40.5'$	07 Jul	-0.009	0.978
Sacramento R. @ Ferry (41G)	$38^{o}11.5'$	$121^{o}39.5'$	07 Jul	0.236	0.969
Old Sacramento R. @ Isleton (6R)	$38^{o}0.09'$	$121^{o}37.6'$	07 Jul	-0.011	0.963
Old Sacramento R. @ Mathena Ldg.(8R)	$38^{o}11.7'$	$121^{o}33.6'$	07 Jul	-0.007	1.038
Sacramento R. @ Rio Vista	$38^{o}09.5'$	$121^{o}41.0'$	07 Jul	-0.008	1.013
Sacramento R. @ 3 mile Slough (19G)	$38^{o}06.8'$	$121^{o}42.5'$	07 Jul	0.002	0.936
3 mile Slough @ 7 mile Slough	$38^{o}06.9'$	$121^{o}40.9'$	07 Jul	-0.008	0.935
3 mile Slough @ San Joaquin R. (1)	$38^{o}05.1'$	$121^{o}41.1'$	07 Jul	-0.008	0.925
San Joaquin R. @ Bradford I. (26R)	$38^{o}03.9'$	$121^{o}40.5'$	07 Jul	0.005	1.021
San Joaquin R. (42R)	$38^{o}06.1'$	$121^{o}36.1'$	08 Jul	0.008	0.906
San Joaquin R. (57G)	$38^{o}03.7'$	$121^{o}33.3'$	08 Jul	0.006	0.948
San Joaquin R. (12R)	$38^{o}02.6'$	$121^{o}29.9'$	08 Jul	0.108	1.206
San Joaquin R. (24R)	$37^{o}59.8'$	$121^{o}26.6'$	08 Jul	0.144	1.373
San Joaquin R. (40R)	$37^{o}58.7'$	$121^{o}22.9'$	08 Jul	0.167	1.545

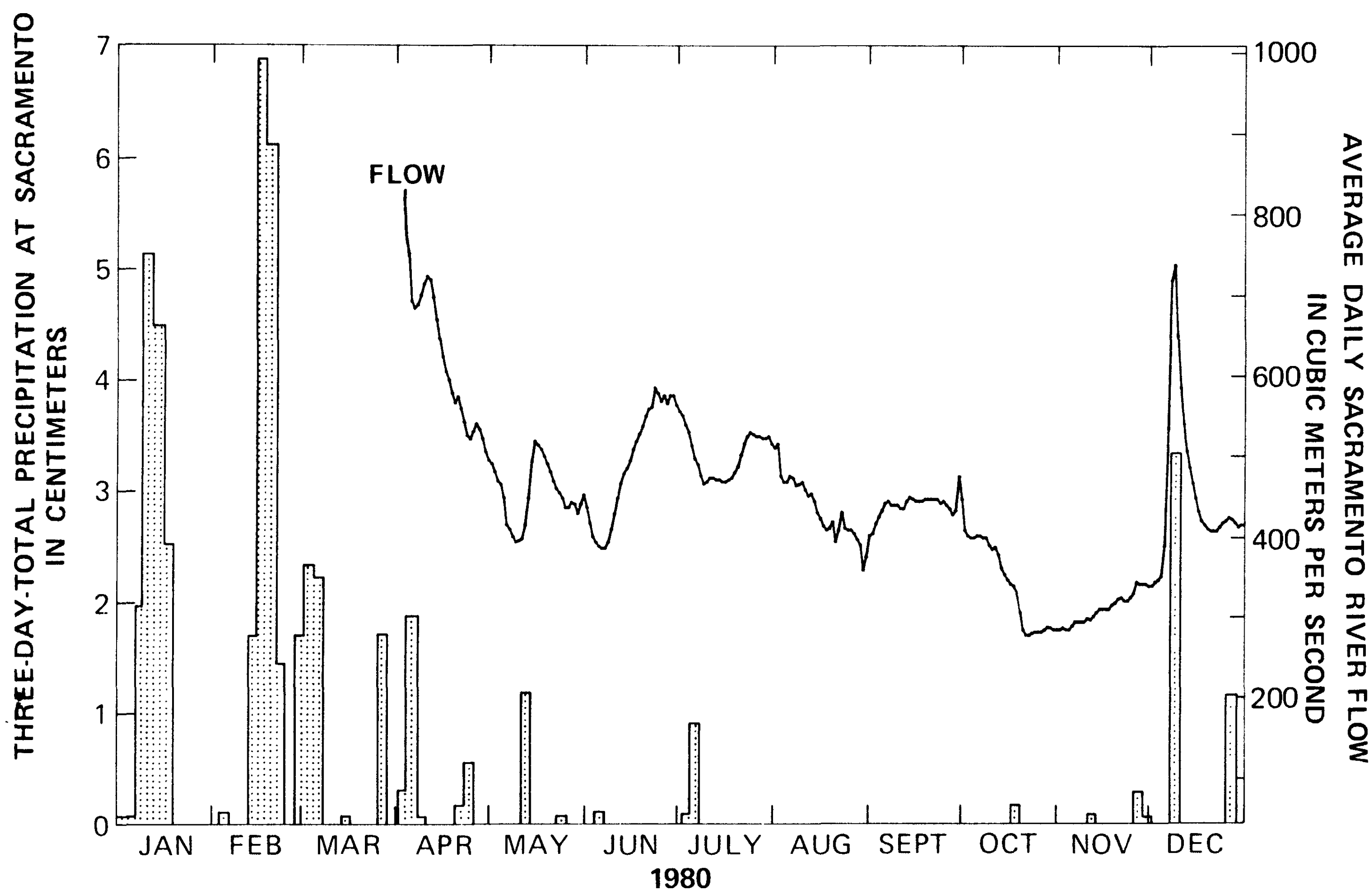

Figure A. Spring through fall average daily Sacramento River flow at Sacramento and three-day-total precipitation at Sacramento during 1980.

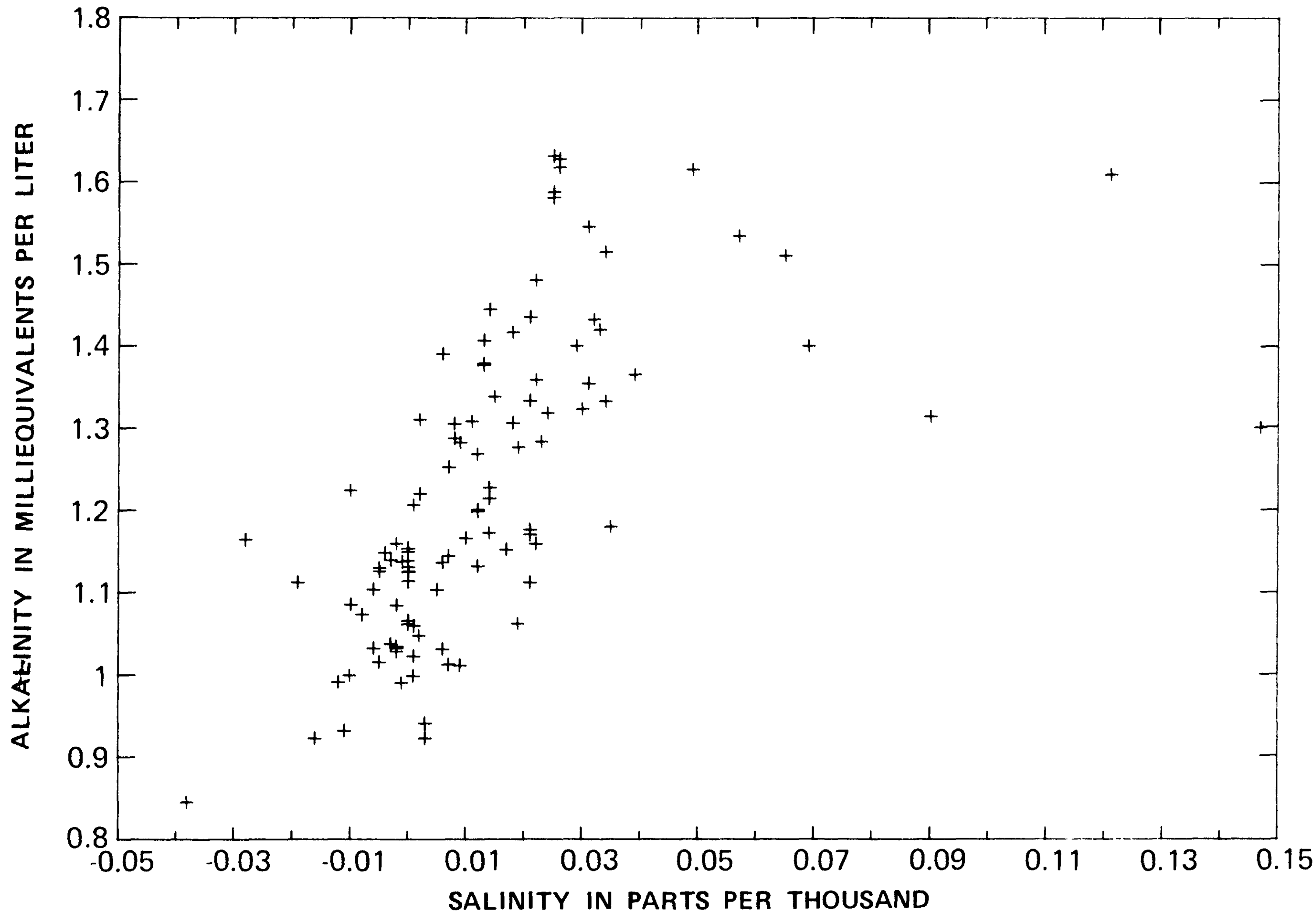

Figure B. Alkalinity with respect to salinity in the Sacramento River water at Rio Vista during 1980.