HYDROLOGY AND CHEMISTRY OF FLOODWATERS IN THE YOLO BYPASS, SACRAMENTO RIVER SYSTEM, CALIFORNIA, DURING 2000.

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CONTENTS

Appendix A

Appendix B: Illustrations

Appendix C: Tables

CONVERSION FACTORS

Metric are used in this report. Conversion factors to other commonly used units are provided here for the measurements made in this study.

Multiply	By	To obtain
µM (micromolar)	atomic weight	µg/L
kg (kilogram)	2.205	lb (pound)
m^3 (cubic meter)	35.3	ft^3 (cubic feet)

All gauge heights have been adjusted to the National Geodetic Vertical Datum of 1929 (NGVD of 1929).

The use of brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Hydrology and Chemistry of Floodwaters in the Yolo Bypass, Sacramento River System, California, during 2000.

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ABSTRACT

Discharges to and floodwaters in the Yolo Bypass were sampled during winter and spring, 2000. The primary purpose of the study was to link changes in water quality in the Yolo Bypass to inflows from the Sacramento River (over Fremont Weir) and from four local streams that discharge to the west side of the floodplain. Specific conductance, chloride, sulfate, dissolved inorganic nutrients, dissolved organic carbon, particulate carbon and nitrogen, suspended particulate matter (mass), and selected dissolved metals were measured in most of the samples. When the Sacramento River was spilling over Fremont Weir, the water chemistry in the Yolo Bypass was very similar to that in the river except along the western margin of the floodplain where influences of local stream inflow were evident. When flow over Fremont Weir stopped, floodwaters drained from the Yolo Bypass, and the local streams were the major discharges as the floodwaters receded eventually to the perennial channel along the eastern margin of the floodplain. After the initial draining of the floodplain, chemical concentrations at sites along the perennial channel showed strong influences of inflows from Cache Creek and Ridge Cut, which are sources of nutrients and contaminants that are potentially hazardous to wildlife. Runoff from spring storms increased flow in the perennial channel and flushed accumulated nutrients and organic matter to the tidal river. Releases of freshwater to the perennial channel might be beneficial in maintaining habitat quality for aquatic species during the dry seasons.

INTRODUCTION

The Sacramento River is the largest source of fresh water to San Francisco Bay Estuary. Studies of this estuary by the U.S. Geological Survey (USGS) require increasingly detailed knowledge of the factors that influence river discharge and the transport of dissolved and particulate substances to the estuary. Over the last century and a half, major modifications of this river system have changed the patterns of discharge and constituent transport from their natural states (for examples see Nichols and others, 1986). Among these modifications are numerous reservoirs and an extensive system of levees and bypasses that provide flood protection in the Sacramento Valley. The Yolo Bypass is the largest flood-control bypass. It prevents flooding of farmlands and municipalities near the city of Sacramento by diverting floodwaters at Fremont Weir and routing them directly to the head of the San Francisco Bay Estuary near Rio Vista (Fig. 1). In years when floodwaters flow to the bypass system, the Yolo Bypass is often a greater discharger to the estuary than the main channel of the Sacramento River (see Schemel and others, 1995).

In addition to the importance of the Yolo Bypass as a source of fresh water and riverine substances to the estuary, recent studies by the California Department of Water Resources (CDWR) and other agencies have shown that periodic flooding of the Yolo Bypass provides numerous ecological benefits, and that the Yolo Bypass is a potentially valuable asset for restoration of the Sacramento-San Joaquin River-Delta ecosystem. For example, the Yolo Bypass has been identified as an important habitat for fishes, migratory birds, and other wildlife that inhabit the floodplain seasonally or year round (Sommer and others, 2001a). The Yolo Bypass Wildlife Area was the largest wetland restoration project in the western states when it was dedicated by then-President Clinton in 1997, and it has since been enlarged. When inundated by Sacramento River inflow, the amount of shallow-water habitat available to aquatic species increases greatly and the Yolo Bypass becomes an important migration route for chinook salmon that provides better food and shelter than the main river channel (Sommer and others, 2001b). In addition to benefits to wildlife, large areas of the Yolo Bypass are used for irrigated agriculture when the floodplain is not inundated in late spring and summer. Therefore, the Yolo Bypass provides a diverse assortment of ecosystem and economic benefits in addition to flood protection.

Until recently, little was known about water quality in the Yolo Bypass. A preliminary investigation by USGS and CDWR in 1998 identified large changes in water quality with the onset of flooding and while the floodplain was draining (Schemel and Cox, 1999). The purpose of the study described in this report was primarily to link water quality in the Yolo Bypass to inflows from the Sacramento River and local streams that enter the west side of the floodplain. This report presents the methods, numerical data, and an overview of the results from the study during winter and spring 2000.

Hydrology of the Yolo Bypass

The Yolo Bypass occupies a small portion of an extensive area that was flooded during wet years before reclamation and flood control measures were implemented in the early 20th century. Starting in the mid-19th century, attempts to establish towns and reclaim marshlands in the Sacramento Valley were impeded by frequent episodes of severe flooding from the Sacramento River and its tributaries (Kelley, 1989). Accounts of the flood of 1862, the greatest flood in the recorded history of California, reported widespread inundation throughout the greater Sacramento-San Joaquin (Central) Valley of California (Brewer, 1966; Kelley, 1989). Precipitation during 1862 remains the highest on record (the longest record dates from about 1850 at Mission Dolores in San Francisco), but a recent year, 1998, had the second highest precipitation in the 150-year record. Although significant flooding occurred in the Sacramento Valley in 1998, as well as 1997, 1986, and other recent years, the aerial extent and the level of damage was limited in part because of the effectiveness of the Sacramento River bypasses (Teets and Young, 1986; Kennedy, 1997).

The inadequacy of levees alone to contain the Sacramento River during major floods of the early 1900's led to the design of the existing system of levees, weirs, and bypasses (Kelley, 1989). Most of the basic features of this system were in place by the early 1930's, but several large reservoirs constructed more recently as components of State and Federal water projects now provide additional protection from flooding. Even though the design capacity of the Yolo Bypass (in the range of approx. 14,000 to 15,000 m^3s^{-1}) was exceeded in February 1986, extensive flooding was prevented largely by regulation of reservoir discharges (Fig. 2).

The CDWR DAYFLOW program, an accounting of gauged river and stream flows, provides estimates of daily mean discharges in the Yolo Bypass and in the major rivers that flow to San Francisco Bay Estuary for water years since 1956 (a water year is October through September; DAYFLOW program documentation and data are available at http://www.iep.water.ca.gov/dayflow/). DAYFLOW underestimates discharges from the Yolo Bypass when values are in the low range and when the floodplain is draining because the estimates are computed from gauged inflows (see below). Comparisons of daily mean discharges in the Sacramento River main channel at Freeport to DAYFLOW estimates in the Yolo Bypass show that discharges at Freeport rarely exceed the range of 2000-3000 m^3s^{-1}, but that the Yolo Bypass flows can be nearly five times higher (Fig. 2). Discharge through the Yolo Bypass increases rapidly when flow at Freeport reaches about 2000 m^3s^{-1}, indicating that floodwaters exceed the height of Fremont Weir at that level of flow (see Schemel and others, 1996, for details). Major inundation of the floodplain is caused primarily by discharge over Fremont Weir. Sacramento Weir contributes additional floodwaters from the Sacramento River only during the highest flows, and its discharge typically is much smaller than that over Fremont Weir.

A (perennial) channel along the eastern margin of the Yolo Bypass carries discharges from local streams and agricultural irrigation, as well as return discharges supplied by a network of canals that cross the floodplain (see CALFED, 2001, for details). During the storm season, floodwaters are contained in the perennial channel when flows in the Yolo Bypass are less than about 100 m^3s^{-1}. At higher discharges, flooding extends toward the levees along the western margin. The deepest part of the Yolo Bypass is along the eastern margin, but the mean water depth across the floodplain is typically only 2-3m. As discharge decreases, shallower areas along the western margin become exposed as water drains southward and eastward and eventually is confined primarily to the perennial channel.

Weather and climate are highly variable in northern California (Cayan and Peterson, 1989; Cayan and others, 1999). Consequently, the timing, extent, and duration of flooding in the Yolo Bypass vary greatly from year to year. Inundations of the Yolo Bypass have occurred as early as October and as late as June, but most major inundations have occurred during the winter months. In the 45-year DAYFLOW record, daily mean discharges exceeding about two-thirds of the capacity of the Yolo Bypass have occurred only in two years, 1986 and 1997 (Fig. 2). Discharges in the Yolo Bypass have exceeded those in the lower Sacramento River channel at Freeport in over one-third of the years. Daily mean flow exceeded 1000 m^3s^{-1} in 26 of the years, and the average duration of flow at this level or higher among those years was 25 days. Although the high inter-annual variability makes generalizations misleading, daily mean flow for the average year exceeded 100 m^3s^{-1} for about 41 days and 1000 m^3s^{-1} for about 14 days over the 45-year record. Daily mean flows of 100 m^3s^{-1} or greater exceed the capacity of the perennial channel along the eastern margin, which can be considered the onset of floodplain inundation. In 10 of the 45 years, daily mean flow did not exceed 100 m^3s^{-1}, and there was no appreciable flow through the Yolo Bypass during the six consecutive years of severe drought following the major flood of 1986 (Fig. 2).

Inflows from the local streams that enter the western margin of the Yolo Bypass generally are small in comparison to floodwater discharges over Fremont Weir. However, local streams are often the greatest sources of freshwater to the floodplain in autumn and spring and in dry years when Sacramento River water does not spill over the weirs. Localized flooding in the Yolo Bypass early in the storm season is often caused by local stream discharges. Even though discharges from the local streams are a small fraction of the total flow during inundation periods, these inflows can be identified in aerial photographs as distinct bands extending to the southern outlet along the shallow western margin of the Yolo Bypass during most years (Sommer and others, 2001a).

Cache Creek and Putah Creek are gauged several kilometers upstream of the Yolo Bypass (Anderson and others, 2001; Fig. 1). Discharges from both of these streams are affected by reservoirs as well as storm runoff. Willow Slough, a much smaller discharger that is not gauged, carries storm runoff and possibly agricultural and other discharges. Ridge Cut conveys water from the Colusa Basin Drain directly to the Yolo Bypass primarily when water levels in the Sacramento River at Knights Landing are too high to allow gravity flow to the river (CDWR, 1964). The Colusa Basin Drain receives inflow from some creeks as well as discharges and runoff from the Colusa agricultural basin. Although a gauge on the Colusa Basin Drain measures discharge to the Sacramento River near Knights Landing, this gage is not rated for discharge to the Yolo Bypass via Ridge Cut. Discharge to the Yolo Bypass depends on Sacramento River and Colusa Basin Drain gauge heights and other factors such as the condition of the earthen weir at the eastern end of Ridge Cut and water elevations in the Yolo Bypass. Aerial observations suggest that the inflows from Ridge Cut and Cache Creek are the largest of the four local streams.

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METHODS

Samples were collected primarily at three (fixed-location) sites along the eastern margin of the Yolo Bypass (hereafter called HWY5, HWY80, and Lower Bypass) and at upstream (fixed-location) sites on four local streams that discharge to the western margin of the floodplain (Ridge Cut, Cache Creek, Willow Slough, and Putah Creek; Fig. 1). Two of the Yolo Bypass sites were located near the major highway causeways of Interstate 5 and 80. Ridge Cut was sampled at the road 16 bridge; Cache Creek was sampled near the road 113 bridge; Willow Slough was sampled near the road 102 bridge; Putah Creek was sampled near the Old Davis Road bridge. Additional sites that were not sampled on a regular basis included the Sacramento River near the western end of Fremont Weir and the Colusa Basin Drain near the road 99E bridge. For safety reasons, most samples were collected within a few feet of shore. A few additional samples were collected by boat across the flooded area of the Yolo Bypass and near its southern outlet during and after inundation by the Sacramento River.

A bulk sample of near-surface water was collected with a plastic bucket at each site. Sub-samples were poured into pre-combusted glass bottles for dissolved organic carbon and particulate carbon and nitrogen, and into acid-cleaned polyethylene bottles for specific conductance, sulfate, chloride, selected metals, and dissolved nutrients. Samples were returned to the laboratory in ice chests for processing on the following day. In some cases, samples from the Lower Bypass site were refrigerated for up to five days and then shipped overnight for processing in the laboratory.

The sample processing details are provided in Appendix A. In brief, samples for dissolved organic carbon and particulate carbon and nitrogen were filtered with pre-combusted glass fiber filters, whereas samples for dissolved nutrients, chloride, sulfate, and dissolved metals were filtered with cellulose ester membrane filters. Filtrates for dissolved organic carbon (and UV absorption) were stored in pre-combusted brown glass bottles with Teflon caps in a refrigerator at 4C° before analysis on a MQ1001 TOC analyzer. Absorbance at 254nm was determined on freshly filtered samples using a 1-cm quartz cuvette in a Beckman DU spectrophotometer. Glass fiber filters containing particulate carbon and nitrogen were dried in a dessicator before analysis on a Carlo Erba Instruments Model NA 1500NC analyzer. Filtrates for dissolved nutrients (nitrite, nitrate, ammonium, dissolved silica, and dissolved reactive phosphate) were stored in acid-cleaned polyethylene bottles and frozen. Nutrient samples were thawed overnight before analysis on a Technicon AutoAnalyzer II (Hager and Schemel, 1997). Samples for sulfate and chloride were refrigerated until analysis on a Dionex LC20 ion chromatograph. Samples for dissolved metals (total of 18 metals, see below) were acidified with nitric acid and stored at room temperature until analysis on a Thermo Jarrell Ash Corp. IRIS Advantage inductively coupled plasma optical emission spectrophotometer (ICP-OES). Specific conductance was measured by electrode in the laboratory at 25C.

Discharge and water level data for the Sacramento River, local streams, and the Yolo Bypass were obtained from the USGS annual report (Anderson and others, 2001) or internet sites maintained by USGS (http://water.usgs.gov/nwis/discharge/) and CDWR (http://www.iep.water.ca.gov). The CDWR Northern District Office in Sutter, CA, provided gauge height data for the Sacramento River and the Colusa Basin Drain at Knights Landing. All gauge heights were adjusted to the National Geodetic Vertical Datum of 1929.

RESULTS

Results from this study are presented within the context of the weather and hydrology during the study period, January-May 2000. The study period was preceded by a dry autumn, during which precipitation was less than half of the normal amount in northern California. Precipitation was above normal in January and February 2000, but precipitation fell to below-normal level again in March. Although much lower than the level during a typical winter, precipitation in spring 2000 was nearly normal. Among the last 45 years, Yolo Bypass discharge for the 2000 water year ranked 19th and was less than average.

Precipitation at Davis, CA, is not representative of the entire Sacramento River drainage basin, but it is useful here as an indicator of precipitation carried by the local streams that discharge to the western margin of the Yolo Bypass and the Colusa Basin Drain (Fig. 3). Daily precipitation was highest during the period from late January to early March, but the subsequent period from mid-March to mid-April was unusually dry. This break in the storm sequence coincided with a large increase in solar radiation (irradiance; Fig. 3) and maximum daily air temperature (Fig. 4). High-speed winds (Fig. 4) coincided with precipitation in February, but high-speed winds did not coincide with precipitation in mid-March and early April 2000, the period during which the Yolo Bypass was draining (see below).

Precipitation increased flow in the Sacramento River in January and early February, but the river did not exceed the height of Fremont Weir until February 14 (Fig. 5). Discharge over Fremont Weir to the Yolo Bypass continued until March 17. Water levels in the Sacramento River remained below the height of Fremont Weir for the remainder of the study. Discharges in the Yolo Bypass were lower than those in the Sacramento River during the single 4-week-long period of inundation by discharge over Fremont Weir (the inundation period). There was no discharge over Sacramento Weir during the 2000 water year.

Local streams discharged to the Yolo Bypass before, during, and after the inundation period (Fig. 6). Storm-driven pulses in discharge are clearly apparent in the hydrograph from Cache Creek, whereas only much smaller pulses and a continuous release during March are shown for Putah Creek. Discharges from both creeks decreased to low levels in early April, but precipitation in late April coincided with a distinct flow pulse in Cache Creek that was not seen in the gauge data from Putah Creek. Although not gauged, field notes taken during sample collection indicated that Willow Slough also exhibited storm-driven pulses, but discharges were much lower than those from the other creeks.

Under conditions of low water levels, as in early January 2000, the Colusa Basin Drain discharges by gravity directly into the Sacramento River at Knights Landing (Fig. 7). When the level of the river exceeds that of the Colusa Basin Drain, as in late January through March 2000, Colusa Basin discharge is diverted to the Ridge Cut canal and flows directly to the Yolo Bypass (CDWR, 1964). It is difficult to estimate discharge from Ridge Cut because it is the product of runoff from the basin and often rapidly changing water levels in the Sacramento River. Observations at the sampling site indicated that discharge from Ridge Cut might have been similar in magnitude to that from Cache Creek or even greater at times. The short-term variations in river level in late April presumably produced a pulse discharge from Ridge Cut. Therefore, it appears that gauge height variations at the HWY5 and Lower Bypass sites in late April were caused primarily by discharges from both Ridge Cut and Cache Creek (Fig. 7).

The gauge heights from the two locations in the Yolo Bypass show that water levels decreased over a near-month-long period beginning about a week before the Sacramento River stopped spilling over Fremont Weir to early April (Fig. 7). Local Streams continued to discharge after inflow from the river stopped and floodwaters were draining from the Yolo Bypass to the Sacramento River near Rio Vista. Flow was largely confined to the perennial channel by mid-April, although it is likely that canals continued to drain areas of the floodplain (see Discussion). Water levels at the Lower Bypass site were influenced by tides from the estuary both before the inundation period and after the draining period (Fig. 7).

Results from the Fixed-Location Sites

Although concentrations of many chemical constituents in Yolo Bypass waters might be related directly to supply rates from the river or the local streams, concentrations in some cases might be strongly affected by chemical and biological processes occurring in the Yolo Bypass. In presentation of the chemical data, concentrations in the Yolo Bypass are compared with those in the river and local streams to identify potential sources with the understanding that processes in addition to simple mixing might be important.

Results from the fixed-location sites are shown in the following figures 8-23(Appendix B), with the exception of values from the Sacramento River at Fremont Weir, which are summarized in Table 1. Numerical values for all samples are given in Tables 2-5 (Appendix C).

Specific conductance (SPC) is a property of natural waters that is related to the abundance of dissolved ions, and therefore can be an indicator of overall changes in water chemistry. All three sites in the Yolo Bypass showed similar variations in SPC over this study (Fig. 8). SPC was high until mid-February, when values decreased to levels consistent with those in the Sacramento River discharge over Fremont Weir (Table 1). In mid-March, SPC began to increase sharply, reaching pre-inundation levels by early April. During this period, SPC typically was highest at the HWY5 site and lowest at the Lower Bypass site. Precipitation and runoff from the small storm in late-April coincided with a decrease in SPC values.

Local streams were more important to water quality in the Yolo Bypass when there was little or no discharge over Fremont Weir. During the inundation period, SPC in the Yolo Bypass was much lower than values in the four local streams. In general, SPC values in the local streams increased from mid-March to mid-April; however, SPC remained low in Putah Creek during the short period when its discharge was substantial in late March. SPC values in Ridge Cut were among the highest in the local streams. SPC values in late March were highest in Willow Slough. Field notes indicated that discharge was very low in Willow Slough in late March, but discharge had increased in April and May when SPC values were lower.

Chloride, a major anion, exhibited variations in concentrations in the Yolo Bypass and in the local streams that were very similar to SPC (Fig. 9). Chloride concentrations showed a near-linear increase with respect to increasing SPC at all of the sites, although the data were scattered in a few cases. The correlation was good, in part, because concentrations of chloride were high and chloride is transported conservatively through many freshwater systems. This was also the case for some dissolved metals (see below), but correlation with nutrients, for example, was poor presumably because of their high biological reactivity.

Concentrations of sulfate were lowest during the inundation period, which was consistent with values in the Sacramento River (Fig. 10; Table 1). Concentrations increased from mid-March to mid-April at all three Yolo Bypass sites, but then dropped to levels that were lower than those before the inundation period. With few exceptions, sulfate was much more concentrated in Ridge Cut than in the other local streams. From mid-March to mid-April, concentrations of sulfate in the Yolo Bypass exceeded concentrations in the local streams except for Ridge Cut, indicating that Ridge Cut was a major discharger to the Yolo Bypass. The decrease in sulfate concentrations in the Yolo Bypass in late April was consistent with reduced concentrations in Ridge Cut and discharge pulses from Cache Creek and Ridge Cut.

Dissolved inorganic nitrogen (DIN), the total concentration of nitrite, nitrate, and ammonium, was relatively low in the Yolo Bypass and in the river during the inundation period (Fig. 11; Table 1). DIN concentrations in the Yolo Bypass increased from late March to mid-April, but decreased at the Lower Bypass site following late-April precipitation and runoff. DIN concentrations in the local streams also were lowest during the inundation period, but increased substantially in all but Ridge Cut from late March through May. The two highest values for DIN in the Yolo Bypass were at HWY5 in April (270 µM) and May (226 µM), and these values appeared more likely related to inflow from Cache Creek than from Ridge Cut. Most of the DIN was nitrate at all sites throughout this study (see Table 3).

Although ammonium is often applied as a fertilizer and can be present in agricultural runoff and other wastewaters, it also can be an indicator of organic matter degradation and nutrient regeneration processes. During the inundation period, ammonium concentrations were low at the Yolo Bypass sites and in the river (Fig. 12; Table 1). Increases after mid-March were greatest at the HWY80 and Lower Bypass sites. Ammonium concentrations in Ridge Cut were typically higher than in the other local streams with the exception of Willow Slough in mid-April. Cache Creek and Putah Creek typically were lowest in ammonium, often less than half the concentration in Ridge Cut. Concentrations of ammonium were greater than nitrite but much lower than nitrate at all sites during this study.

Dissolved reactive phosphate (DRP) concentrations at the Yolo Bypass sites and in the river were also low during the inundation period, but values increased sharply in the Yolo Bypass after mid-March (Fig. 13; Table 1). DRP concentrations decreased at the Lower Bypass site during the late-April precipitation and runoff, but increased again in May. Although DRP concentrations in Putah Creek were higher than in the other local streams in April and May, inflow from Putah Creek was probably minimal after early-April, and Putah Creek inflow could not have affected concentrations at the HWY5 and HWY80 sites (Fig. 13). Concentrations at the Yolo Bypass sites in mid-April and May were generally higher than would be expected if Cache Creek and Ridge Cut were the major sources of DRP.

Dissolved silica is a nutrient that is particularly important for the growth of diatoms, which are a highly nutritious energy source to primary consumers. In contrast to most of the dissolved constituents presented thus far, the highest concentrations of dissolved silica at all three Yolo Bypass sites occurred during the inundation period (Fig. 14). These concentrations were consistent with high concentrations in the Sacramento River (Table 1). Concentrations decreased after mid-March to a minimum in early-April, which was followed by an increase and finally a decrease near the end of the study. Dissolved silica did not show a large change during the late-April precipitation and runoff, as has been shown for many of the other analytes. Concentrations of dissolved silica in Cache Creek and Ridge Cut were typically less than those in Putah Creek. Concentrations were highly variable in Willow Slough, and the values in late March were the lowest in this study (see Discussion).

Most of the organic carbon that is transported by rivers is usually in dissolved form (DOC). DOC at the Yolo Bypass sites was lowest during the inundation period, and then increased in late March to values that were relatively stable for the remainder of the study (Fig. 15; Table 1). Of the local streams, DOC was generally highest in Ridge Cut and lowest in Cache Creek. Although there were a few exceptions, DOC concentrations in Putah Creek and Willow Slough were similar to Cache Creek. Specific ultra-violet absorbance at 254nm (SUVA) was computed by dividing the absorbance value by the DOC concentration. All of the local stream and Yolo Bypass sites showed the same general pattern in that the SUVA values were highest during the inundation period (Fig. 16; Table 1). Generally, the high values indicated that the DOC consisted of more complex organic molecules during the inundation period than during the late winter and spring when DOC might contain more recently produced organic matter. Low SUVA values for recently produced organic matter indicate that it can be more easily utilized as an energy source.

The Sacramento River is the major riverine source of suspended particles to San Francisco Bay (see Schemel and others, 1995). Samples collected from the Yolo Bypass during this study are not representative of the concentrations of suspended sediments through the water column or across the floodplain, and in some cases samples from the streams might not be representative of their mean values as well. The Yolo Bypass is a relatively shallow floodplain, and resuspension of particles might be an important factor regulating concentrations. The highest concentrations in mid-February and late March were associated with periods of high winds(Figs. 17 and 4). Discharges from Cache Creek were high during the inundation period, and concentrations of suspended particles there were the highest among the local streams. However, Cache Creek discharges into a settling basin, and it was unlikely that all of the sediment reached the Yolo Bypass.

Composition of the suspended particles, particularly the organic matter content, was more important than concentrations to this study. Percent carbon of the suspended particles ranged from about 1 to 4 percent in most of the samples (Fig. 18). The percent carbon was unusually high (>10 percent) in Willow Slough in late March. Field notes indicated a high abundance of filamentous algae in the water and very low flow in the stream at that time.

The carbon to nitrogen ratio (C:N) is higher in detrital organic material compared to phytoplankton and other aquatic plants. In general, C:N ratios in the Yolo Bypass and in the local streams were high during the inundation period then decreased sharply in late March (Fig. 19). This is consistent with measurements made in the Yolo Bypass in 1998 (Schemel and Cox, 1999) and with chlorophyll samples collected in the Yolo Bypass and the local streams in 2000, which indicated an increase in algal biomass immediately following the inundation period and extending into the spring (Mueller-Solger, personal communication).

Dissolved Metals

Filtered samples were scanned for 18 metals using a radial-view (ICP-OES) method appropriate for parts-per-million-level concentrations. Seven of the metals, Cadmium, Cobalt, Copper, Manganese, Nickel, Vanadium, and Zinc, were not detected in concentrations significantly higher than the blank (less than 0.01 mg/L). In addition to these 7 elements, concentrations of Aluminum, Iron, and Lithium were mostly below 0.1 mg/L, and will not be reported here. Concentrations of Boron (B), Barium (Ba), Calcium (Ca), Potassium (K), Magnesium (Mg), Silicon (Si), Sodium (Na), and Strontium (Sr) generally exceeded 0.1 mg/L, and their values are reported in Table 5. Si also was measured as dissolved silica by a colorimetric method, and the ICP-OES results were very similar. Si by ICP-OES values averaged 13% higher than those by colorimetry, which could be explained by the dissolution of colloidal particles in the strong acid used to preserve the metals samples.

In general, concentrations were lowest (less than 4 mg/L) for B, Ba, K, and Sr. Concentrations exceeded 5 mg/L for Ca, Mg, and Na in all of the samples, including those from the Sacramento River, where concentrations were typically lowest among the fixed sites (Tables 1 and 5). Concentrations of these three most-concentrated metals increased in a near-linear manner with increasing specific conductance at most of the sampling sites, although scatter in the data was substantial in some cases. Among the less-concentrated metals, Sr concentrations exhibited good linearity with respect to specific conductance, while the others typically exhibited poor correlation. Results for Ca, Mg, Na, and Sr are described below.

All four metals showed a distinct drop in concentration in the Yolo Bypass upon inundation by the Sacramento River, an increase from mid-March to mid-April, and lower concentrations following the late-April runoff (Figs. 20-23). In some cases, large differences in concentrations among the local streams possibly could be used to identify major sources of waters in the Yolo Bypass. During most of the study, Na was much more concentrated in Ridge Cut than in Cache Creek or Putah Creek (Fig. 20). In the weeks following the inundation period, concentrations of Na were high at HWY5 and HWY80 relative to the Lower Bypass, where Sacramento River water was still draining from the floodplain. Low concentrations of Na in Putah Creek also could have influenced levels at the Lower Bypass site. Even though concentrations of Na were high in Willow Slough in late March, discharge was very low. Concentrations of Na at all three sites in the Yolo Bypass in mid-April were higher than levels in all of the local streams except Ridge Cut, which (as in the case of sulfate) indicated the importance of this inflow as waters became confined to the perennial channel.

Concentrations of Ca showed a pattern similar to Na in the Yolo Bypass, but the differences in concentrations among the local streams were not as great (Fig. 21). The differences in concentrations among the local streams were much less for Mg (Fig. 22). From mid-March to mid-April, little difference was seen in concentrations of Mg among the three sites in the Yolo Bypass. Differences between concentrations at HWY5 and HWY80 and concentrations at the Lower Bypass site were greater for Ca and greatest for Na. This pattern was also apparent for Sr, even though its concentrations were low compared to Na, Ca, and Mg (Fig. 23).

Samples collected by boat in the Yolo Bypass

Even though discharges over Fremont Weir are typically much greater than inflows from local streams during periods of inundation, discharge plumes from the local streams are often identifiable in aerial photographs. In some cases these inflows are prominent bands extending from their sources all the way to the southern outlet of the Yolo Bypass (Sommer and others, 2001a). In an attempt to locate discharge plumes from the local streams and to determine the extent of water from the Sacramento River, near-surface waters were sampled on four days (February 17-20) by boat shortly after the onset of major flooding. The samples were collected across the flooded bypass about half way between highway 80 and the southern outlet. Specific conductance and concentrations of nutrients and metals were consistent among three of the four sites on all four days, and only the site nearest the western margin of the floodplain had significantly higher concentrations, indicating the presence of discharge from local streams (see data tables). A local stream source could be identified on only two days. Concentrations of Na on February 18 and 20 were at levels consistent with discharge from Ridge Cut, the local stream with the highest Na values. Values for most of the analytes on most days were within the ranges for all four local streams, but these values were still significantly different (mostly higher) than concentrations in the Sacramento River discharge. Since Ridge Cut is the most upstream inflow, it is likely that plumes from the other local streams were confined to very shallow water along the western margin at that time.

Samples were collected by boat at locations near the southern outlet of the Yolo Bypass while the floodplain was draining after inundation (March 23) and after the floodplain had drained to the level of the perennial channel (April 11). Specific conductance, nutrients, and metal concentrations on March 23 were consistent with values at the Lower Bypass site, indicating discharge from the Yolo Bypass to the river. On April 11, however, values near the southern outlet were lower than those at the Lower Bypass site, indicating substantial dilution by tidal mixing with water from the Sacramento River.

DISCUSSION

Floodwaters from Fremont Weir were responsible for the major inundation of the floodplain from mid-February to mid-March, 2000. Even though 2000 was not a particularly wet winter, Sacramento River discharge to the floodplain was substantially greater than the total inflow from the local streams. Results from the samples collected by boat during the inundation period confirmed that surface waters were dominated by Sacramento River water and that local streams only affected the western margin. This is consistent with aerial photographs from previous years, although discharge plumes from local streams are probably more extensive in winters with higher discharges than 2000.

Discharge over Fremont Weir began to decrease in early March, and water levels in the Sacramento River dropped below the height of Fremont Weir in mid-March. Draining of the floodplain was rapid after mid-March, reaching the level of the perennial channel by early April. Observations made at the sites in the Yolo Bypass indicated that open water areas drained relatively quickly, followed by ponds and canals that cross the floodplain. Rapid draining of the open water areas is also indicated by the gauge height data from the Lower Bypass (Fig. 7). We expect that the numerous canals continued to drain shallow groundwaters from the floodplain for weeks after the inundation period.

During and after the draining period, the paths of discharges from the local streams to the perennial channel are not always clear and probably change as the floodplain is utilized for agriculture. An overview of water sources (including local streams and wells) and channels in the Yolo Bypass can be found in a recent management strategy report prepared for the CALFED Bay-Delta Program (CALFED, 2001). When water levels are still high in the Sacramento River relative to the Colusa Basin Drain, discharge from Ridge Cut can flow down a channel directly to the perennial channel upstream of our HWY5 site. Later in spring and in summer, gates in the Ridge Cut weir near the western levee of the Yolo Bypass supply water to irrigation water canals, and drainage canals route the return flow to the perennial channel. It appeared that some discharge from Ridge Cut was flowing directly to the perennial channel in mid-April, but that most of the flow from the Colusa Basin Drain was discharging to the Sacramento River at Knights Landing in May 2000.

Cache Creek also can flow directly to the perennial channel near our HWY5 site, but part of its flow can be diverted to an irrigation canal along the western levee of the Yolo Bypass. The primary flow of Cache Creek appeared to be runoff from precipitation during this study, and discharge directly to the perennial channel was evident as late as mid-April.

Willow Slough did carry runoff from storms during winter, but low-to-moderate discharges also were observed in April and even in May at times when storm runoff could not have been the source. During the three samplings from mid- to late-March, discharge was very low in Willow Slough, and concentrations of many dissolved analytes were high. Constituent transports to the Yolo Bypass in mid- to late-March were probably insignificant because of the low flows. At low water levels in the Yolo Bypass, Willow Slough discharge flows southward along the western levee to the basin at the end of Putah Creek. Water from this basin is used for agriculture and the return flows are routed to the perennial channel.

We noted that Putah Creek carried some runoff from the winter storms even though this was not evident in the gauge data. However, the major discharge during this study appeared related to reservoir releases extending to early April. Some of this water and discharge from Willow Slough could have been impounded in a basin on the floodplain, although a channel can carry overflow directly to the perennial channel. It is likely that neither Willow Slough nor Putah Creek discharged directly to the perennial channel after early April 2000. Discharge from Willow Slough and Putah Creek that reached the perennial channel could have influenced water chemistry at the Lower Bypass site, but not at HWY5 or HWY80. Discharges from numerous canals that carry agricultural return flows were probably more significant late in this study at the Lower Bypass site.

Although direct observations were lacking in some cases, it is likely that Cache Creek and Ridge Cut were the major direct sources of local stream flow to the perennial channel from mid-March to mid-April. This was indicated by the chemical data at both HWY5 and HWY80 in many cases. Groundwater, agricultural return flows, and perhaps other sources could have been significant in late April and May, when local streams probably did not flow directly to the perennial channel. These other sources could explain why some results from the Yolo Bypass sites were not consistent with the assumption that the local streams were the major sources, particularly at the Lower Bypass site.

The sharp increases in concentrations of many dissolved analytes in the Yolo Bypass immediately after the inundation period indicated a rapid transition from domination by Sacramento River water to increasing influence of waters from the local streams as floodwaters receded to the perennial channel. Generally higher concentrations at the HWY5 and HWY80 sites compared to those at the Lower Bypass site also suggest that Sacramento River water was draining southward in the floodplain and being replaced by water primarily from the two major local stream inflows, Cache Creek and Ridge Cut.

Mass balance calculations cannot be used to verify that Cache Creek and Ridge Cut are the major sources to the perennial channel because flows were not measured in Ridge Cut. However, the chemical data do suggest that the HWY5 and HWY80 sites were affected by discharge from Ridge Cut. Concentrations of Na and sulfate were much higher in Ridge Cut relative to the other local streams, including Cache Creek. In late March and early April, concentrations of Na and sulfate at HWY5 and HWY80 were between the values in Cache Creek and Ridge Cut, indicating that waters in the perennial channel were primarily a mixture of these two sources.

It is expected that concentrations of dissolved constituents vary greatly with discharge in both Cache Creek and Ridge Cut. Specific conductance (SPC) was used as a surrogate for discharge variability in order to examine fundamental differences in the chemical variability in these two streams. We pooled the data from our study with data collected at two-week or monthly intervals in the Colusa Basin Drain and in Cache Creek from February 1996 through April 1998 to see if different patterns emerged for Na and sulfate (Figs. 24 and 25; Domalgalski and Deleanis, 2000). Discharges were available for Cache Creek over this earlier study, and, generally speaking, the highest SPC values represented low discharges and the lowest SPC values corresponded to discharges that were higher than those in 2000. The relationships between Na and SPC were similar for the two local streams, but most of the values in the Colusa Basin Drain were grouped higher than those in Cache Creek. Consequently, Na can be a tracer for mixing when differences in concentration between the two streams are relatively large. The relationships between sulfate and SPC were clearly different for the two streams (Fig. 25). Most concentrations of sulfate in the Colusa Basin Drain were substantially higher than those in Cache Creek over a wide range of SPC values. Therefore, sulfate might be a good tracer of discharge from Ridge Cut at the Yolo Bypass sites over a wide range of hydrologic conditions. The extent to which sulfate can be altered by bacterial processes in the perennial channel is unknown, so we estimated the fraction of the total inflow that came from Ridge Cut at the HWY5 and HWY80 sites using concentrations of both Na and sulfate.

If we assume that the chemical concentrations were largely determined by two-component mixing, estimates can be based on the following relationship:

The receiving water concentration in the perennial channel [TD] = (the fraction of the total inflow contributed by Ridge Cut, QRC, times the concentration in Ridge Cut, [RC]) + (the fraction of total inflow contributed by Cache Creek, 1-QRC, times the concentration in Cache Creek, [CC]).

Rearranging the expression gives: QRC = ([TD] – [CC])/([RC] – [CC])

Simple two-component mixing models such as this have been useful in identifying sources of water to floodplain lakes (Forsberg and others, 1988; Carignan and Neiff, 1992).

Calculations for March 17, immediately after flow over Fremont Weir had stopped, gave very low QRC values because most of the water was from the Sacramento River. Calculations for March 23 gave comparable results for Na and sulfate at HWY5, 0.63 and 0.78, respectively, and HWY80, 0.78 and 0.72, respectively. Similarly, results for March 28 for Na and sulfate were: HWY5, 0.54 and 0.57, respectively, and HWY80, 0.39 and 0.40, respectively. The calculations for HWY5 suggest that the inflow from Ridge Cut was similar to or perhaps even greater than the inflow from Cache Creek over the two weeks following inundation by the Sacramento River. It is likely that channels draining the floodplain had a greater effect at HWY80, and that the Lower Bypass site also was affected by flow primarily from Putah Creek. Assuming the other local stream inflows had concentrations of Na and sulfate similar to Cache Creek, the calculations indicate that from 10 (Na value) to 29 (sulfate value) percent of the water in the Lower Bypass was from Ridge Cut on March 28.

Concentrations of dissolved inorganic N and P nutrients increased at the Yolo Bypass sites while the floodplain was draining and continued to increase in the perennial channel until the small flow pulse in mid-April. Depletion of these nutrients by biogeochemical processes, such as phytoplankton production, was not observed, indicating that the rate of supply by local streams and other sources and processes outweighed removal mechanisms. Over-enrichment of N and P nutrients can lead to nuisance algal blooms, particularly if depletion of dissolved Si occurs (see reviews by Conley and others, 1993, and Cloern, 2001). Dissolved Si was most concentrated in the Sacramento River inflow, but concentrations in the Yolo Bypass were reduced to about half that in the river by the end of March. Inflow from the local streams could account for at least some of this decline in dissolved Si, but removal by phytoplankton production probably was a factor as well (see below). It is most important to note that dissolved Si was never reduced to sub-micromolar concentrations indicative of Si limitation. However, the abundance of dissolved Si relative to the other nutrients was reduced to a level such that an intense diatom bloom would deplete dissolved Si from the water column before the other nutrients.

A recent USGS assessment of water and sediment quality in the Sacramento River Basin identified many sources of contaminants that can degrade habitats and pose risks to aquatic and other species, including human beings (Domalgalski and Deleanis, 2000). Some of these contaminants are derived from natural sources, such as mercury (Hg) deposits in the coastal range watershed, whereas other contaminants are products of human activities, such as pesticides from agricultural applications and urban runoff. During winter, a large fraction of the runoff from the Sacramento River Basin can flow through the Yolo Bypass carrying dissolved and particulate contaminants to the Delta and San Francisco Bay (for example; Domagalski and Kuivila, 1993; Bergamaschi and others, 2001). Undoubtedly, some contaminants from the Sacramento River can be trapped in the Yolo Bypass as the floodplain begins to drain. In addition, local stream inflows, irrigation return flows, and discharges from the local urban areas are potential sources of contaminants to the Yolo Bypass. The Yolo Bypass provides habitat for a wide range of aquatic organisms, migratory birds, and many other species, which could be affected by contaminated waters and sediments.

Ridge Cut and Cache Creek were identified above as major sources of discharge to the Yolo Bypass for weeks after the inundation of the floodplain by Sacramento River discharge. The Colusa Basin Drain is the source of water for Ridge Cut. Irrigation return flow is typically a large fraction of the water in the Colusa Basin Drain, and this water can be substantially enriched in dissolved salts, sediments, and chemicals derived from agricultural activities in the Basin (for example see Schemel and others, 1989, and references therein). The Colusa Basin Drain is a major source of pesticides and their degradation products particularly during spring (Domagalski, 1996 and 2000). Similarly, many canals carry return flows to the perennial channel from agricultural areas in the Yolo Bypass floodplain from spring through summer. Pesticides and their degradation products that have been detected in the Yolo Bypass appear to be related to runoff events during winter and agricultural return flows later in the year (Domagalski, 2000).

The Sacramento River Basin has many natural and man-made sources of Hg (Domagalski, 1998). The highest loading of Hg to San Francisco Bay has been attributed to sources in the Cache Creek watershed. Highest transport rates for Hg coincide with the highest discharges, and most of the Hg from the Sacramento River system entered the Estuary via the Yolo Bypass during the 1997 and 1998 water years (Domagalski, 2001). Although levels of total Hg were lower than those in Cache Creek, significant concentrations of methyl mercury, which is particularly hazardous to aquatic organisms, have been measured in the Colusa Basin Drain. Conditions that could produce methyl mercury include stagnant waters and marshes with an abundance of sulfate and organic carbon, which are conditions similar to those in the Yolo Bypass during spring of our study.

Plans to develop habitat in the Yolo Bypass might need to consider water sources, contaminants, and biogeochemical processes in order to optimize conditions for wildlife. Runoff from local streams during April of our study increased flow and reduced concentrations of many substances that had accumulated in the perennial channel of the Yolo Bypass. Habitat conditions in the perennial channel also might be enhanced by periodic flushing by water from the Sacramento River, releases from reservoirs on Cache or Putah creeks, or other suitable freshwater sources during the irrigation season.

Discharge from the Yolo Bypass is a source of many dissolved and particulate substances to the tidal Sacramento River. Transports of dissolved and particulate substances from the Yolo Bypass are often greater than those from the upstream Sacramento River channel during winter floods, but inputs from the draining of the floodplain channels after the inundation period and runoff from spring storms also might be important to the river. Our results show a large change in the quality of dissolved and particulate organic matter in the Yolo Bypass after the inundation period. SUVA values and C:N ratios decreased, which was a strong indication that recently produce organic matter was more abundant. Chlorophyll *a* measurements have confirmed that increased primary production by diatoms and other phytoplankton was a major feature of the draining period through mid-April (W. Sobczak and A. Mueller-Solger, personal communications). In addition, chlorophyll *a* monitors at Rio Vista have shown for many years that concentrations in the Sacramento River increase during the draining of the Yolo Bypass and often following late-season storms that flush materials from the perennial channel (Sommer and others, 2001). These results suggest that the Yolo Bypass not only is a producer of highly nutritious organic matter for its inhabitants, but that it exports organic matter to the river-delta-estuary system, where supplies of phytoplankton organic carbon have become increasingly scarce in recent years (Jassby and others, 2002). Recommendations for rehabilitation of the Delta include better utilization of potentially productive areas including the Yolo Bypass, other floodplains, and marshlands (Jassby and Cloern, 2000).

Floodplains of large river systems are critically important components of their ecosystems (Junk and others, 1989; Tockner and others, 2000). Large expanses of the Sacramento River valley were floodplains and wetlands before the California gold rush. Serious ecological damage to the Sacramento River might be expected from the huge reduction in floodplain and wetland areas by reclamation for agriculture alone. The Yolo Bypass is a remnant of a once extensive floodplain that has been engineered and leveed to provide flood protection. In recent years, we have learned that this floodplain also provides many benefits to the river ecosystem and the San Francisco Bay (see Sommer and others, 2001, and references therein). Actions that could preserve and enhance ecological benefits of the Yolo Bypass recently have been proposed as part of the Bay-Delta Ecosystem Restoration Program (see CALFED, 2001). This study in 2000 and our previous study in 1998 provide knowledge of water quality conditions in the Yolo Bypass and local streams that should prove useful in the implementation of proposed management actions.

SUMMARY

Results from this study during winter and early spring 2000 link variations in water quality in the Yolo Bypass to discharges from the Sacramento River and local streams that enter the western margin of the floodplain. When floodwaters were flowing over Fremont Weir, the water chemistry in the Yolo Bypass was very similar to that in the Sacramento River except along the western margin where the influences of local stream inflows were evident. When flow over Fremont Weir stopped, the floodplain subsequently drained, and discharges from local streams became major sources of water and waterborne constituents. As waters were confined to the perennial channel along the eastern margin of the floodplain, chemical concentrations indicated strong influences of discharges from Cache Creek and Ridge Cut. Both of these streams are sources of contaminants that are potentially hazardous to wildlife. Sources of some constituents were not clearly identified during early spring, which might be expected as canals drain shallow groundwaters from the floodplain and agricultural activities commence in the area. The perennial channel provides habitat for aquatic species throughout the year. Water chemistry in the perennial channel of the floodplain was influenced by runoff from storms during spring, which flushed accumulated nutrients and organic matter from the channel. Such freshwater inflows could reduce the risk of over enrichment of inorganic nitrogen and phosphorus nutrients, nutrients that promote algal blooms that could degrade habitat quality. Habitat conditions during the dry irrigation season might be enhanced by periodic releases of suitable freshwater to the perennial channel.

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Appendix A: FILTRATION AND SAMPLE PREPARATION METHODS FOR THE YOLO BYPASS STUDY IN 2000

DISSOLVED INORGANIC CONSTITUENTS:

Cellulose ester filters (47mm-diameter, 0.45um-pore-size; Millipore type HA or equivalent with tare weights in the range of 90-100 mg) were used to filter samples for ICP, IC, and nutrient analyses. The polycarbonate filter apparatus (Sartorius 16510, or equivalent) was cleaned with dilute HCl between batches of samples and rinsed with acid-distilled water between samples. After processing the sample, each filter was dried in a desiccator for a month and weighed to provide an estimate of the suspended particulate matter concentration in the sample. The procedure was as follows:

1) Rinse filtration apparatus by filling the upper reservoir to the 200ml mark with acid-distilled water and swirling the liquid as it drains through to the lower reservoir. The liquid in the lower reservoir is shaken before being discarded. This is repeated for a total of two rinses.
2) Install filter, making sure that it is centered properly.
3) Weigh sample bottle on the pan balance and record value.
4) Shake sample, then pour approximately 50ml into filtration apparatus. Swirl contents to rinse sample reservoir, then apply vacuum. Place the plastic cap loosely onto the sample reservoir. After aliquot has been filtered, turn off vacuum and disconnect vacuum line. Holding the entire assembly, gently swirl the liquid so that the lower reservoir is rinsed to the level of the "O" ring. Remove filtrate reservoir and pour off the filtrate over the graduated side of the reservoir (use this same side for all pouring). Reassemble apparatus.
5) Repeat step 4.
6) Shake sample, then pour between 150 and 200ml of sample into sample reservoir and apply vacuum. Place the plastic cap loosely onto the sample reservoir while the sample is being filtered. Weigh the sample bottle and record the difference in weight on the petri dish that will be used to store the filter. After the sample has filtered, turn off the vacuum and disconnect the vacuum line.
7) Remove the sample reservoir-filter assembly from the filtrate reservoir and pour the samples in the following manner. Fill the 60ml poly ICP bottle to the shoulder. Pour out the artificial river water from the 30ml nutrient bottle. Rinse the nutrient bottle and cap three times with a small amount of filtrate, then fill the bottle to the shoulder. Fill the 60ml IC bottle to the shoulder with the remaining filtrate.
8) Remove the sample reservoir and remove the filter. Place the filter in the petri dish and label the dish with the sample location, date, and time.
9) Repeat procedure from step 1 for the next sample. After all samples are filtered, soak the filtration apparatus in dilute HCl overnight, rinse with distilled water, and allow to dry.
10) Place nutrient bottles in freezer, IC bottle in refrigerator, and store the ICP bottle at room temperature after acidification with concentrated nitric acid to 1% final concentration.

Appendix A: continued.

DISSOLVED ORGANIC CARBON:

Stainless steel pressure filtration funnels (Gelman, 47-mm, or equivalent) with glass fiber filters were used to process the dissolved organic carbon (DOC) samples. The filtration funnels were cleaned initially in a boiling low-DOC MilliQ water bath. Between samples the apparatus was rinsed once with room temperature low-DOC MilliQ water and then placed in a boiling low-DOC MilliQ water bath. Glass fiber filters (47 mm type A/E, or equivalent) were cleaned by baking in a muffle furnace at 450°C for 12 hours. Sample bottles (amber glass) were rinsed with distilled water, air dried, covered with Al foil, and then baked at 450°C for 12 hours. The teflon-lined caps were (Qorpak, or equivalent) were rinsed with distilled water, soaked in 2% HCL for 2 hours, rinsed with distilled water, and then air dried. Samples were prepared as follows:

1) Rinse the inside of the filtration funnel with an aliquot of sample by swirling the liquid as it drains and discard the sample.
2)Rinse the funnel again and let the sample drain into a sample bottle. Rinse the collection bottle and cap with filtered sample.
3) Fill the funnel again. Take the first part of the filtered sample and rinse the sample bottle and cap again. The remainder of the filtered sample is kept. Once the sample bottle is filled, take two caps full of sample from the bottle to rinse the cap.
4) Store sample in refrigerator until analysis.

PARTICULATE CARBON AND NITROGEN:

Stainless steel vacuum filter holders were used to collect particles onto 13mm glass fiber filters for carbon and nitrogen analysis. The filter holders were cleaned initially in a boiling low-DOC MilliQ water bath. Between samples, the apparatus was rinsed once with room temperature low-DOC MilliQ water, and then cleaned in a boiling low DOC MilliQ water bath. Filters were baked at 450°C for 6 hours.

1) Rinse a glass cylinder with sample, and then measure 20-ml of sample. Pour sample into vacuum filter and apply vacuum without letting the sample settle in the cylinder. Keep adding known volumes of sample to the vacuum filter until the rate of filtering decreases. Record volume of sample filtered.
2) Once the filter is dry, turn off vacuum. Disassemble filter funnel and remove filter.
3) Place filter on petri dish. Store sample in desiccator until analysis.

Appendix B: ILLUSTRATIONS

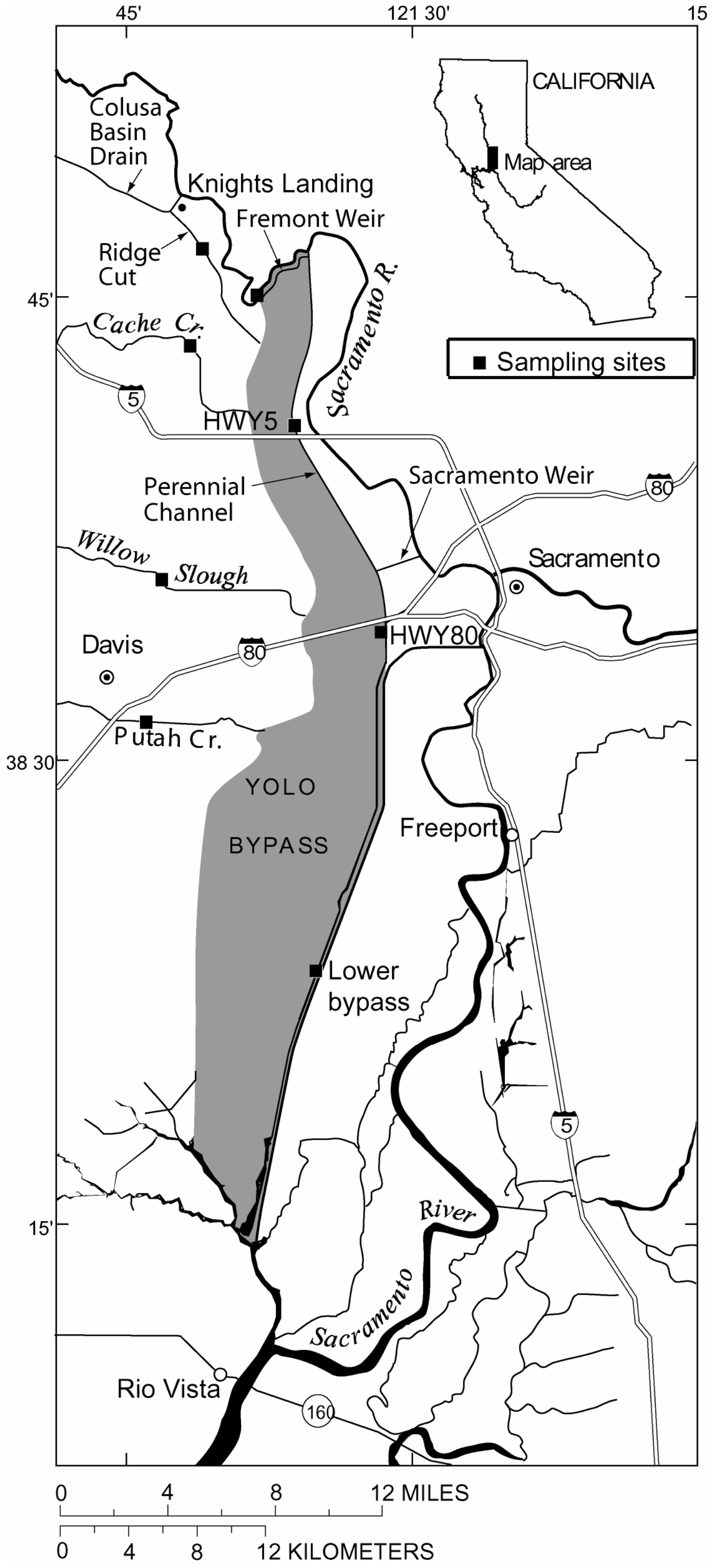

Figure 1. Map showing the Sacramento River, Yolo Bypass, local streams, and locations of the fixed sampling sites.

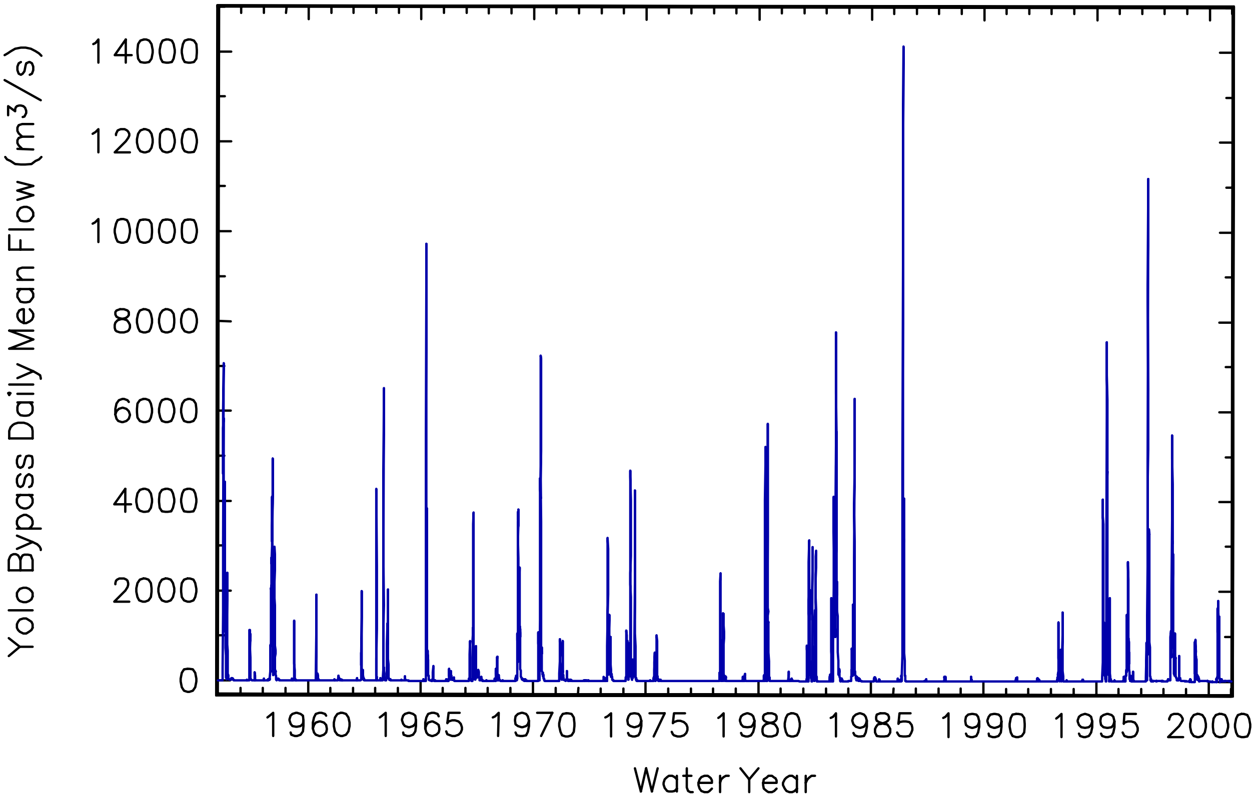

Figure 2. Daily mean discharge in the Yolo Bypass (DAYFLOW value) for the 1956-2000 water years.

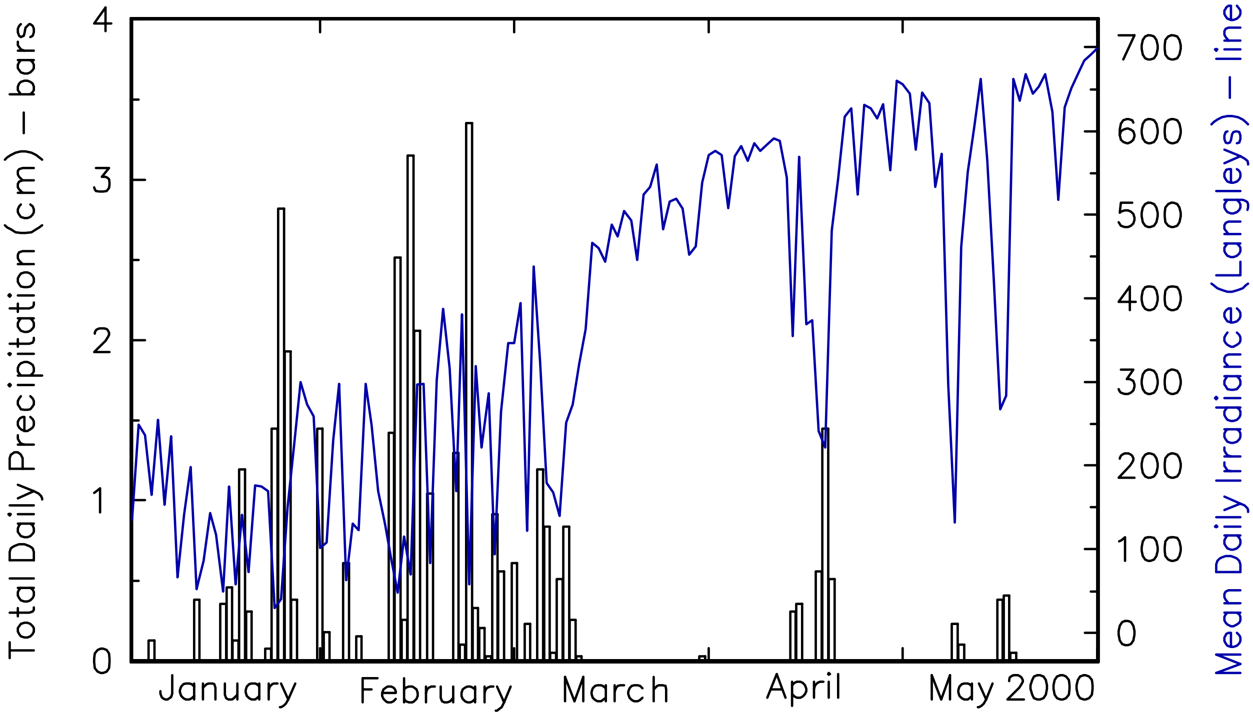

Figure 3. Daily total precipitation and mean daily irradiance at Davis, California, January through May, 2000.

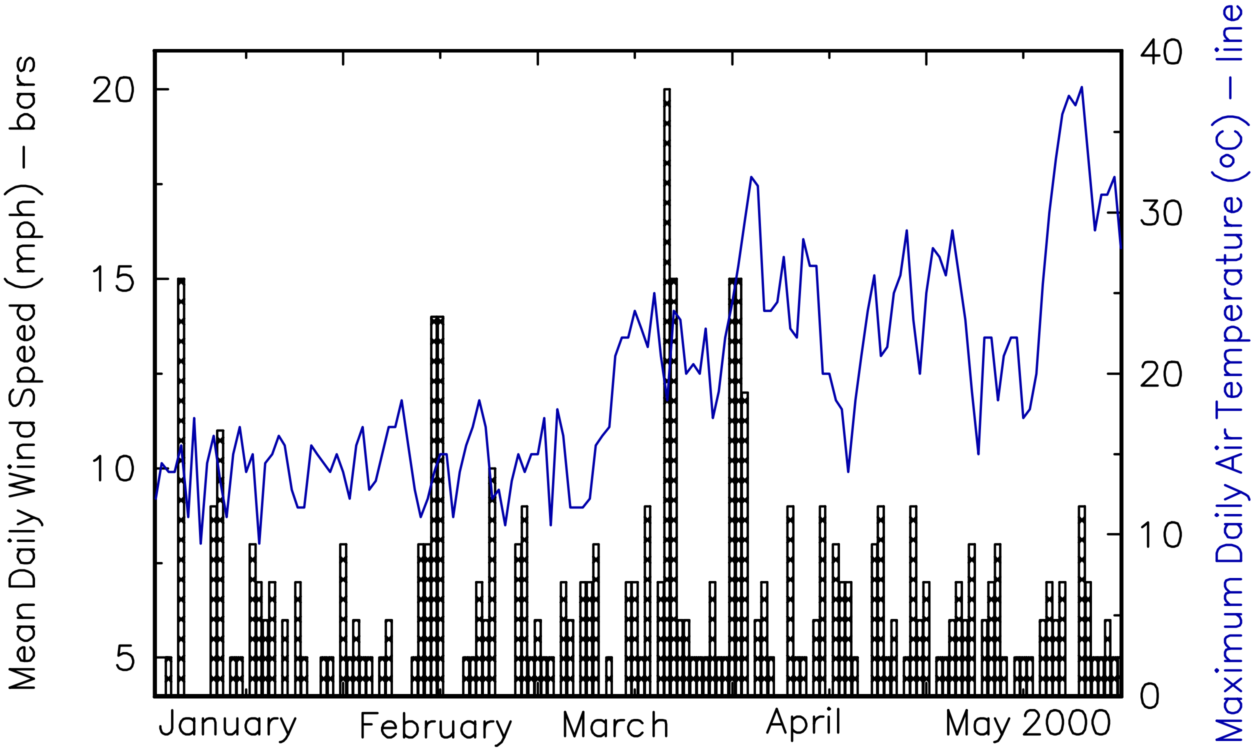

Figure 4. Daily mean wind speed and maximum daily air temperature at Davis, California, January through May, 2000.

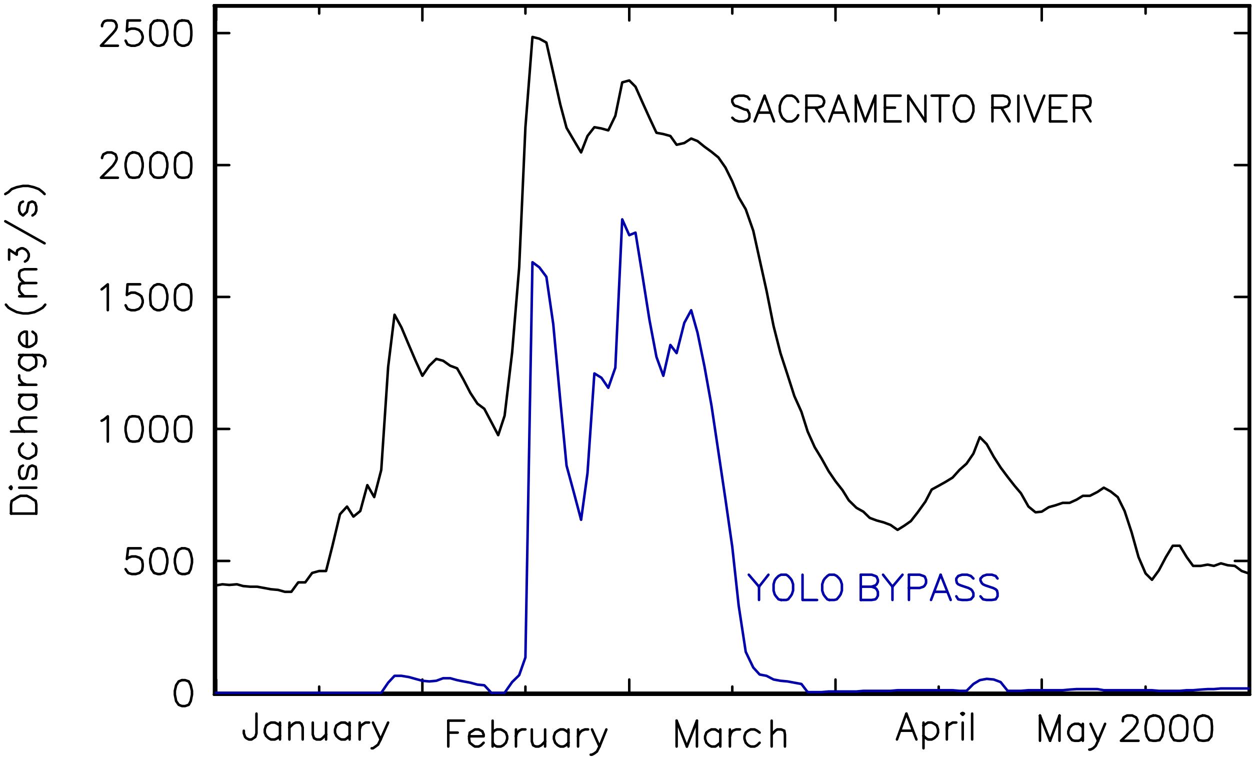

Figure 5. Daily mean discharge in the Sacramento River at Freeport and in the Yolo Bypass (DAYFLOW value), January through May, 2000.

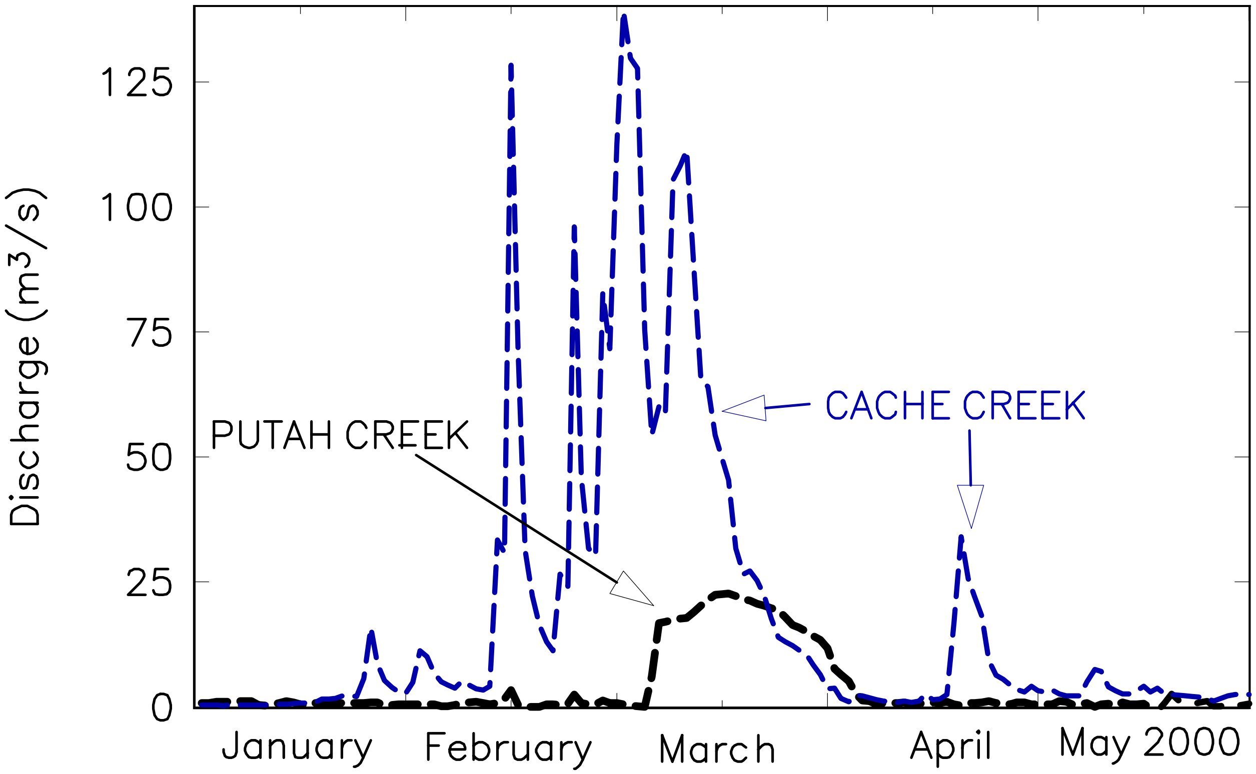

Figure 6. Daily mean discharge in Cache Creek and Putah Creek, January through May, 2000.

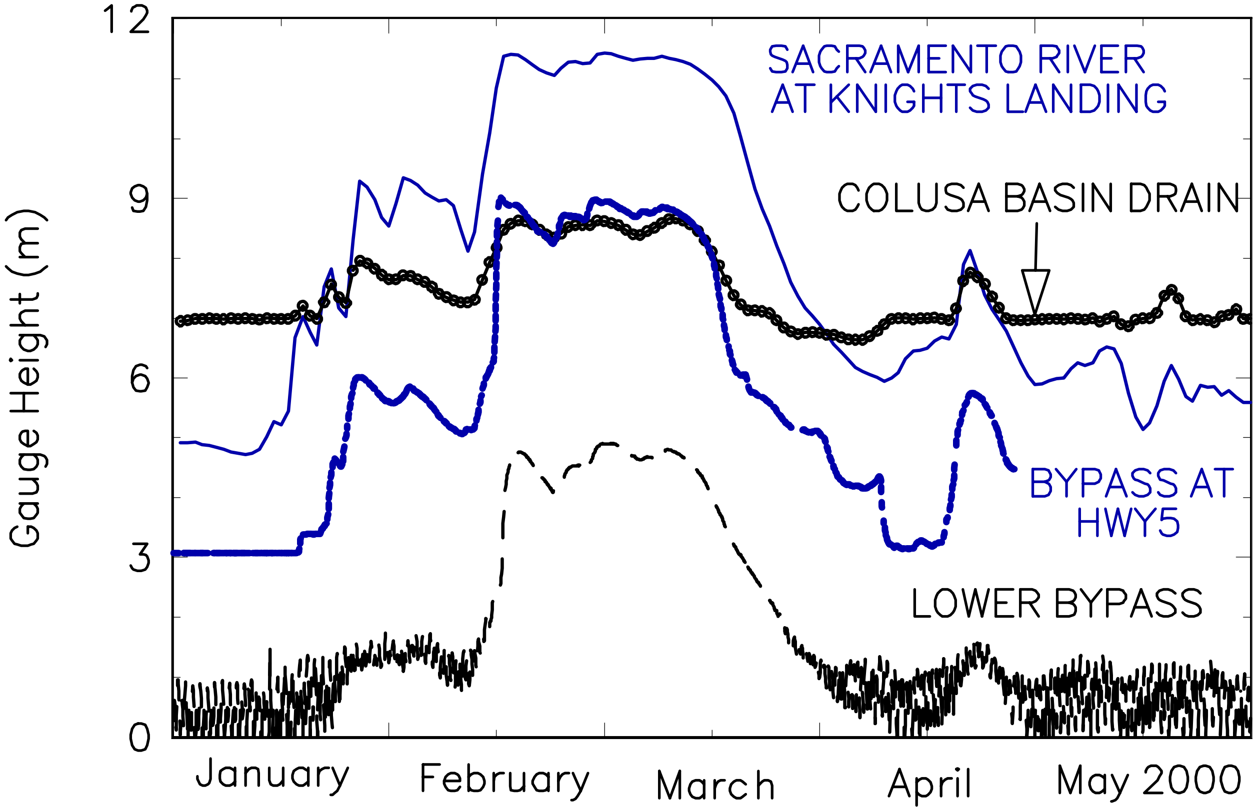

Figure 7. Water levels (gauge height) in the Sacramento River and Colusa Basin Drain at Knights Landing and the Yolo Bypass at HWY5 and in the Lower Bypass, January through May, 2000.

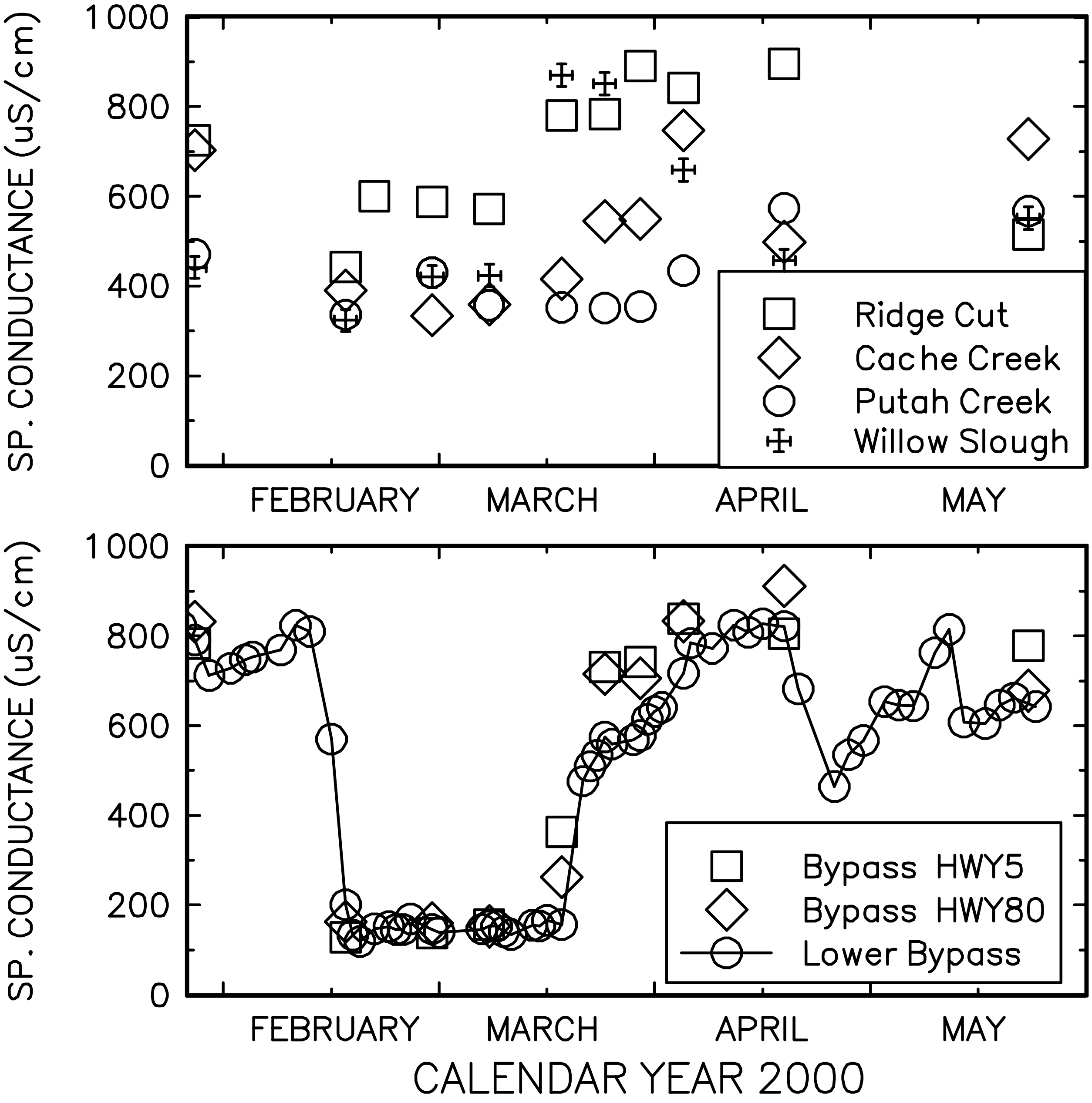

Figure 8. Specific conductance in the local streams (upper panel) and at sites in the Yolo Bypass (lower panel), January through May, 2000.

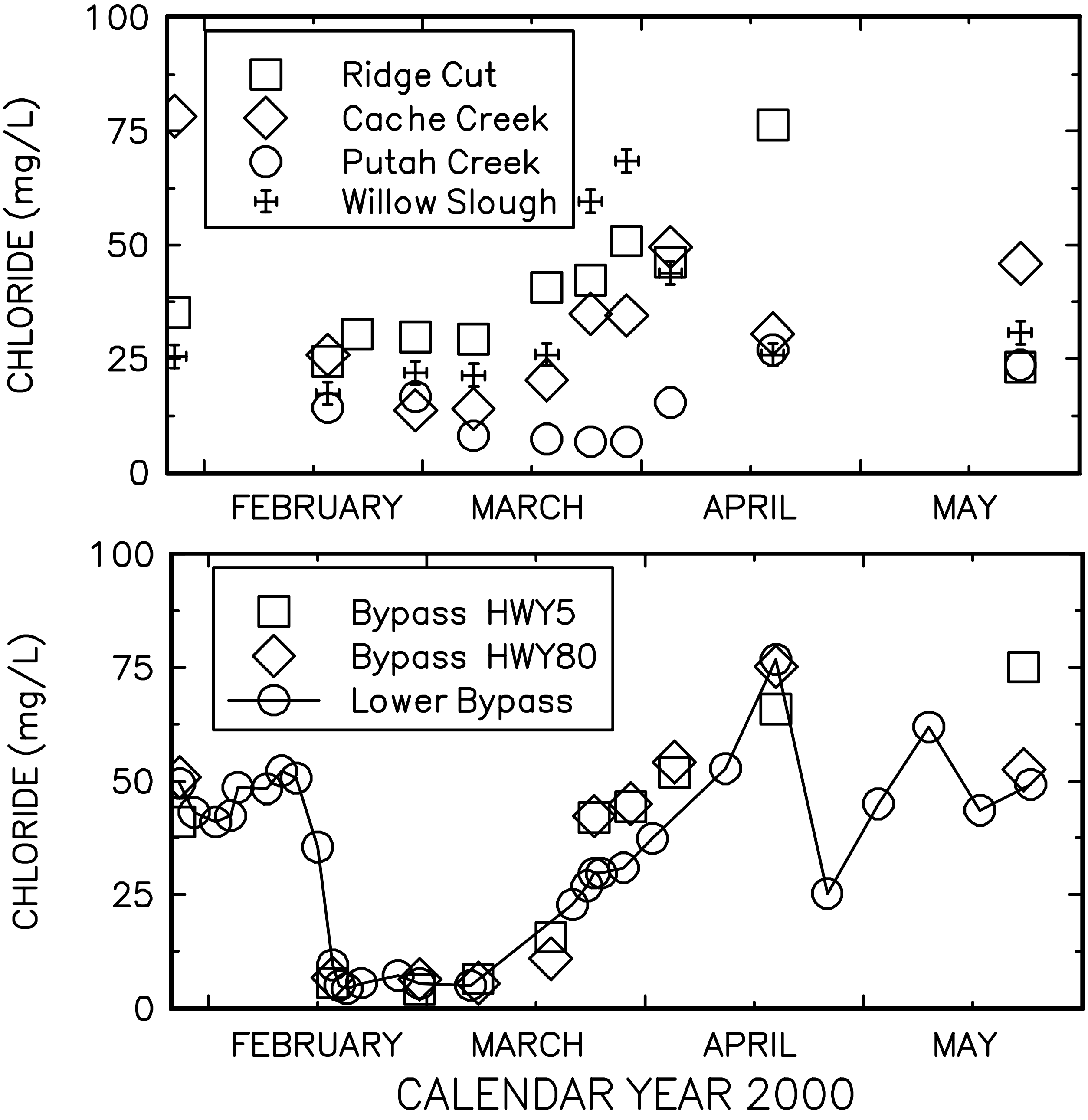

Figure 9. Chloride concentrations at sites in the local streams and at sites in the Yolo Bypass, January through May, 2000.

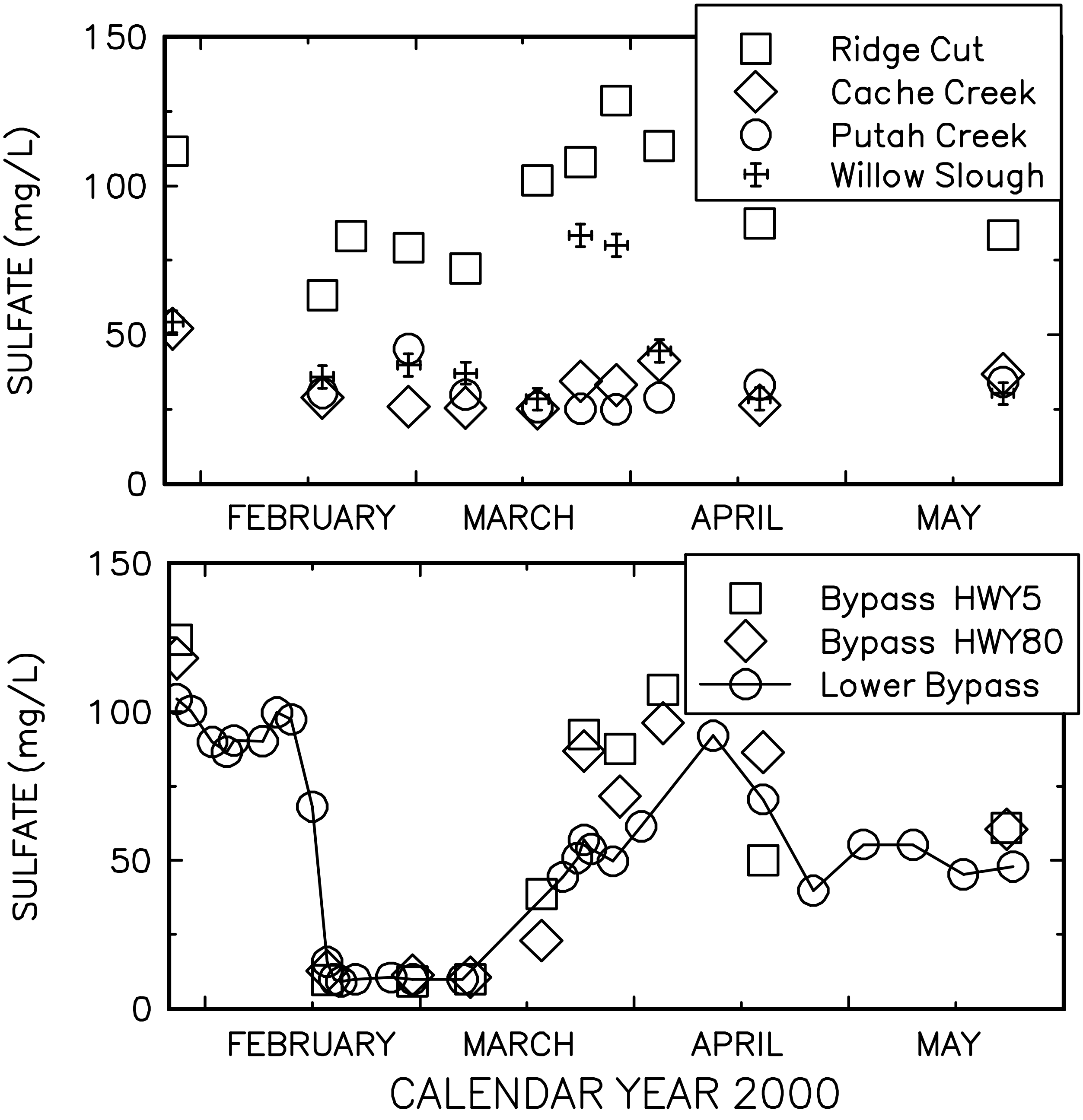

Figure 10. Sulfate concentrations at sites in the local streams and at sites in the Yolo Bypass, January through May, 2000.

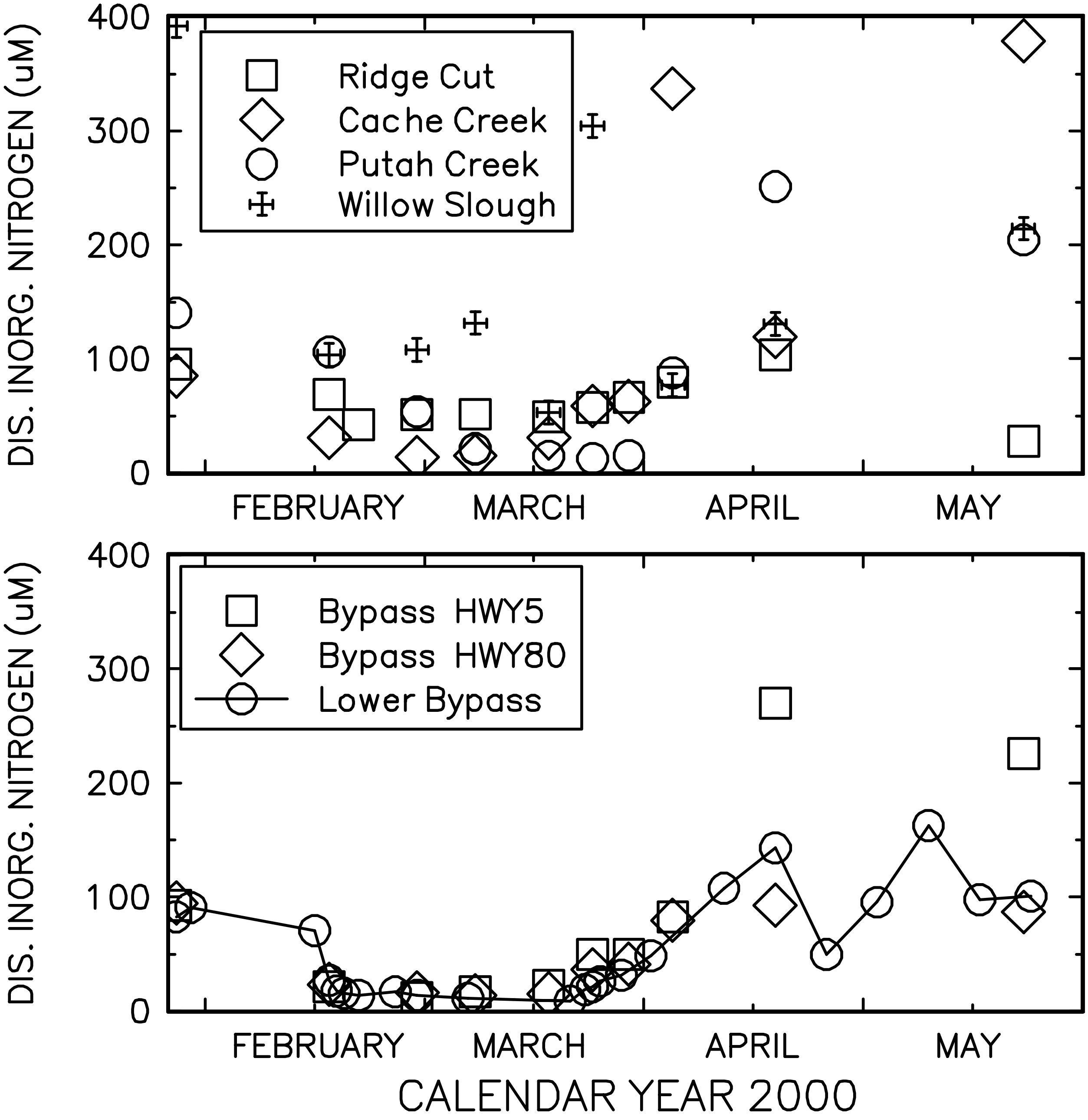

Figure 11. Dissolved inorganic nitrogen concentrations at sites in the local streams and at sites in the Yolo Bypass, January through May, 2000.

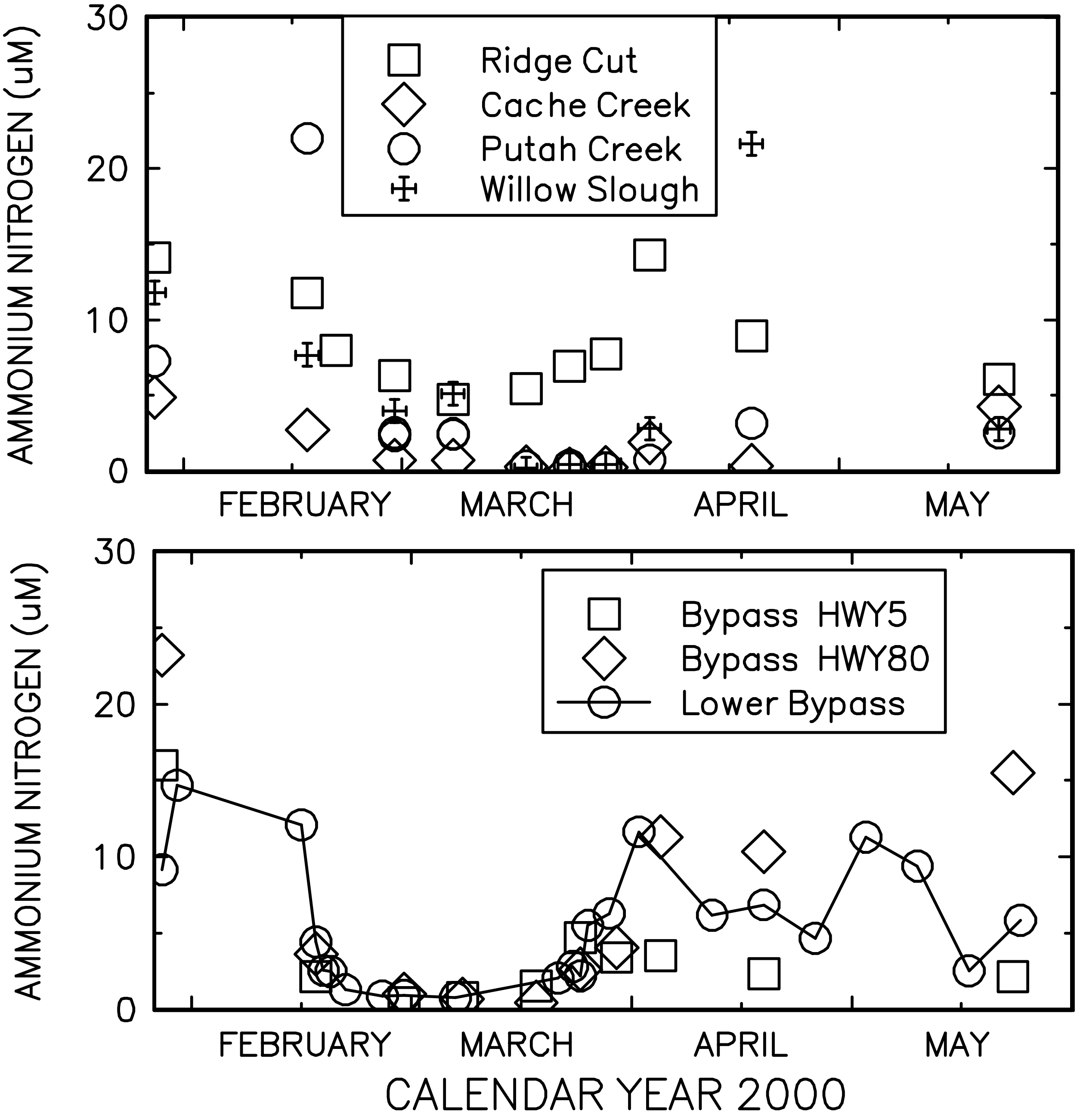

Figure 12. Ammonium nitrogen concentrations at sites in the local streams and at sites in the Yolo Bypass, January through May, 2000.

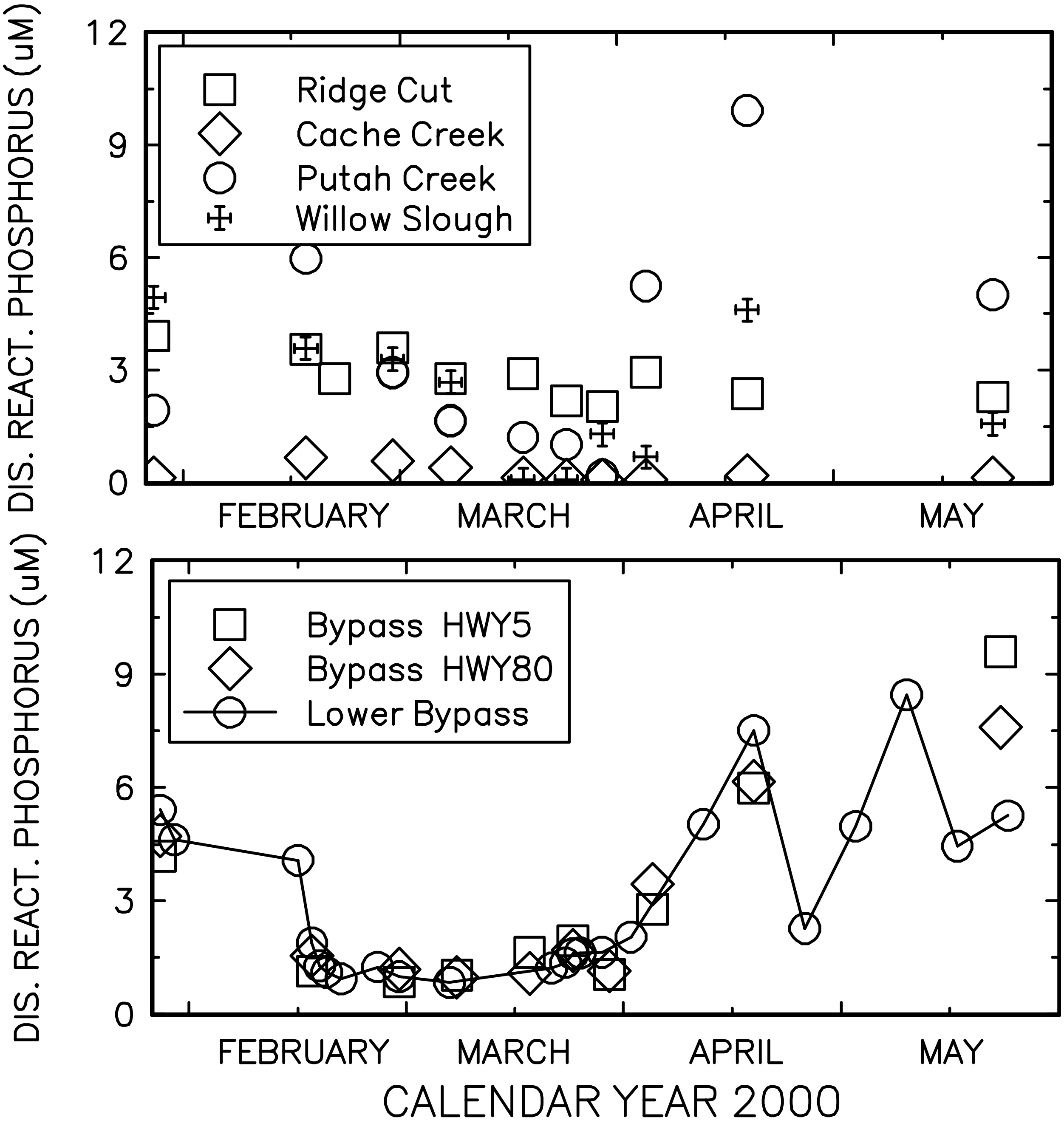

Figure 13. Dissolved reactive phosphorus concentrations at sites in the local streams and at sites in the Yolo Bypass, January through May, 2000.

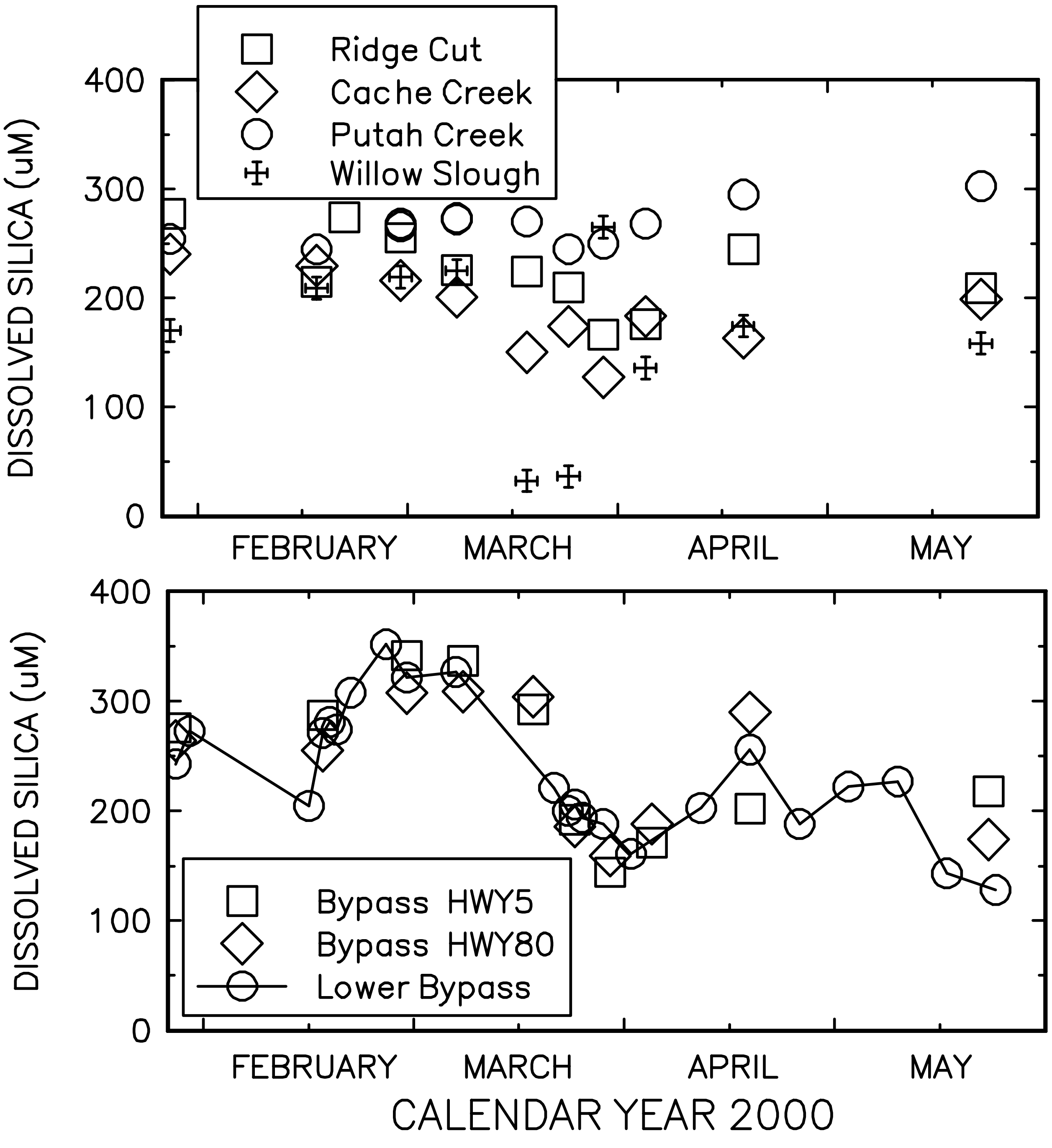

Figure 14. Dissolved silica concentrations at sites in the local streams and at sites in the Yolo Bypass, January through May, 2000.

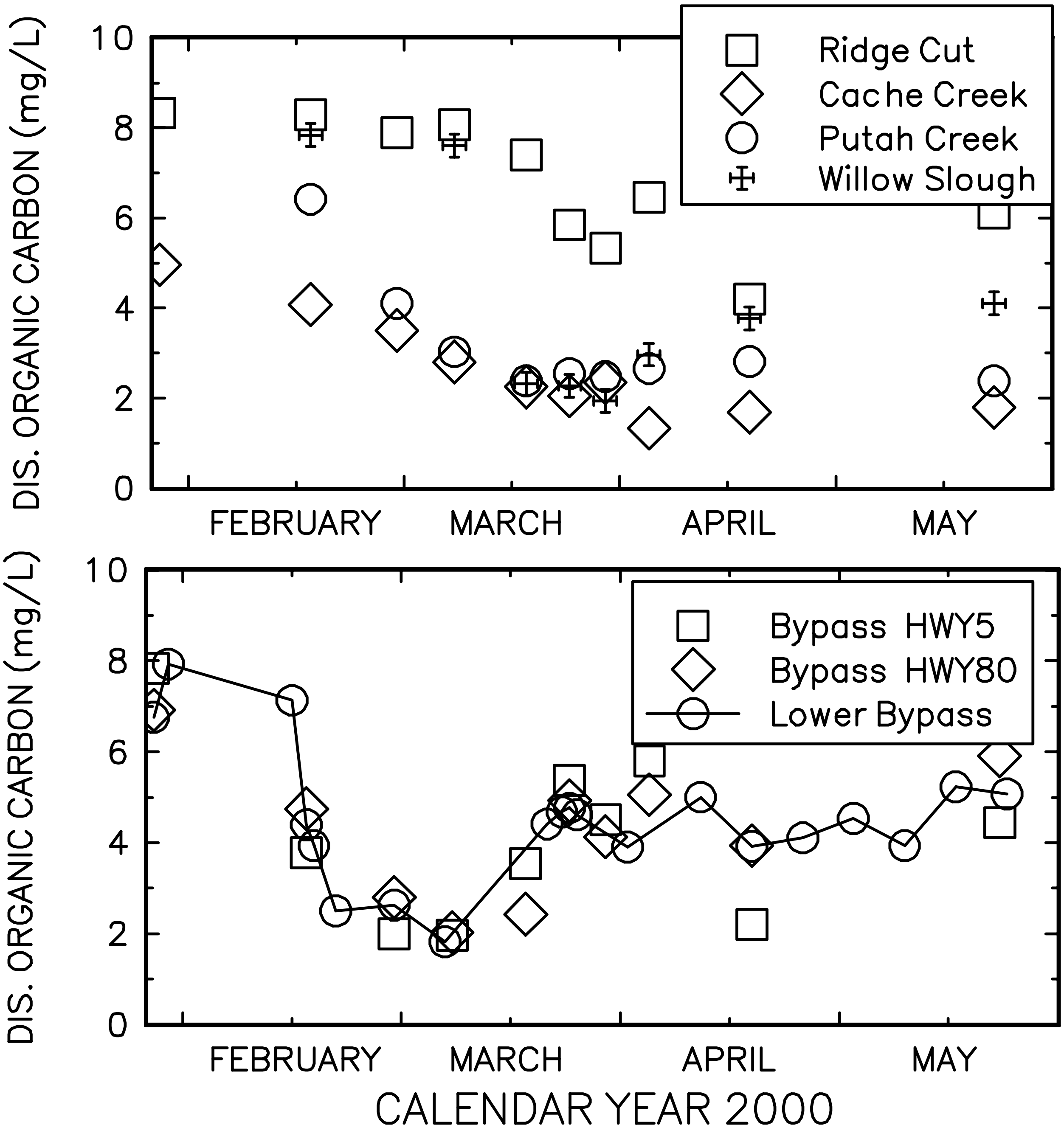

Figure 15. Dissolved organic carbon concentrations at sites in the local streams and at sites in the Yolo Bypass, January through May, 2000.

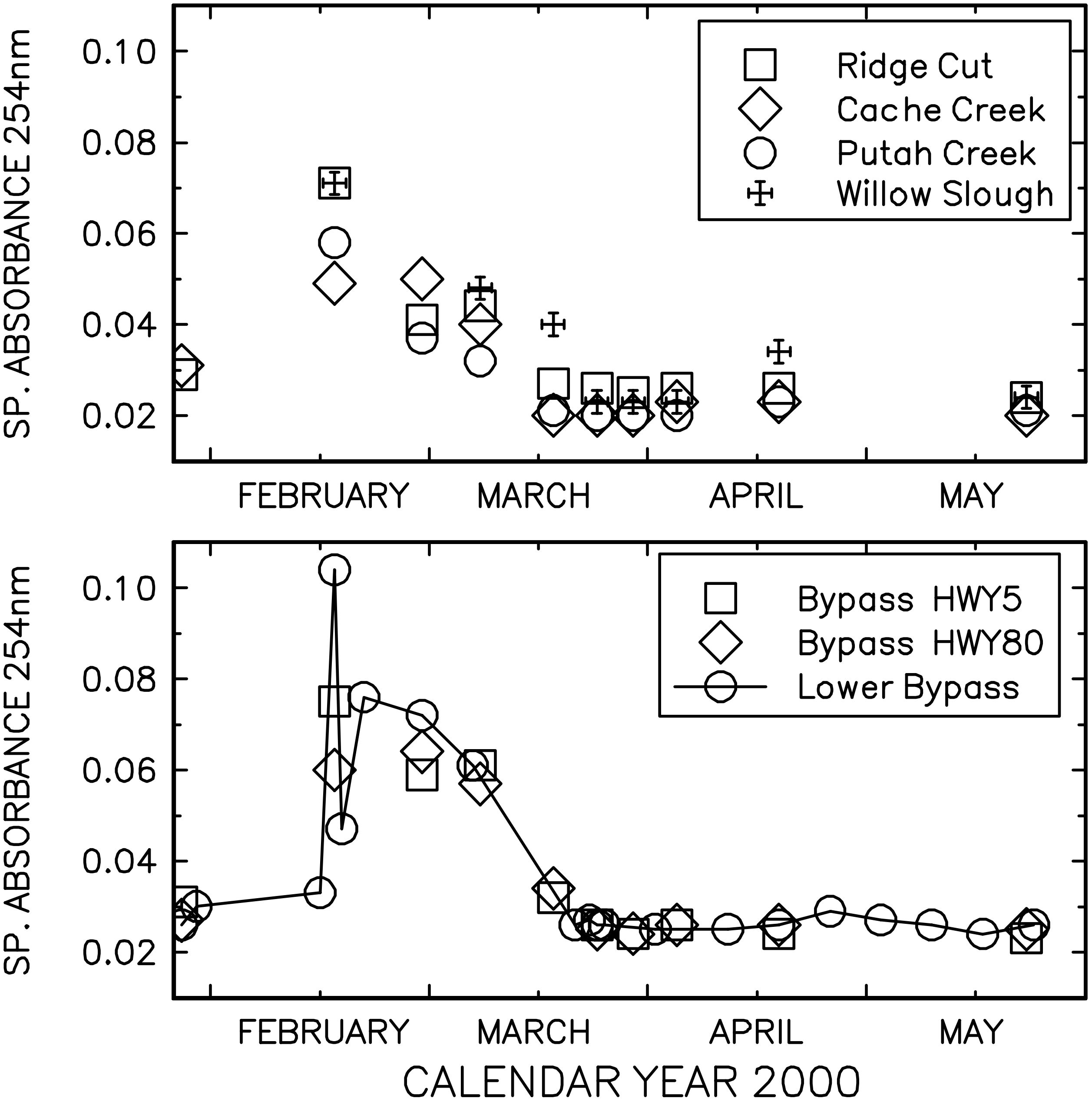

Figure 16. Specific ultra violet absorbance at 245nm at sites in the local streams and at sites in the Yolo Bypass, January through May, 2000.

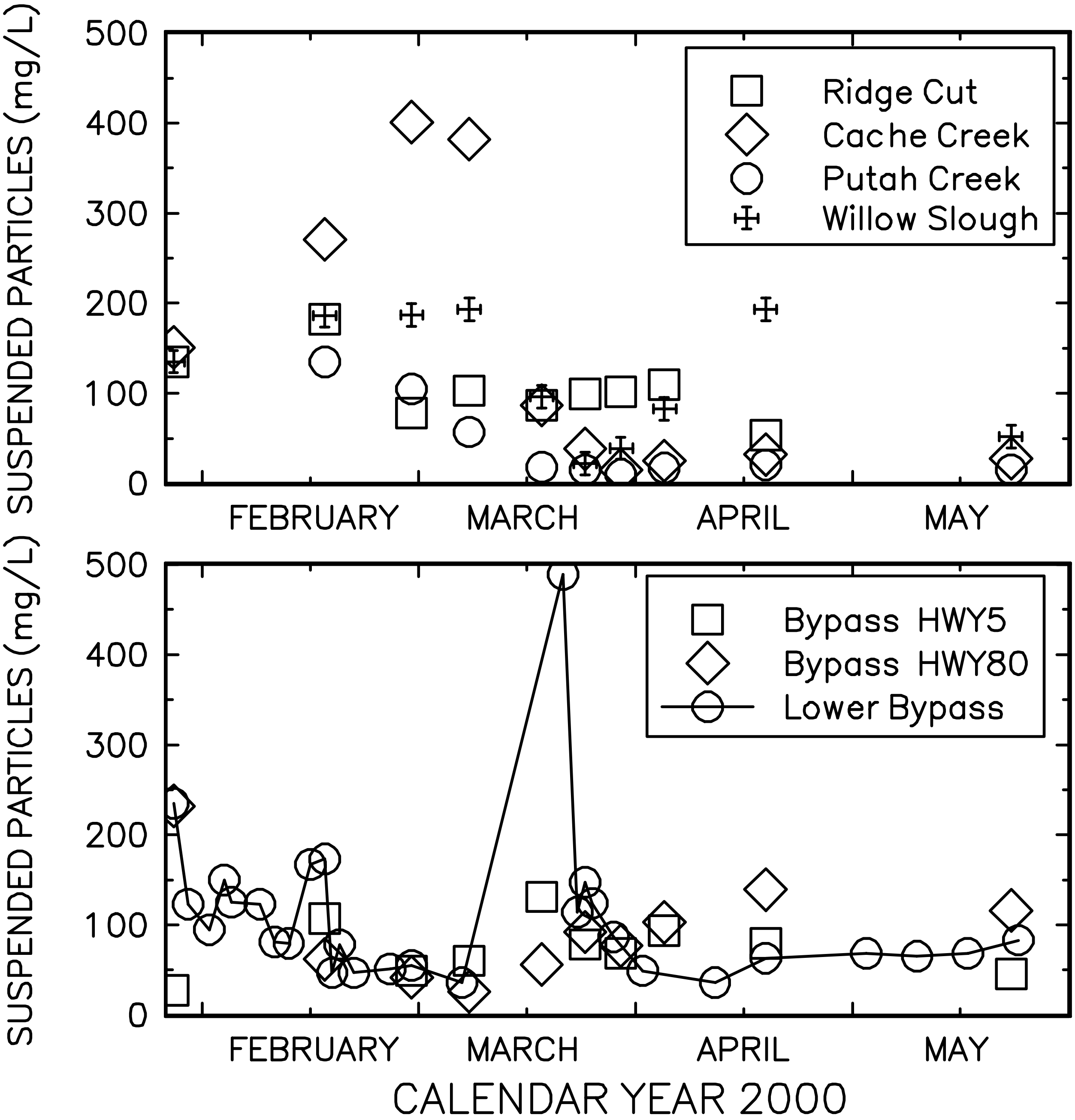

Figure 17. Suspended particle concentrations at sites in the local streams and at sites in the Yolo Bypass, January through May, 2000.

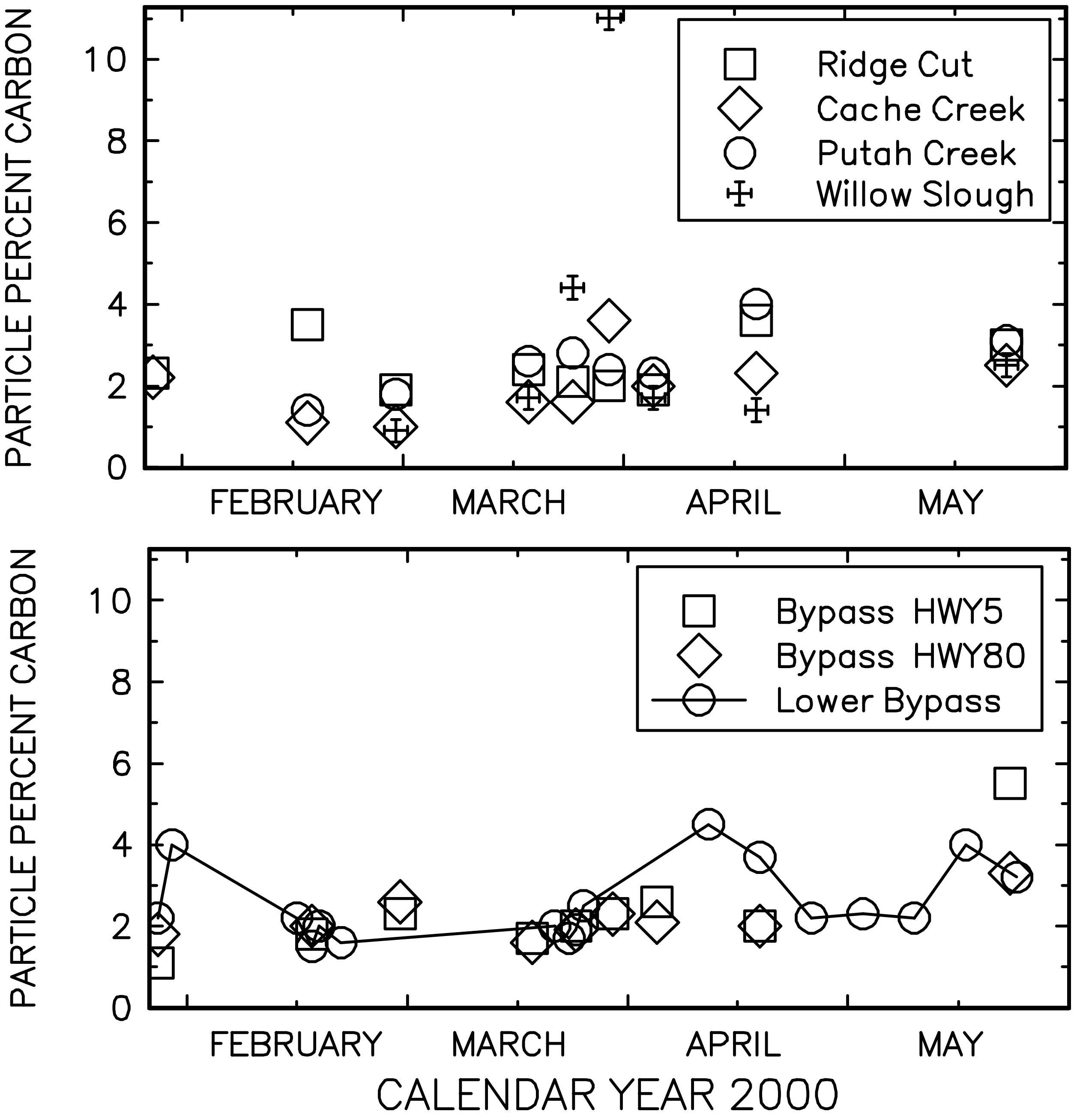

Figure 18. Suspended particle percent carbon at sites in the local streams and at sites in the Yolo Bypass, January through May, 2000.

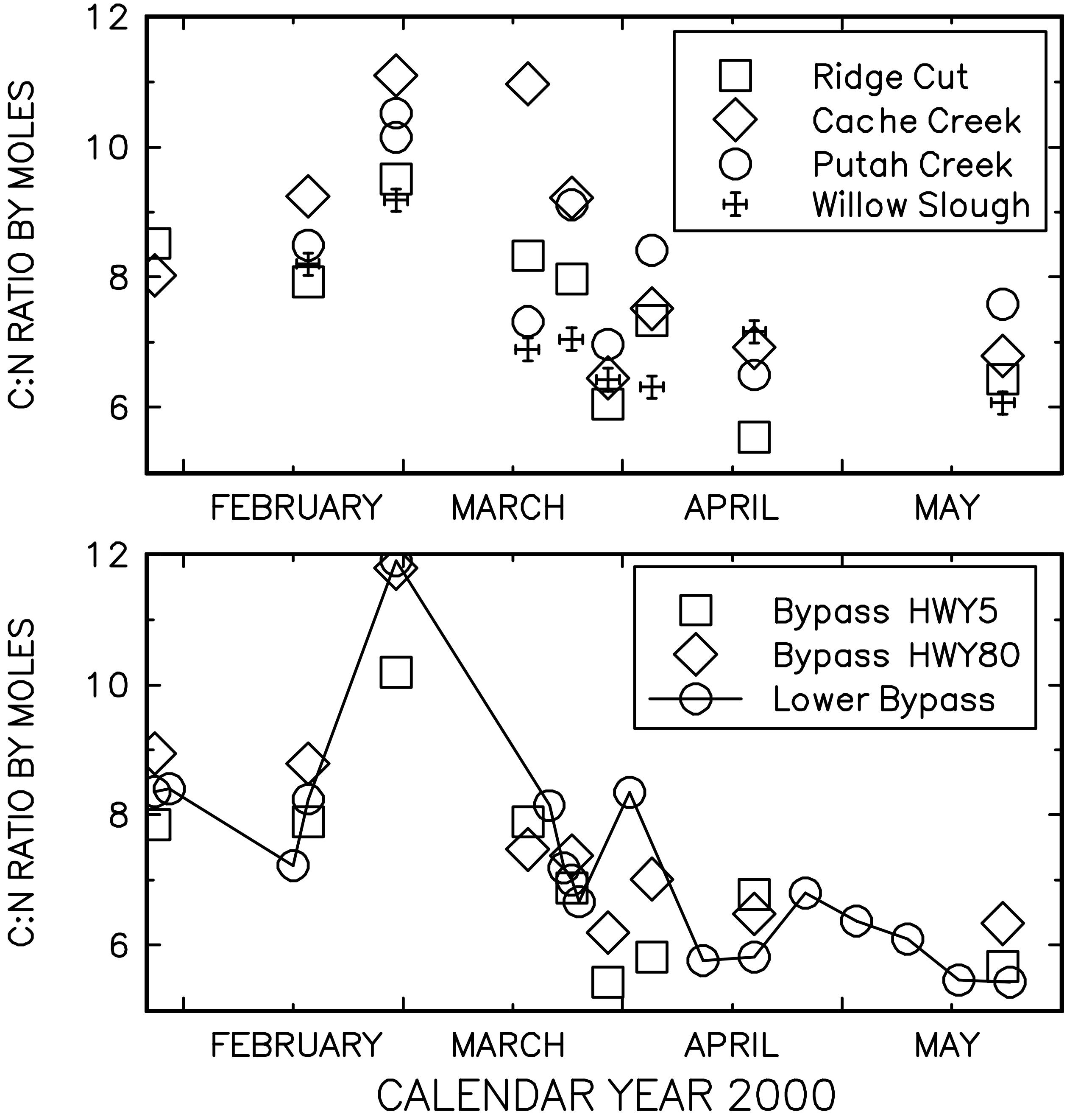

Figure 19. Carbon to Nitrogen ratio by moles at sites in the local streams and at sites in the Yolo Bypass, January through May, 2000.

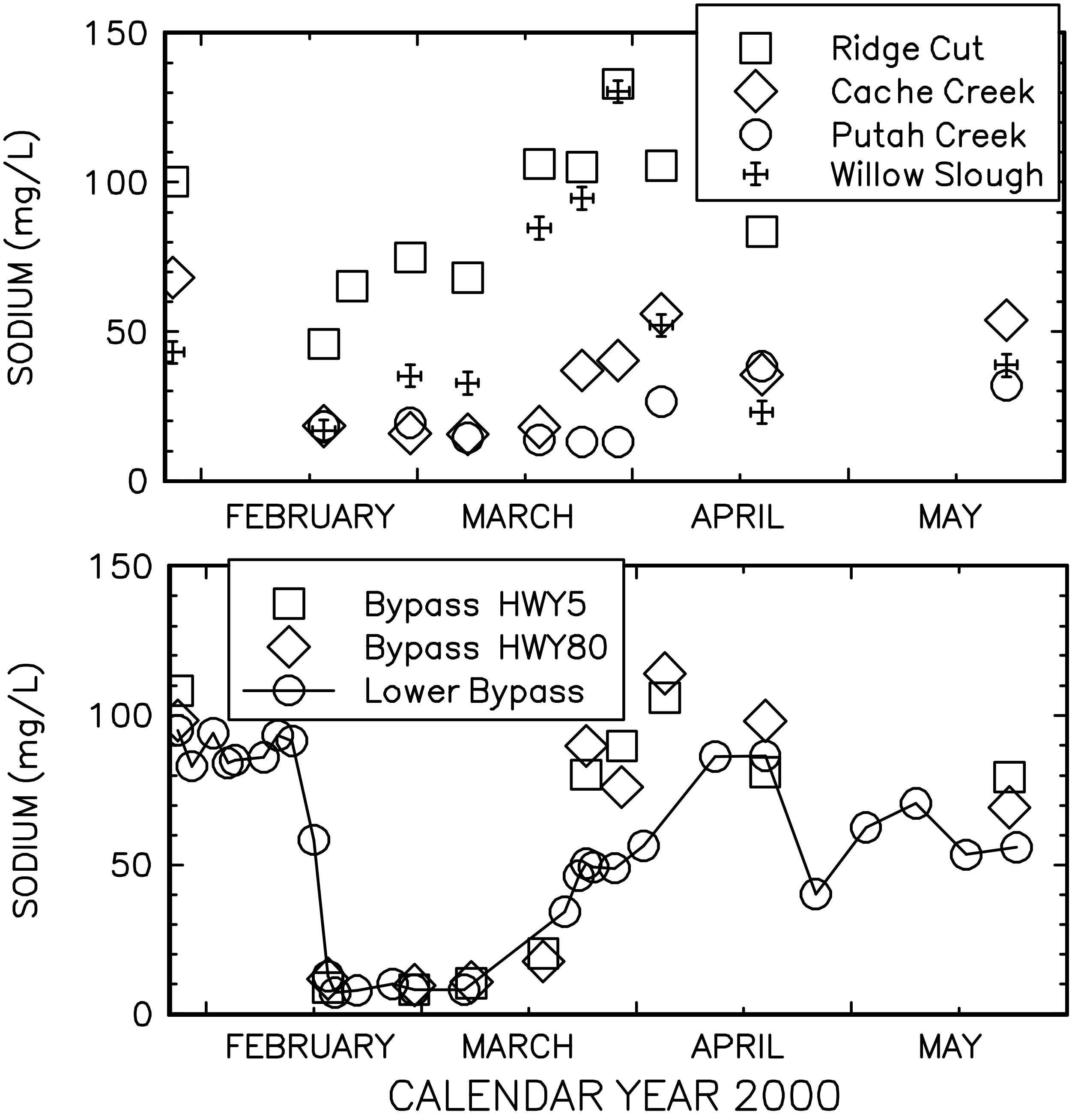

Figure 20. Sodium concentrations at sites in the local streams and at sites in the Yolo Bypass, January through May, 2000.

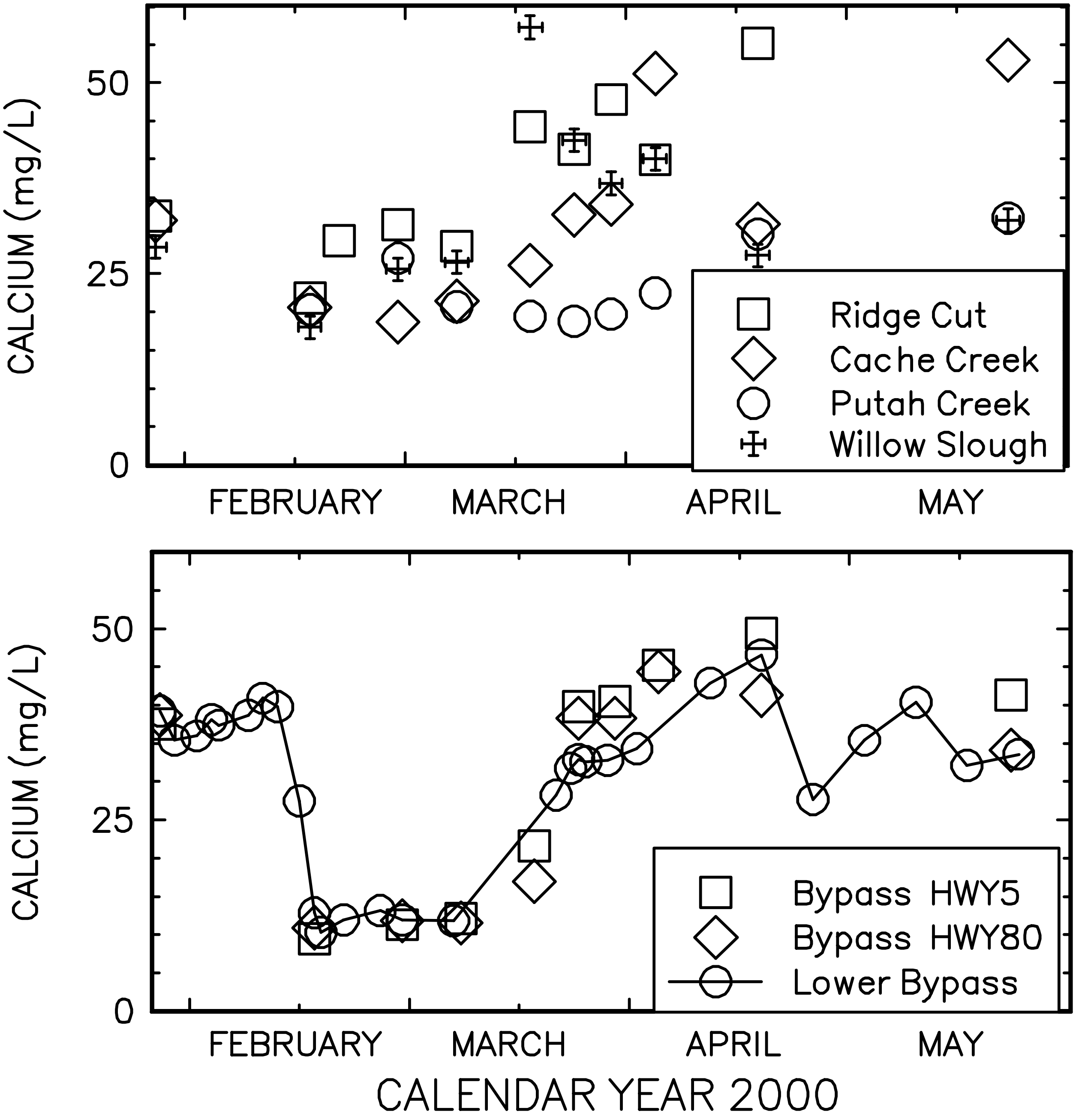

Figure 21. Calcium concentrations at sites in the local streams and at sites in the Yolo Bypass, January through May, 2000.

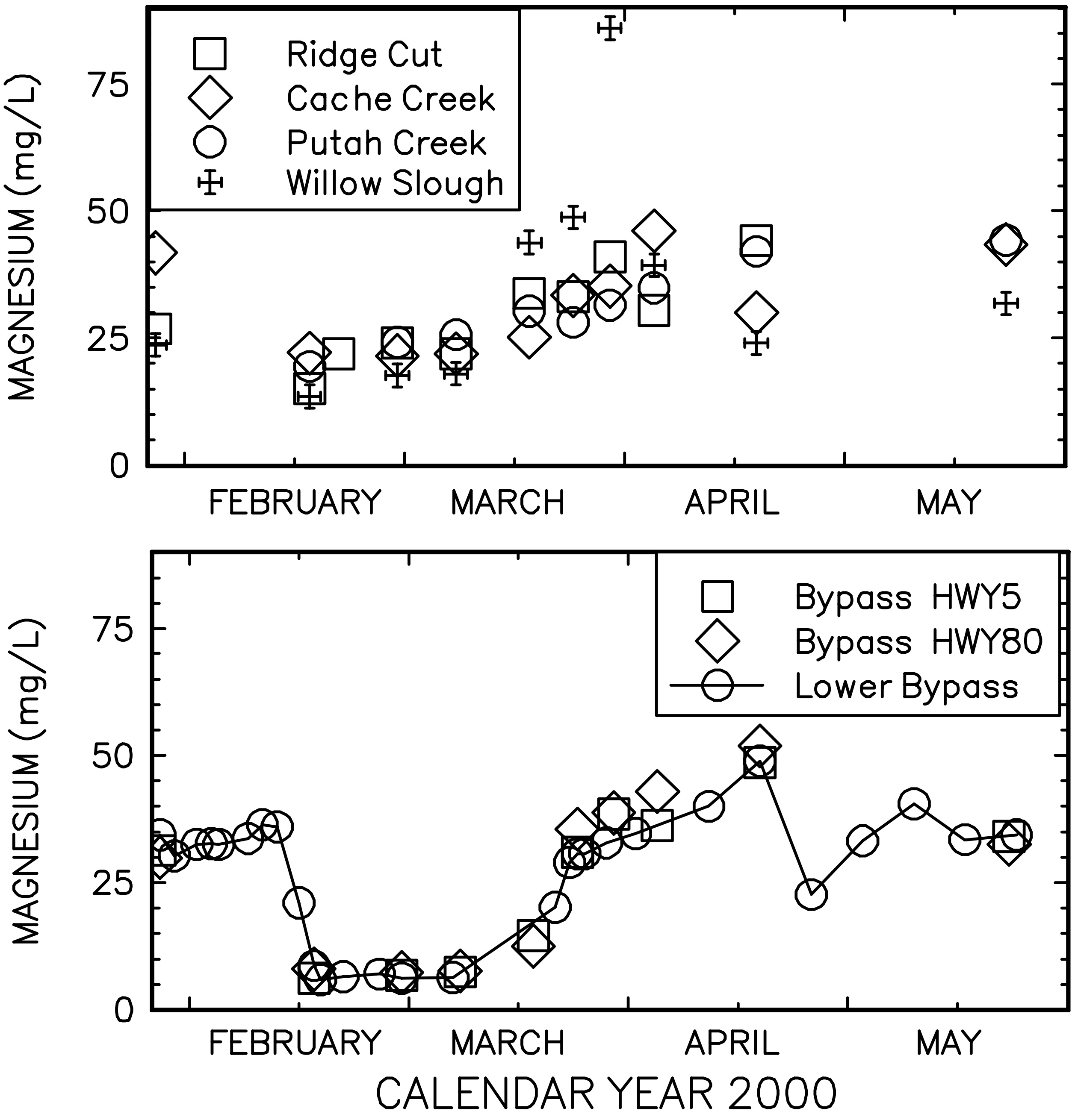

Figure 22. Magnesium concentrations at sites in the local streams and at sites in the Yolo Bypass, January through May, 2000.

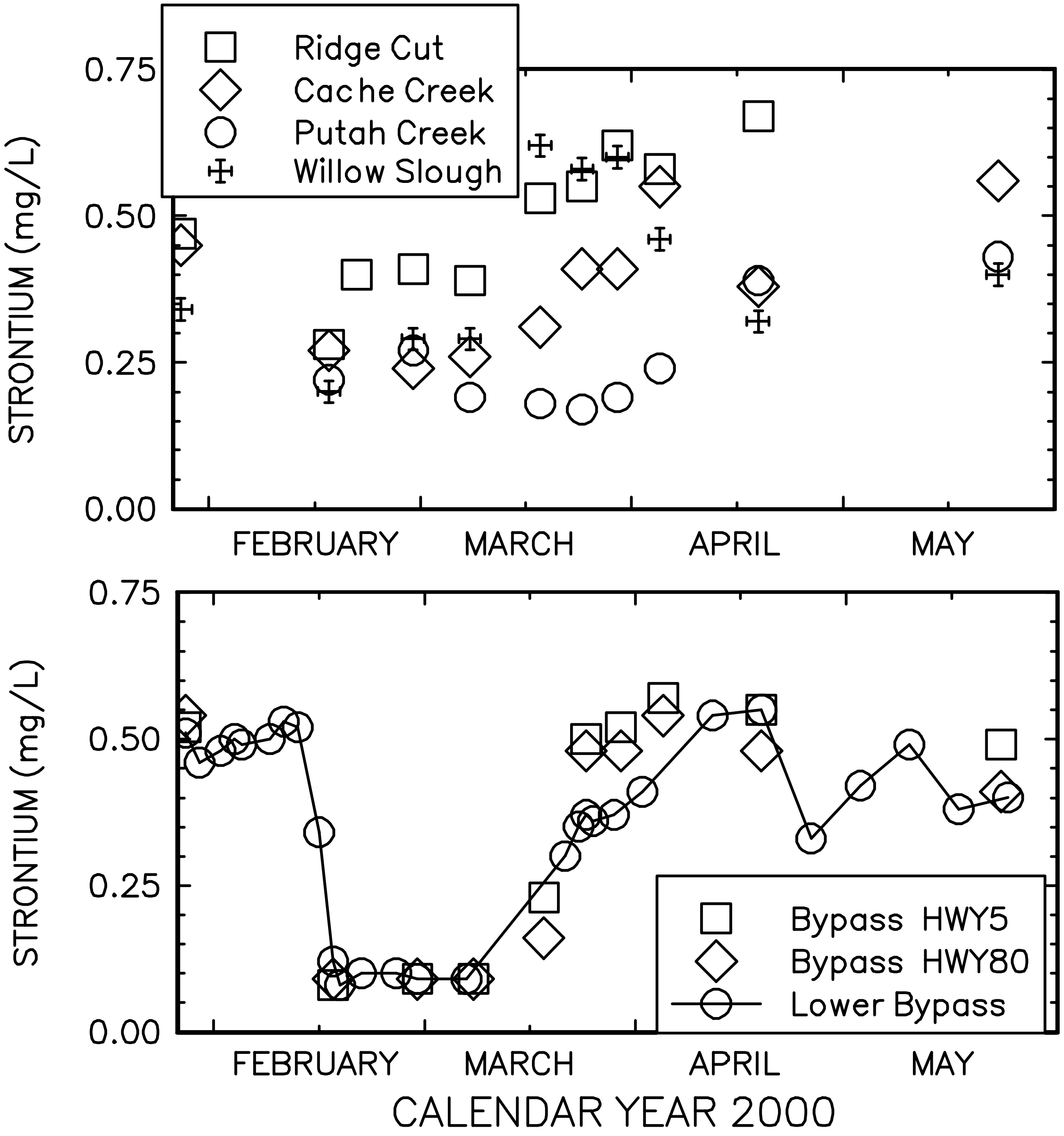

Figure 23. Strontium concentrations at sites in the local streams and at sites in the Yolo Bypass, January through May, 2000.

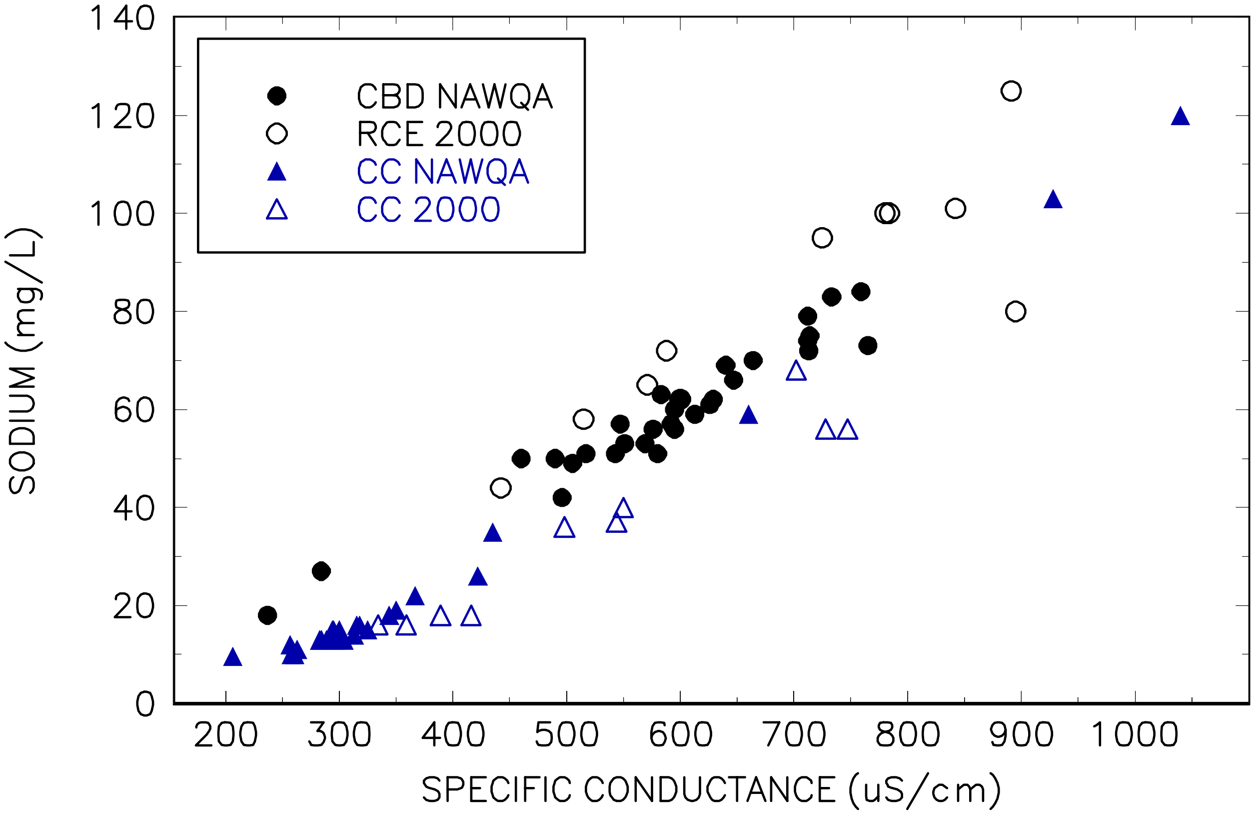

Figure 24. Sodium concentrations in Cache Creek and Ridge Cut (or Colusa Basin Drain) during the 1996-1998 NAWQA study and in 2000.

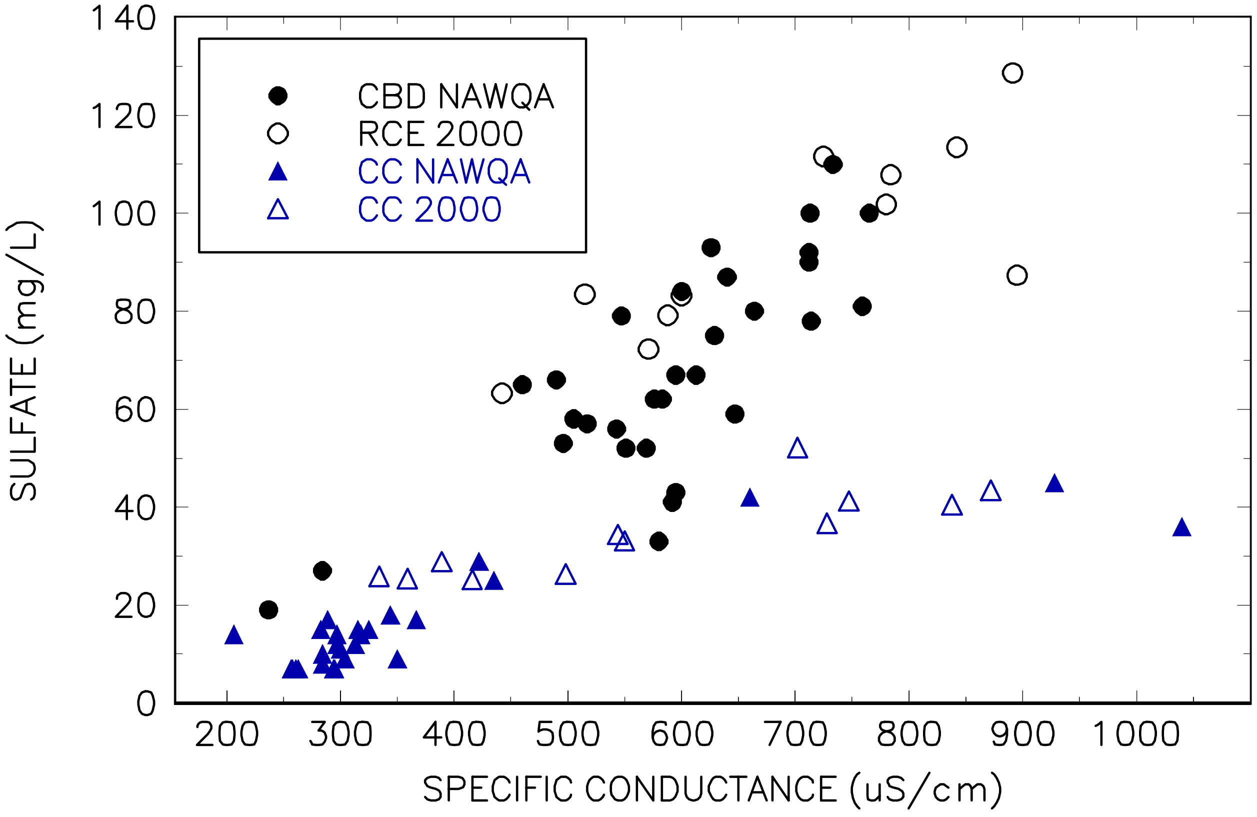

Figure 25. Sulfate concentrations in Cache Creek and Ridge Cut (or Colusa Basin Drain) during the 1996-1998 NAWQA study and in 2000.

Appendix C: TABLES

Table 1. Specific Conductance in μS cm^{-1}, chloride, sulfate, dissolved organic carbon, suspended particles, particulate carbon and nitrogen, and dissolved metals in mg/L, and dissolved nutrients in μM in the Sacramento River at Fremont Weir during the inundation period, March 2000.

Analyte	March 7	March 17
Specific Conductance	121	147
Chloride	3.5	4.0
Sulfate	9.2	10.4
Dissolved organic carbon	2.9	1.3
Specific UV absorbance	0.079	--
Suspended particles	145	68
Particulate carbon	--	0.82
Particulate nitrogen	--	0.09
Dissolved metals:		
Boron	0.04	0.04
Barium	0.02	0.02
Calcium	10	13
Potassium	1.3	1.2
Magnesium	5.1	6.4
Sodium	6.3	7.2
Silicon	9.4	10.6
Strontium	0.06	0.09
Dissolved nutrients:		
Nitrate	10.9	14.0
Nitrite	0.1	0.1
Ammonium	0.9	0.3
Dissolved reactive phosphate	1.1	0.7
Dissolved silica	308	339

Table 2. Specific conductance (uS/cm) and concentrations of chloride and sulfate (mg/L).

Sample ID	Date	Specific Conductance	Chloride	Sulfate
Fremont Weir (FRW)				
FRW	7-Mar-00	121	3	9
FRW	17-Mar-00	147	4	10
Lower Bypass (STTD)				
STTD	26-Jan-00	790	49	104
STTD	28-Jan-00	712	43	100
STTD	31-Jan-00	728	41	90
STTD	2-Feb-00	747	42	87
STTD	3-Feb-00	753	49	90
STTD	7-Feb-00	769	48	90
STTD	9-Feb-00	823	52	100
STTD	11-Feb-00	810	51	98
STTD	14-Feb-00	570	35	68
STTD	16-Feb-00	201	10	16
STTD	25-Feb-00	169	7	11
STTD	28-Feb-00	146	5	10
STTD	6-Mar-00	146	5	10
STTD	20-Mar-00	476	23	44
STTD	22-Mar-00	534	27	51
STTD	23-Mar-00	574	30	57
STTD	24-Mar-00	559	30	54
STTD	27-Mar-00	568	31	50
STTD	31-Mar-00	640	37	61
STTD	10-Apr-00	824	53	92
STTD	17-Apr-00	921	77	71
STTD	24-Apr-00	464	25	40
STTD	1-May-00	654	45	55
STTD	8-May-00	763	62	55
STTD	15-May-00	604	44	45
STTD	22-May-00	642	49	48

Table 2 continued.

Sample ID	Date	Specific Conductance	Chloride	Sulfate
Toe Drain at I-80 (TD80)				
TD80	26-Jan-00	832	51	118
TD80	16-Feb-00	163	7	13
TD80	28-Feb-00	160	6	11
TD80	7-Mar-00	153	5	11
TD80	17-Mar-00	262	11	23
TD80	23-Mar-00	715	42	87
TD80	28-Mar-00	705	45	71
TD80	3-Apr-00	833	54	93
TD80	17-Apr-00	911	75	84
TD80	21-May-00	678	52	60
Toe Drain at I-5 (TD5)				
TD5	26-Jan-00	783	41	124
TD5	16-Feb-00	128	5	10
TD5	28-Feb-00	138	4	9
TD5	7-Mar-00	157	7	10
TD5	17-Mar-00	363	16	39
TD5	23-Mar-00	731	42	92
TD5	28-Mar-00	741	44	88
TD5	3-Apr-00	837	52	107
TD5	17-Apr-00	805	66	50
TD5	21-May-00	778	75	61
Ridge Cut Canal West Side at Road 16 (RCW16)				
RCW16	26-Jan-00	744	38	115
RCW16	16-Feb-00	442	24	62
RCW16	7-Mar-00	554	28	69
Ridge Cut Canal East Side at Road 16 (RCE16)				
RCE16	26-Jan-00	725	35	112
RCE16	16-Feb-00	442	24	63
RCE16	20-Feb-00	600	30	83
RCE16	28-Feb-00	588	30	79
RCE16	7-Mar-00	571	29	72
RCE-16	17-Mar-00	780	41	102
RCE-16	23-Mar-00	784	42	108
RCE-16	28-Mar-00	891	51	129
RCE-16	3-Apr-00	842	46	113
RCE-16	17-Apr-00	895	76	87

Table 2 continued.

Sample ID	Date	Specific Conductance	Chloride	Sulfate
Colusa Basin Drain at Road 99E (CBD99)				
CBD99E	20-Feb-00	613	31	85
CBD99E	28-Feb-00	612	31	84
CBD99E	21-May-00	515	23	83
Cache Creek at Road 113 (CC113)				
CC113	26-Jan-00	702	78	52
CC113	16-Feb-00	389	26	29
CC113	28-Feb-00	334	14	26
CC113	7-Mar-00	359	14	25
CC113	17-Mar-00	416	20	25
CC113	23-Mar-00	544	35	34
CC113	28-Mar-00	550	35	33
CC113	3-Apr-00	747	49	41
CC113	17-Apr-00	498	30	26
CC113	21-May-00	728	46	37
Willow Slough at Road 102(WS102)				
WS102	26-Jan-00	441	26	54
WS102	16-Feb-00	323	17	36
WS102	28-Feb-00	421	22	40
WS102	7-Mar-00	423	21	37
WS102	17-Mar-00	870	26	28
WS102	23-Mar-00	851	60	81
WS102	28-Mar-00	1181	68	78
WS102	3-Apr-00	659	44	45
WS102	17-Apr-00	457	26	28
WS102	21-May-00	551	31	30
Putah Creek at Old Davis Road (PCD)				
PCD	26-Jan-00	471		
PCD	16-Feb-00	336	14	30
PCD	28-Feb-00	430	17	45
PCD	7-Mar-00	358	8	30
PCD	17-Mar-00	352	7	26
PCD	23-Mar-00	351	7	25
PCD	28-Mar-00	354	7	25
PCD	3-Apr-00	434	15	29
PCD	17-Apr-00	573	27	33
PCD	21-May-00	567	24	34

Table 2 continued.

Sample ID	Date	Specific Conductance	Chloride	Sulfate
Boat Samples from Yolo Bypass: Band A =East Side; Band D = West Side				
BAND A	17-Feb-00	133	5	10
BAND B	17-Feb-00	109	4	9
BAND C	17-Feb-00	118	4	10
BAND D	17-Feb-00	220	9	23
BAND A	18-Feb-00	119	4	9
BAND B	18-Feb-00	117	4	9
BAND C	18-Feb-00	114	4	10
BAND D	18-Feb-00	368	20	47
BAND B	19-Feb-00	132	4	10
BAND C	19-Feb-00	127	4	10
BAND D	19-Feb-00	288	13	33
BAND A	20-Feb-00	147	6	10
BAND B	20-Feb-00	140	4	10
BAND C	20-Feb-00	145	4	11
BAND D	20-Feb-00	416	16	42
Boat Samples from Southern Outlet of Yolo Bypass				
LH-1	11-Apr	527	33	51
PS-1	23-Mar	558	28	54
PS-1	11-Apr	341	20	29
PS-2	23-Mar	536	26	51
PS-2	11-Apr	322	19	27
PS-3	23-Mar	551	27	54
YB-1	11-Apr	221	11	18

Table 3. Concentrations of nitrite (NO2), Nitrate plus Nitrite (N+N), Ammonium (NH4), dissolved inorganic nitrogen (DIN), dissolved reactive phosphorus (DRP), and dissolved silica (DiSi).

Station ID	Date	NO2	N+N	NH4	DIN	DRP	DiSi
Fremont Weir (FRW)							
FRW	7-Mar-00	0.14	11.1	0.89	12	1.09	308
FRW	17-Mar-00	0.08	14.1	0.33	14.4	0.68	339
Lower Bypass (STTD)							
STTD	26-Jan-00	3.59	73.5	9.16	82.7	5.41	243
STTD	28-Jan-00	2.87	76.2	14.7	90.9	4.62	273
STTD	14-Feb-00	1.63	58.6	12.08	70.7	4.08	205
STTD	16-Feb-00	0.53	22.1	4.43	26.5	1.88	271
STTD	25-Feb-00	0.17	15.6	0.89	16.5	1.25	352
STTD	28-Feb-00	0.17	12.5	0.9	13.4	0.99	321
STTD	6-Mar-00	0.15	10.5	0.77	11.3	0.84	327
STTD	20-Mar-00	0.2	6.8	2.03	8.8	1.22	221
STTD	22-Mar-00	0.35	16.1	2.8	18.9	1.36	200
STTD	23-Mar-00	0.4	19.3	2.19	21.5	1.6	206
STTD	24-Mar-00	0.61	20.7	5.49	26.2	1.62	194
STTD	27-Mar-00	0.81	25.2	6.26	31.4	1.64	188
STTD	31-Mar-00	1.3	36.6	11.63	48.3	2.05	161
STTD	10-Apr-00	3.18	101.4	6.15	107.5	5.03	203
STTD	17-Apr-00	4.62	136	6.85	143	7.52	256
STTD	24-Apr-00	1.67	45	4.63	49.6	2.27	188
STTD	1-May-00	3.27	84.1	11.29	95.4	4.98	222
STTD	8-May-00	5.31	154	9.4	163	8.46	227
STTD	15-May-00	2.05	95.1	2.5	97.6	4.45	142
STTD	22-May-00	2.24	94.8	5.82	100.6	5.26	128
Toe Drain at I-80 (TD80)							
TD80	26-Jan-00	2.13	71.5	23.2	94.7	4.72	264
TD80	16-Feb-00	0.46	19.7	3.62	23.3	1.54	255
TD80	28-Feb-00	0.26	15.2	1	16.2	1.19	308
TD80	7-Mar-00	0.2	12.8	0.66	13.4	0.97	309
TD80	17-Mar-00	0.27	14.7	0.45	15.1	1.08	304
TD80	23-Mar-00	0.72	33.8	2.65	36.4	1.69	186
TD80	28-Mar-00	0.84	37	4.04	41	1.15	159
TD80	3-Apr-00	1.6	68.2	11.29	79.5	3.44	188
TD80	17-Apr-00	2.95	82.5	10.31	92.8	6.17	290
TD80	21-May-00	2.68	71.4	15.5	86.9	7.6	174

Table 3 continued.

Station ID	Date	NO2	N+N	NH4	DIN	DRP	DiSi
Toe Drain at I-5 (TD5)							
TD5	17-Jan-00	1.21	363	7.83	370.8	29.2	270
TD5	26-Jan-00	2.28	77.1	16	93.1	4.17	276
TD5	16-Feb-00	0.26	19.3	2.11	21.4	1.13	287
TD5	28-Feb-00	0.12	11.5	0.45	12	0.86	342
TD5	7-Mar-00	0.16	15.5	0.79	16.3	1.03	337
TD5	17-Mar-00	0.46	21.2	1.53	22.7	1.63	293
TD5	23-Mar-00	1.05	45.1	4.7	49.8	1.94	192
TD5	28-Mar-00	1.1	46.6	3.39	50	1.05	144
TD5	3-Apr-00	1.5	79.2	3.51	82.7	2.78	171
TD5	17-Apr-00	2.26	268	2.31	270	5.99	202
TD5	21-May-00	1.76	224	2.16	226	9.59	218
Ridge Cut Canal West Side at Road 16 (RCW16)							
RCW16	17-Jan-00	3.37	85.9	5.15	91.1	1.4	323
RCW16	26-Jan-00	2.57	81.7	14.5	96.2	4.31	275
RCW16	16-Feb-00	1.95	55.3	11.83	67.1	3.75	212
RCW16	7-Mar-00	1.24	45.4	4.57	50	2.88	227
Ridge Cut Canal East Side at Road 16 (RCE16)							
RCE16	26-Jan-00	2.59	81.2	14.1	95.3	3.91	277
RCE16	16-Feb-00	2.03	56.9	11.76	68.7	3.55	215
RCE16	20-Feb-00	1.37	34.1	7.98	42.1	2.77	274
RCE16	28-Feb-00	1.52	44.7	6.3	51	3.59	255
RCE16	7-Mar-00	1.19	46.7	4.7	51.4	2.76	225
RCE-16	17-Mar-00	1.23	43.6	5.46	49	2.9	224
RCE-16	23-Mar-00	1.35	50.4	6.91	57.3	2.18	210
RCE-16	28-Mar-00	1.66	58.9	7.73	66.7	2.02	166
RCE-16	3-Apr-00	2.27	65.5	14.27	79.8	2.93	176
RCE-16	17-Apr-00	4.41	94.5	8.95	103.5	2.37	245
Colusa Basin Drain at Road 99E (CBD99E)							
CBD99E	20-Feb-00	1.33	32.4	8.14	40.6	2.58	273
CBD99E	28-Feb-00	1.52	40.6	6.52	47.1	3.52	254
CBD99E	21-May-00	1.18	21.8	6.07	27.9	2.28	209

Table 3 continued.

Station ID	Date	NO2	N+N	NH4	DIN	DRP	DiSi
Cache Creek at Road 113 (CC113)							
CC113	17-Jan-00	1.52	309	0.55	309.6	0.05	143
CC113	26-Jan-00	0.81	79.8	4.86	84.7	0.13	240
CC113	16-Feb-00	0.28	28.4	2.7	31.1	0.66	230
CC113	28-Feb-00	0.16	12.7	0.71	13.4	0.59	216
CC113	7-Mar-00	0.18	14.3	0.71	15	0.4	201
CC113	17-Mar-00	0.15	30.3	0.24	30.5	0.12	150
CC113	23-Mar-00	0.19	58.4	0.12	58.6	0.08	174
CC113	28-Mar-00	0.22	62.2	0.22	62.4	0.08	127
CC113	3-Apr-00	1.31	335	1.89	337	0.08	183
CC113	17-Apr-00	0.81	119	0.34	119	0.18	163
CC113	21-May-00	2.6	375	4.22	379	0.13	199
Willow Slough at Road 102 (WS102)							
WS102	26-Jan-00	6.06	380	11.8	391.8	4.94	170
WS102	16-Feb-00	1.56	96	7.65	103.7	3.58	209
WS102	28-Feb-00	1.18	103.7	3.95	107.6	3.29	219
WS102	7-Mar-00	1.46	126.3	5.09	131.4	2.67	225
WS102	17-Mar-00	0.27	52.8	0.16	53	0.07	32
WS102	23-Mar-00	3.28	304	0.43	304	0.08	36
WS102	28-Mar-00	10.86	458	0.4	458	1.29	265
WS102	3-Apr-00	1.04	74.1	2.8	76.9	0.68	136
WS102	17-Apr-00	5.72	109	21.63	130.6	4.6	174
WS102	21-May-00	5.15	211	2.75	214	1.57	158
Putah Creek at Old Davis Road (PCD)							
PCD	17-Jan-00	1.02	183	2.36	185.4	0.76	251
PCD	26-Jan-00	1.05	133	7.24	140.2	1.93	254
PCD	16-Feb-00	0.77	84	21.98	105.9	5.97	244
PCD	28-Feb-00	0.22	51.3	2.5	53.8	2.95	268
PCD rerun	28-Feb-00	0.22	51	2.32	53.3	2.92	266
PCD	7-Mar-00	0.3	18.6	2.4	21	1.66	273
PCD rerun	7-Mar-00	0.3	18.4	2.46	20.9	1.63	272
PCD	17-Mar-00	0.06	14.3	0.34	14.6	1.21	270
PCD	23-Mar-00	0.29	12.2	0.38	12.6	1.01	245
PCD	28-Mar-00	0.08	14.8	0.18	15	0.2	250
PCD	3-Apr-00	0.36	87	0.71	87.7	5.24	268
PCD	17-Apr-00	1.18	248	3.13	251	9.92	295
PCD	21-May-00	1.35	201	2.5	204	5	303

Table 3 continued.

Station ID	Date	NO2	N+N	NH4	DIN	DRP	DiSi
Boat Samples from Yolo Bypass: Band A = East Side; Band D = West Side							
BAND A	17-Feb-00	0.28	15.2	2.56	17.8	1.27	281
BAND B	17-Feb-00	0.22	15.8	3.12	18.9	1.15	268
BAND B	17-Feb-00	0.21	15.3	2.64	17.9	1.16	270
BAND C	17-Feb-00	0.25	15.6	3.1	18.7	1.46	279
BAND D	17-Feb-00	0.55	24.8	4.6	29.4	2	269
BAND D	17-Feb-00	0.55	25.1	4.55	29.7	1.96	268
BAND A	18-Feb-00	0.23	13.2	2.49	15.7	1.11	274
BAND B	18-Feb-00	0.15	11.5	0.72	12.2	0.92	272
BAND C	18-Feb-00	0.2	11.7	1.05	12.7	1.2	267
BAND D	18-Feb-00	1.59	39.7	5.75	45.4	3.17	220
BAND B	19-Feb-00	0.12	11.6	1.57	13.1	0.83	302
BAND C	19-Feb-00	0.17	10.6	2.16	12.8	1.06	283
BAND D	19-Feb-00	0.98	27.4	5.99	33.4	2.2	246
BAND A	20-Feb-00	0.15	12.2	1.27	13.5	0.93	308
BAND B	20-Feb-00	0.11	10.4	0.97	11.4	0.82	329
BAND C	20-Feb-00	0.16	9.3	1.26	10.5	1	316
BAND D	20-Feb-00	1.15	27	5.71	32.7	2.42	256
Boat Samples from Southern Outlet of Yolo Bypass							
PS-1	23-Mar-00	0.35	17.7	1.68	19.4	1.46	194
PS-2	23-Mar-00	0.31	15.1	1.72	16.9	1.32	204
PS-3	23-Mar-00	0.35	17.6	1.76	19.4	1.52	208
PS-1	11-Apr-00	0.8	30	6.23	36.2	1.89	236
PS-2	11-Apr-00	0.75	27.6	6.49	34.1	1.81	228
LH-1	11-Apr-00	1.16	50.9	4.18	55.1	2.91	212
YB-1	11-Apr-00	0.58	18.8	9.29	28.1	1.42	242

Table 4. Dissolved organic carbon (DOC mg/L), specific ultraviolet absorbance of the DOC (SUVA), suspended particulate matter (SPM mg/L), particulate matter (SPM), particulate carbon (PC mg/L) and particulate nitrogen (PN mg/L).

Site	Date	DOC	SUVA	SPM	PC	PN
Fremont Weir (FRW)						
FRW	3/7/2000	2.9	0.079	145		
FRW	3/17/2000	1.3		68	0.82	0.09
Lower Bypass (STTD)						
STTD	1/26/2000	6.8	0.026	235	5.15	0.72
STTD	1/28/2000	7.9	0.03	123	4.95	0.69
STTD	2/14/2000	7.1	0.033	167	3.64	0.59
STTD	2/16/2000	4.4	0.104	173	2.55	0.36
STTD	2/28/2000	2.6	0.072	55	1.08	0.11
STTD	3/6/2000	1.8	0.061	36		
STTD	3/20/2000	4.4	0.026	489	9.58	1.37
STTD	3/22/2000	4.7	0.027	114	1.94	0.32
STTD	3/23/2000	4.8	0.026	147	2.81	0.47
STTD	3/24/2000	4.6	0.026	124	3.12	0.55
STTD	3/31/2000	3.9	0.025	49	1.23	0.17
STTD	4/10/2000	5	0.025	36	1.6	0.32
STTD	4/17/2000	3.9	0.026	63	2.3	0.46
STTD	4/24/2000	4.1	0.029	76	1.7	0.29
STTD	5/1/2000	4.5	0.027	68	1.55	0.29
STTD	5/8/2000	3.9	0.026	65	1.45	0.28
STTD	5/15/2000	5.2	0.024	68	2.7	0.58
STTD	5/22/2000	5.1	0.026	83	2.67	0.58
Toe Drain at I-80 (TD80)						
TD80	1/26/2000	6.9	0.027	232	4.22	0.55
TD80	2/16/2000	4.7	0.06	62	1.24	0.17
TD80	2/28/2000	2.8	0.064	42	1.08	0.1
TD80	3/7/2000	2	0.057	26		
TD80	3/17/2000	2.4	0.034	56	0.89	0.14
TD80	3/23/2000	4.9	0.025	92	1.8	0.28
TD80	3/28/2000	4.1	0.024	77	1.79	0.34
TD80	4/3/2000	5.1	0.026	103	2.2	0.37
TD80	4/17/2000	3.9	0.026	139	2.79	0.5
TD80	5/21/2000	5.9	0.025	116	3.84	0.71

Table 4 continued.

Site	Date	DOC	SUVA	SPM	PC	PN
Toe Drain at I-5 (TD5)						
TD5	1/26/2000	7.8	0.031	363	3.97	0.59
TD5	2/16/2000	3.8	0.075	107	1.97	0.29
TD5	2/28/2000	2	0.059	49	1.14	0.14
TD5	3/7/2000	2	0.061	60		
TD5	3/17/2000	3.5	0.032	131	2.27	0.33
TD5	3/23/2000	5.4	0.026	78	1.56	0.26
TD5	3/28/2000	4.5	0.024	68	1.59	0.34
TD5	4/3/2000	5.8	0.026	94	2.48	0.5
TD5	4/17/2000	2.2	0.024	80	1.61	0.28
TD5	5/21/2000	4.4	0.023	46	2.51	0.52
Ridge Cut Canal at road 16 (RCE16)						
RCE16	1/26/2000	8.3	0.029	135	3.04	0.42
RCE16	2/16/2000	8.3	0.071	88	3.1	0.46
RCE16	2/28/2000	7.9	0.041	78	1.48	0.19
RCE16	3/7/2000	8.1	0.044	103		
RCE16	3/17/2000	7.4	0.027	87	2.1	0.29
RCE16	3/23/2000	5.9	0.026	99	2.04	0.3
RCE16	3/28/2000	5.3	0.025	102	2.05	0.4
RCE16	4/3/2000	6.5	0.026	110	2.1	0.34
RCE16	4/17/2000	4.2	0.024	54	1.95	0.42
Colusa Basin Drain at road 99E (CBD99E)						
CBD99E	2/28/2000	7.9	0.051	79	1.41	0.17
CBD99E	5/21/2000	6.1	0.024	67	1.96	0.36
Cache Creek at road 113 (CC113)						
CC113	1/26/2000	5	0.031	151	3.31	0.48
CC113	2/16/2000	4.1	0.049	271	3.04	0.39
CC113	2/28/2000	3.5	0.05	401	3.99	0.44
CC113	3/7/2000	2.8	0.04	382		
CC113	3/17/2000	2.3	0.02	87	1.35	0.14
CC113	3/23/2000	2	0.02	38	0.59	0.07
CC113	3/28/2000	2.3	0.02	15	0.52	0.1
CC113	4/3/2000	1.3	0.023	25	0.49	0.08
CC113	4/17/2000	1.7	0.023	32	0.73	0.12
CC113	5/21/2000	1.8	0.02	28	0.7	0.12

Table 4 continued.

Site	Date	DOC	SUVA	SPM	PC	PN
Willow Slough at road 102 (WS102)						
WS102	2/16/2000	7.8	0.071	186	3.58	0.51
WS102	2/28/2000	8.9	0.053	187	1.69	0.21
WS102	3/7/2000	7.6	0.048	193		
WS102	3/17/2000	2.3	0.04	96	1.67	0.28
WS102	3/23/2000	2.3	0.023	22	0.96	0.16
WS102	3/28/2000	1.9	0.023	39	4.3	0.78
WS102	4/3/2000	3	0.023	83	1.45	0.27
WS102	4/17/2000	3.8	0.034	193	2.79	0.46
WS102	5/21/2000	4.1	0.024	52	1.32	0.25
Putah Creek at Old Davis Road (PCD)						
PCD	2/16/2000	6.4	0.058	135	1.91	0.26
PCD	2/28/2000	4.1	0.037	105	1.84	0.21
PCD	3/7/2000	3	0.032	57		
PCD	3/17/2000	2.4	0.021	18	0.46	0.07
PCD	3/23/2000	2.5	0.02	15	0.42	0.05
PCD	3/28/2000	2.5	0.02	10	0.25	0.04
PCD	4/3/2000	2.7	0.02	17	0.39	0.06
PCD	4/17/2000	2.8	0.023	21	0.84	0.15
PCD	5/21/2000	2.4	0.021	15	0.47	0.07
Boat Samples from Yolo Bypass: Band A = East Side; Band D = West Side						
BAND A	2/17/2000			47		
BAND B	2/17/2000			102		
BAND C	2/17/2000	3.9	0.07	74	1.26	0.14
BAND D	2/17/2000	4.8	0.084	73	1.37	0.18
BAND A	2/18/2000			78		
BAND B	2/18/2000			104		
BAND C	2/18/2000			82		
BAND B	2/19/2000			57		
BAND C	2/19/2000			58		
BAND D	2/19/2000			72		
BAND A	2/20/2000	2.5	0.076	47	0.74	0.1
BAND B	2/20/2000	2.2	0.064	37	0.54	0.07
BAND C	2/20/2000	2.6	0.072	33	0.59	0.06
BAND D	2/20/2000	7	0.051	47	1.26	0.17

Table 4 continued.

Site	Date	DOC	SUVA	SPM	PC	PN
Boat Samples from stations near the southern outlet of the Yolo Bypass						
PS = Prospect Slough; LH = Little Holland Tract; YB = Yolo Bypass						
PS 1	3/23/2000			130		
PS 2	3/23/2000			98		
PS 3	3/23/2000			77		
PS 1	4/11/2000			79		
PS 2	4/11/2000			84		
LH 1	4/11/2000			98		
YB 1	4/11/2000			40		

Table 5. Analytical results for selected metals by ICP-OES (see text). Concentrations in mg/L.

SITE & DATE month/day	B	Ba	Ca	K	Mg	Na	S	Sr
Fremont Weir (FRW)								
FRW3/7	0.04	0.02	10	1.3	5	6	9.4	0.06
FRW3/17	0.04	0.02	13	1.2	6	7	10.6	0.09
Lower Bypass (STTD)								
STTD 1/26	0.53	0.09	39	3.9	34	95	8.1	0.51
STTD 1/28	0.46	0.08	35	5	30	83	8.5	0.46
STTD 1/31	0.37	0.08	36	4.8	33	94	9.2	0.48
STTD 2/2	0.43	0.09	38	4.1	33	84	8.9	0.5
STTD 2/3	0.62	0.09	37	3.9	32	85	8.3	0.49
STTD 2/7	0.58	0.09	39	4	34	86	9.1	0.5
STTD 2/9	0.66	0.1	41	4	36	93	8.9	0.53
STTD 2/11	0.61	0.1	40	4	36	91	8.8	0.52
STTD 2/14	0.43	0.07	28	3.5	21	58	6.4	0.34
STTD 2/16	0.11	0.03	13	2.1	9	13	8.5	0.12
STTD 2/25	0.07	0.02	13	1.5	7	10	10.8	0.1
STTD 2/28	0.05	0.02	12	1.4	6	8	9.8	0.09
STTD 3/6	0.04	0.02	12	1.3	6	8	10.2	0.09
STTD 3/20	0.42	0.06	28	2.4	20	34	7	0.3
STTD 3/22	0.5	0.07	32	2.5	29	46	6.5	0.35
STTD 3/23	0.5	0.08	33	2.5	31	50	6.3	0.37
STTD 3/24	0.51	0.08	33	2.6	31	49	6.1	0.36
STTD 3/27	0.6	0.08	33	2.6	33	49	6	0.37
STTD 3/31	0.68	0.09	34	2.5	35	56	4.8	0.41
STTD 4/10	0.6	0.11	43	3.1	40	86	6.2	0.54
STTD 4/17	1.46	0.13	47	3.5	49	87	7.7	0.55
STTD 4/24	0.6	0.07	28	2.5	23	40	5.8	0.33
STTD 5/1	0.85	0.1	35	2.9	33	62	6.8	0.42
STTD 5/8	1.22	0.11	40	3.5	40	71	6.8	0.49
STTD 5/15	1.09	0.09	32	3.3	33	53	4.2	0.38
STTD 5/22	1.17	0.09	34	3.4	34	56	4.1	0.4

Table 5 continued.

SITE & DATE month/day	B	Ba	Ca	K	Mg	Na	S	Sr
Toe Drain at I-80 (TD80)								
TD80 1/26	0.48	0.08	39	4	30	98	8.1	0.54
TD80 2/16	0.03	0.02	11	2.3	8	12	8.4	0.09
TD80 2/28	0.03	0.02	12	1.5	7	10	9.5	0.09
TD80 3/7	0.03	0.02	11	1.7	8	11	10.4	0.09
TD80 3/17	0.11	0.03	17	1.9	13	18	10	0.16
TD80 3/23	0.63	0.09	38	3.1	35	90	6.1	0.48
TD80 3/28	0.93	0.09	38	3	39	76	5.3	0.48
TD80 4/3	0.8	0.1	44	3.5	43	114	6.3	0.54
TD80 4/17	1.47	0.09	41	3.3	52	98	8.8	0.48
TD80 5/21	1.06	0.09	34	3.7	32	69	5.4	0.41
Toe Drain at I-5 (TD5)								
TD5 1/26	0.23	0.08	38	4.7	31	108	8.9	0.52
TD5 2/16	-0.01	0.02	9	1.6	6	9	9.4	0.08
TD5 2/28	-0.01	0.02	11	1.5	7	8	11	0.09
TD5 3/7	-0.01	0.02	12	1.5	7	10	11.1	0.09
TD5 3/17	0.08	0.04	22	1.9	15	20	9.3	0.23
TD5 3/23	0.44	0.08	40	2.7	31	80	5.9	0.5
TD5 3/28	0.72	0.09	40	3.1	39	90	4.8	0.52
TD5 4/3	0.54	0.1	45	2.9	36	106	5.6	0.57
TD5 4/17	1.8	0.14	49	3.9	49	81	6.7	0.55
TD5 5/21	1.16	0.11	41	4	34	79	6.6	0.49
Ridge Cut Canal West Side at Road 16 (RCW16)								
RCW 1/26	0.2	0.08	36	5.1	30	105	10.4	0.49
RCW 2/16	0.11	0.06	22	4	15	44	6.6	0.28
RCW 3/7	0.12	0.06	29	3.2	21	68	7.4	0.38
Ridge Cut Canal East Side at Road 16 (RCE16)								
RCE16 1/26	0.18	0.08	32	5	27	100	9.1	0.47
RCE16 2/16	0.1	0.05	22	4	15	46	6.5	0.28
RCE16 2/20	0.12	0.07	29	3.9	22	65	8.4	0.4
RCE16 2/28	0.14	0.07	31	4	24	75	8.2	0.41
RCE16 3/7	0.13	0.06	29	3	22	68	7.3	0.39
RCE16 3/17	0.28	0.09	44	3.6	34	106	7.8	0.53
RCE16 3/23	0.25	0.08	41	3	33	105	6.8	0.55
RCE16 3/28	0.33	0.1	48	3.3	41	133	5.7	0.62
RCE16 4/3	0.28	0.09	40	2.9	30	106	5.6	0.58
RCE16 4/17	1.1	0.11	55	3.6	44	84	7.6	0.67

Table 5 continued.

SITE & DATE month/day	B	Ba	Ca	K	Mg	Na	S	Sr
Colusa Basin Drain at Road 99E (CBD99E)								
CBD99E 2/20	0.2	0.07	30	4	22	70	8.4	0.4
CBD99E 2/28	0.2	0.08	32	3.6	22	69	7.8	0.41
CBD99E 5/21	0.21	0.07	26	2.1	18	58	6.3	0.33
Cache Creek at Road 113 (CC113)								
CC113 1/26	1.86	0.11	32	3.6	42	68	7.7	0.45
CC113 2/16	0.65	0.06	21	1.9	22	18	7.1	0.27
CC113 2/28	0.44	0.04	19	1.6	22	16	7	0.24
CC113 3/7	0.56	0.05	21	1.6	22	16	6	0.26
CC113 3/17	0.89	0.07	26	2	25	18	4.8	0.31
CC113 3/23	1.13	0.09	33	2.4	33	37	5.6	0.41
CC113 3/28	1.26	0.1	34	2.6	35	40	4.1	0.41
CC113 4/3	1.83	0.15	51	3	46	56	5.8	0.55
CC113 4/17	1.08	0.1	32	2.2	30	36	5.2	0.38
CC113 5/21	1.89	0.16	53	3.1	43	54	6	0.56
Willow Slough at Road 102 (WS102)								
WS102 1/26	0.99	0.1	29	6.4	24	43	6.4	0.34
WS102 2/16	0.68	0.07	18	4.5	14	17	8.1	0.2
WS102 2/28	0.69	0.08	26	3.8	18	35	6.7	0.29
WS102 3/7	0.68	0.08	27	3.4	18	33	6.9	0.29
WS102 3/17	1.75	0.16	57	3.1	44	85	6	0.62
WS102 3/23	2.09	0.12	42	2.6	49	95	1	0.58
WS102 3/28	2	0.13	37	2	86	130	8.6	0.6
WS102 4/3	1.41	0.11	40	2.9	39	52	4.1	0.46
WS102 4/17	0.88	0.08	27	3	24	23	5.2	0.32
WS102 5/21	1.15	0.1	32	3.3	32	39	4.8	0.4
Putah Creek at Old Davis Road (PCD)								
PCD 2/16	0.18	0.05	20	3	19	18	8.1	0.22
PCD 2/28	0.21	0.06	27	2.5	24	19	8.5	0.27
PCD 3/7	0.13	0.05	21	1.8	26	14	8.9	0.19
PCD 3/17	0.11	0.05	19	1.6	30	14	8.7	0.18
PCD 3/23	0.12	0.05	19	1.7	28	13	8.4	0.17
PCD 3/28	0.11	0.05	20	1.5	31	13	8	0.19
PCD 4/3	0.19	0.06	22	2.2	35	27	9	0.24
PCD 4/17	0.35	0.09	30	3.3	42	38	9.4	0.39
PCD 5/21	0.38	0.1	32	1.9	44	32	9.4	0.43

Table 5 continued.

SITE & DATE month/day	B	Ba	Ca	K	Mg	Na	S	Sr
Boat Samples from Yolo Bypass: Band A = East Side; Band D = West Side								
BANDD 2/17	0.12	0.03	13	2.3	9	13	8.2	0.14
BANDC 2/17	0.06	0.02	9	1.5	5	7	8.6	0.07
BANDB 2/17	0.04	0.02	9	1.4	5	6	8.2	0.07
BANDA 2/17	0.04	0.02	10	1.6	6	7	9	0.08
BANDB 2/18	0.04	0.02	10	1.4	5	6	8.2	0.07
BANDC 2/18	0.04	0.02	9	1.4	5	6	8.1	0.07
BANDD 2/18	0.16	0.06	20	3.5	13	34	8.8	0.22
BANDB 2/19	0.04	0.02	11	1.4	6	7	9.6	0.09
BANDC 2/19	0.04	0.02	11	1.4	6	6	8.8	0.09
BANDD 2/19	0.12	0.04	17	2.8	11	16	7.5	0.18
BANDA 2/20	0.05	0.02	12	1.5	6	8	9.6	0.1
BANDB 2/20	0.05	0.02	12	1.4	6	7	10.1	0.09
BANDC 2/20	0.06	0.02	12	1.5	6	8	9.6	0.09
BANDD 2/20	0.13	0.06	21	3.5	14	32	8.1	0.24
Boat Samples from Southern Outlet of Yolo Bypass								
PS1 3/23	0.5	0.07	33	2.6	30	47	6.3	0.36
PS2 3/23	0.5	0.07	32	2.6	28	47	6.4	0.34
PS3 3/23	0.52	0.07	32	2.7	29	51	6.6	0.35
PS1 4/11	0.22	0.04	21	1.8	15	20	7.3	0.2
PS2 4/11	0.21	0.04	19	1.9	16	19	7.8	0.18
LH1 4/11	0.42	0.06	28	2.8	26	53	7.1	0.32
YB1 4/11	0.11	0.03	15	1.4	10	12	7.6	0.12