Task 2. Methyl mercury Concentrations and Loads in the Central Valley and Freshwater Delta

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Introduction

The Sacramento and San Joaquin Rivers and the Sacramento-San Joaquin Bay Delta Estuary are on the federal Clean Water Act 303(d) list because of elevated mercury concentrations in fish (SWRCB, 2007). The California Office of Environmental Health Hazard Assessment (OEHHA) has issued fish advisories for both rivers and the Delta recommending limited or no consumption of certain fish species because of mercury contamination (OEHHA, 2006, 2008a, 2008b). Methyl mercury is a developmental neurotoxin. It is produced in sediment by sulfate reducing bacteria (Compeau and Bartha, 1985). Life forms most at risk are human and wildlife fetuses and young. The primary route of exposure is from consumption of mercury-contaminated fish. Statistically significant positive correlations have been observed in the Delta and elsewhere between average annual unfiltered methyl mercury concentrations in water and in fish (Brumbaugh *et al*., 2001; Foe *et al*., 2002; Slotton *et al*., 2003; Tetra Tech, 2005; Wood *et al*., 2008). The relationship suggests that aqueous methyl mercury may be an important factor controlling methyl mercury bioaccumulation in the aquatic food chain. If so, identifying primary sources and sinks are essential for understanding the contamination problem and for developing control programs to reduce risk.

A previously sponsored CALFED mass balance study demonstrated that the Sacramento and San Joaquin Rivers were the single largest source of methyl mercury to the Delta (Foe, 2003). The two rivers delivered about 60 percent of the methyl mercury entering the estuary. The Sacramento is the larger of the two rivers and contributed about 75 percent of the water and, depending on month, 50 to 85 percent of the methyl mercury. The only exception was when the Yolo Bypass flooded whereupon it became the dominant source. The Yolo Bypass is a flood conveyance system designed to divert floodwater from the Sacramento River around the City of Sacramento. The San Joaquin River has less flow but is an important local source of water and methyl mercury in the south Delta.

A methyl mercury Total Maximum Daily Load (TMDL) report has been prepared for the Delta (Wood *et al*., 2008). The mass balance estimate includes data collected in the first CALFED grant as well as information from other methyl mercury studies (Figure 1). The mass balance calculations demonstrate that, during a relatively dry period, the Delta is a net methyl mercury sink. On average about half of the methyl mercury (-7.6 g/day) is lost. Processes responsible for the loss have not been identified but are a key objective of other parts of the present CALFED grant (Task 5).

The Central Valley is sixty-thousand square miles, or 40 percent of the land mass of the State of California. On the east, the valley is bounded by the Sierra Nevada Mountains and on the west by the Coastal Range. Most of the precipitation falls in winter in the mountains and is captured by reservoirs for release in summer for downstream urban and agricultural use. Major land uses in the mountains are forestry and animal grazing while on the valley floor it is agriculture. The Central Valley is not heavily populated. Most of the population is clustered around the Delta in the Cities of Sacramento and Stockton with a combined population of about a million people.

The presence of mercury mining waste may be a factor contributing to methyl mercury production in the Central Valley. Gold was discovered in the Sierra Nevada Mountains in 1848 and was mined by placing sluice boxes into streams and adding elemental mercury to amalgamate the precious metal. Six million kilograms (kg) of mercury are believed to have been lost in gold mining (Churchill, 2000). At about the same time mercury was discovered in the Coastal Range (Pemberton, 1983). The mercury mines were of national significance and accounted for about 90 percent of all the mercury produced in the United States between 1850 and 1980. Cinnabar ore was crushed and roasted on site to produce elemental mercury and the waste rock was left to erode into surface water. About 30 million kg of mercury are believed to have been lost in mercury mining. The result of the historic mercury and gold mining is widespread sediment mercury contamination in Coastal Range and Sierra Nevada streams and rivers on the Valley floor that drain to the Bay-Delta Estuary.

No mass balance study has been conducted in the Central Valley identifying key hydrologic and land use practices responsible for methyl mercury production. A robust mass balance study should provide two essential pieces of information for managers. First, it would identify and quantify the magnitude of the primary methyl mercury sources and sinks in the Central Valley. Source identification is essential to prioritize development and implementation of best management practices to reduce methyl mercury exposure. Second, the mass balance should attempt to determine the nature of methyl mercury transport (conservative or non conservative) in major Valley rivers. This information is needed to ascertain whether upstream controls will reduce only upstream methyl mercury exposure or will also have downstream benefits.

The purpose of this study is threefold. First, identify the major sources of methyl mercury in the Sacramento and San Joaquin Basins and determine the magnitude of the loads exported to the Delta. Second, determine the efficiency with which methyl mercury is transported from Central Valley sources to the Delta. Finally, construct a methyl mercury mass balance box model for the Delta in collaboration with other Researchers in this project.

Method and Materials

Delta

The purpose of subtask 2.1 was to characterize methyl mercury concentrations and loads entering and leaving the Delta. Water was collected on 27 occasions, about monthly, between April 2003 and July 2006 from all major freshwater sources and export sites (Figure 2 and Appendix B for site descriptions). Sources included the Sacramento, San Joaquin, Mokelumne and Cosumnes Rivers and Prospect Slough as each entered the legal boundary of the Delta. Export sites were the Delta Mendota Canal (DMC), State Water Project (SWP) and the Sacramento River channel off Mallard Island. The DMC and SWP are the two major man-made conveyances transporting water out of the Delta to central and southern California. The channel off Mallard Island is the major conduit for water leaving the Delta to San Francisco Bay. All water source and export sites are gauged and flow information is available on line (see Louie *et al*., 2008). Water was also collected from the channel about 7 miles above (lower Sherman Island) and below (Port Chicago) Mallard Island. Mallard Island was defined in this study as the western boundary of the Delta. The Mallard Island channel is the only major sampling site located in the tidal prism. The purpose of sampling above and below Mallard Island was to determine whether there was a methyl mercury gradient in the western Delta requiring an estimate of dispersive flux (tidal pumping). Finally, water was collected from Old River at Tracy Boulevard and from Middle River at Bullfrog. These two sites are located along the major pathway of water moving from the San Joaquin and Sacramento Rivers across the Delta to the DMC and SWP export pumps. It was thought that data from these two sites might be useful in future methyl mercury modeling efforts.

Sacramento and San Joaquin Basins

The purpose of subtask 2.2 was to characterize methyl mercury concentrations and loads in the Sacramento and San Joaquin Basins. Thirty-two monthly surveys were conducted in the Sacramento Basin between March 2003 and June 2006. Eight sites were located along the 350-miles of Sacramento River between Redding and Freeport. Freeport is just downstream of the legal boundary of the Delta (Figure 2). These sites were the Sacramento River at Redding, Bend Bridge, Woodsen Bridge, Hamilton City, Ord Ferry, Butte City, Colusa, and Freeport. In addition, all major tributaries to the Sacramento River were monitored. These are the Feather, Yuba, Bear and American Rivers, and Colusa Basin Drain and Sacramento Slough. Sacramento Slough and Colusa Basin Drain are the principal agricultural drains discharging water from the east and west sides of the Valley, respectively. Finally, the largest nine small tributaries entering the Sacramento River between Redding and Colusa were sampled monthly for the last seven months of the study to determine how much of the overall load they contributed. The nine tributaries are Clear, Cow, Battle, Cottonwood, Elder, Thomes, Mill, Deer and Big Chico Creeks. All the sampling sites were located at flow gauge stations. Flow information from the gauges was used to calculate loads.

Methyl mercury samples were collected on thirty-five occasions at eleven locations in the San Joaquin Basin between April 2003 and June 2006. The sampling included four sites along the 55-miles of San Joaquin River between Fremont Ford and Vernalis, the legal boundary of the Delta (Figure 2). Seven tributaries also were sampled. The Merced, Tuolumne and Stanislaus Rivers drain the Sierra Nevada range and are the major sources of water to the San Joaquin River. Salt and Mud Sloughs, Turlock Irrigation District #5, and Orestimba Creek are dominated by agricultural runoff. Again, all sampling sites were located at flow gauge stations so that information from the gauges could be used to calculate methyl mercury loads.

Yolo Bypass and Cache Creek Settling Basin

The purpose of subtask 2.3 was to conduct studies in sub watersheds that produced a disproportionate amount of methyl mercury. The Yolo Bypass and Cache Creek Settling Basin were selected for intensive study.

The Yolo Bypass is a 59,000-acre flood conveyance system designed to divert storm water from the Sacramento River around the City of Sacramento (Figure 2). Monitoring demonstrated that Prospect Slough, primary exit for water from the Bypass, had the highest annual average methyl mercury concentrations of any Delta source. Methyl mercury production was assessed in the Bypass during wet and dry periods. The major dry weather sources of water to the Bypass are the Knights Landing Ridge Cut from Colusa Basin Drain and Cache and Putah Creeks. Sacramento River storm water is diverted into the Bypass from the Fremont and Sacramento Weirs. Prospect Slough is the primary export site during dry weather. Storm water is carried out of the Bypass in Prospect and Shag Sloughs. All major water sources to the Yolo Bypass are gauged. Export flow information is available from Lisbon Weir for dry periods. Discharge rates during high flow are not measured and so were assumed to be the sum of all inputs.

Water Collection and Analysis

Water samples were collected using ultra clean sampling techniques. Briefly, each sample was collected in a double-bagged 4-liter amber glass bottle that had previously been rinsed three times with ambient water. Samples were placed on ice and aliquots decanted from the same bottle for total suspended solids (TSS) or suspended sediment concentrations (SSC), raw and filtered total and methyl mercury. Total mercury results are reported by Louie *et al*. (2008). All samples were filtered within 12 hours of collection and preservative added by the analytical laboratory within 3 days. Methyl mercury analysis was done by Battelle Marine Sciences Laboratory using procedures described in CALFED (2000). Both TSS and SSC analyses were done at Moss Landing Marine Laboratory with Standard Method 2540D and ASTM D3977M, respectively. Suspended sediment concentrations were quantified by TSS until November 2004 whereupon the analysis was shifted to SSC.

Sixty-one samples were analyzed by both methods to develop a regression to convert TSS to SSC[1]. All results are reported as SSC.

Water samples were collected in the field as subsurface grabs. Samples were taken in shallow streams by wading into the middle of the waterway, facing upstream, and collecting the sample after all turbidity had dispersed or by standing on the bank and using a 10 foot pole to reach into fast moving water. When samples were collected by boat, the vessel was anchored and allowed to swing into the wind. The depth of water was determined with a fathometer and a depth integrated sample collected in an acid washed 4 liter bottle by rapidly lowering the bottle to just above the bottom and then retrieving it. Bridge samples were collected by lowering the sampling bottle off of the center of the bridge.

Loads

Methyl mercury (MMHg) loads (g/mo) were estimated by multiplying water volume (acre-ft/mo) by mercury concentration (ng/l) and a conversion factor:

(MMHg concentration)(Water Volume)(1.235×10^{-3})

If mercury concentrations were below the ability of the laboratory to quantify, then half the detection limit was employed. This only occurred at the Sacramento River at Redding and Bend Bridge. The methyl mercury detection limit varied slightly between collections but averaged 0.0114-ng/l.

Average daily methyl mercury loads were estimated for the box model by summing monthly loads and dividing by the number of days in the study.

Quality Assurance/Quality Control Program

About 15 percent of all methyl mercury analyses were for quality assurance and quality control (QA/QC) purposes. The QA/QC program had both field and laboratory components.

Field The field component consisted of the collection of field blanks and field duplicates. A blank was collected on each field trip (145 occasions). The procedure consisted of randomly selecting one site and carrying laboratory water with undetectable amounts of methyl mercury into the field and subsequently processing it in an identical manner as the field samples. Twenty-eight samples were taken for filtered and 117 for unfiltered methyl mercury. Also, on 170 occasions duplicate field samples were simultaneously taken at randomly selected sites. Twenty-eight of these samples were filtered and 142 were not filtered. The difference in mercury concentration between the paired samples was used to assess field variability.

Laboratory The QA/QC program at Battelle Marine Sciences Laboratory consisted of both amendments to and replicate analysis of the same sample. On 322

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[1] SSC=1.08991(TSS)+2.581 (R^2=0.96)

occasions a known amount of methyl mercury was added to a randomly selected field sample and the percent recovery measured. Similarly, 218 replicate analyses of randomly selected field samples were conducted and the percent difference between the two analyses was determined. The purpose of the amendments and replicate measurements was to ascertain the accuracy and precision of the analysis.

Statistics and Data Storage

Calculations of t-tests and confidence limits were performed with Microsoft Excel while multiple regression analyses were done with Statistica software[2]. A P-value of 0.05 was used to establish statistical significance although the actual P-values are provided in text to help the reader evaluate the probability of achieving the results by chance. All methyl mercury, flow and SSC data collected in this project will be made available to CALFED for posting online.

Results and Discussion

Quality Assurance Quality Control Program

Analysis of the field blanks demonstrated sporadic methyl mercury contamination which could not be traced to any single cause (Table 1, Appendix A). Ten percent (3 of 28) of the filtered and 13 percent (16 of 117) of the unfiltered samples had detectable amounts of methyl mercury. All instances of contamination were near the detection limit (0.024 to 0.038-ng/l). The contamination should not have unduly affected the accuracy of the mass balance results, with the possible exception of 25 May 2004 and 22 May and 21 June 2006, as the concentration of the contaminated field blank was only about 30 percent of the concentration of the lowest field sample. The blanks for 25 May 2004, 22 May and 21 June 2006 were all collected on field trips in the upper Sacramento River. Background methyl mercury concentrations in the Sacramento River at Redding and Bend Bridge are low and close to concentrations observed in the field blanks. Methyl mercury concentrations reported for the two upper river sites on these three dates should be viewed with caution.

Field duplicates were collected on 170 occasions to assess the repeatability of the ambient measurements (Table 2, Appendix A). The mean relative percent differences[3] for raw and filtered methyl mercury were 13 and 14 percent, respectively.

The laboratory portion of the QA/QC consisted of the analysis of duplicates and amendments. The relative percent differences of raw and filtered laboratory methyl mercury duplicates were 9 and 14 percent, respectively (Table 3, Appendix A). The relative percent differences of field and laboratory duplicates were similar suggesting that much of the variability observed in field samples may originate in the laboratory.

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[2] Statistica StatSoft, http:// www.statsoft.com

[3] High minus low value divided by the average of the high and low values

On 322 occasions a known amount of methyl mercury was amended into a randomly selected field sample and the percent recovery calculated to assess accuracy (Table 4, Appendix A). The mean percent recovery for raw and filtered methyl mercury samples was 92 percent.

In conclusion, results from the QA/QC program suggest, with the possible exception of a few samples from the upper Sacramento River, that all analytical values are of sufficient quality to be used in the calculation of a methyl mercury budget for the Central Valley and Delta.

Freshwater Delta

The purpose of Task 2A was to characterize methyl mercury concentrations and loads in the Delta. First, a brief description of background information for the estuary is provided with an emphasis on hydrology and the results of the first CALFED sponsored methyl mercury study. Next, methyl mercury concentrations and loads at both source and export sites, and transport across the Delta are examined. Finally, a revised methyl mercury box model incorporating the results of both the present and earlier CALFED study results is presented.

Background

The Bay-Delta Estuary is the largest estuary on the west coast of North America. The freshwater Delta receives drainage from over 40 percent of the State of California. The Delta includes approximately 1,100-miles of channels and 100,000-acres of open water. Four watersheds drain to the Delta: the Sacramento, San Joaquin, Mokelumne and Cosumnes basins (Figure 2). The Sacramento River carries the majority of the water and drains the northern half of the Central Valley. The San Joaquin is smaller and carries water from the southern half of the Valley. The Cosumnes and Mokelumne are much smaller watersheds and drain to the east side of the Delta. Finally, Prospect Slough carries water from the Yolo Bypass. Prospect Slough receives runoff from Putah and Cache Creeks. The Bypass is also a flood conveyance system designed to route flood water from the Sacramento River around the City of Sacramento for discharge to the Delta during winter storms. Discharge down Prospect Slough is small except when the Bypass is carrying flood water.

Most of the precipitation falls in the Central Valley in winter and is captured in a series of foothill and Sierra Nevada reservoirs for release in summer for downstream urban and agricultural use in the valley. Two large pumping facilities, the State Water Project (SWP) and federal Delta Mendota Canal (DMC), remove water from the southern Delta for export to the Southern Central Valley and southern Califonria. The remainder of the water flows to San Francisco Bay through the channel off Mallard Island. All river sources and export channels, except Mallard Island, were monitored upstream of the tidal prism. Loads were calculated at non tidal sites by multiplying monthly flow (thousand ac-ft/mo) by methyl mercury concentration. The channel off Mallard Island is tidal. Therefore, calculation of methyl mercury loads past Mallard Island to San Francisco Bay necessitated consideration of both dispersive (tidal) and advective (river) flux terms.

CALFED sponsored an earlier methyl mercury mass balance study for the Delta (Foe, 2003). Those findings were augmented with the results from other methyl mercury studies to produce a methyl mercury Total Maximum Daily Load (TMDL) report to the U.S. Environmental Protection Agency (USEPA) (Wood *et al*., 2008). Key TMDL findings were that unfiltered methyl mercury concentrations were highest in river inputs and decreased as water flowed across the Delta to either the pumps or to San Francisco Bay. Mercury concentrations in resident fish followed the same pattern as did water concentrations (Davis *et al*., 2008). The highest fish tissue levels were observed near river inputs and lower concentrations measured in the central and western Delta. The mass balance box model (Figure 1) suggested that about half the methyl mercury (6.7 g/day) was lost in the Delta by one or more unknown mechanisms. However, that 18 month study was conducted during a dry period and it was not known whether similar methyl mercury patterns would reoccur in other water year types.

The present study was conducted during a much wetter hydrologic period in the Central Valley. On average, about twice as much water flowed through the Delta as in the earlier CALFED study (Table 1). The Sacramento River remained the major water source and imported 60 percent of all Delta water. The only exception was when storm water from the Sacramento River water was diverted down the Yolo Bypass. This occurred in the present study on four occasions (May 2005 and January, March and April 2006). In the earlier study the Bypass only flooded in March of 2000. During flood months, Prospect Slough can carry as much or more water as the Sacramento River at Freeport. The major water export sites continue to be to San Francisco Bay through the channel off Mallard Island. In the present study about 78 percent of all the water leaving the Delta was exported to San Francisco Bay. The SWP and DMC pumps are minor exports and together removed about 21 percent of the flow. The Delta water budget in Table 1 appears to be balanced to within 3 percent. However, flow past Mallard Island (net Delta outflow) is calculated in the Dayflow operational model for the Delta as the sum of all incoming tributary flows and direct precipitation on the Delta minus exports at the DMC and SWP pumps. The Dayflow model does not take into account evaporation from open water or agricultural diversions onto three quarters of a million acres of Delta islands. Island agricultural diversions have never been accurately measured and may annually account for between 5 and 10 percent of the water in the Delta. Therefore, both the water and methyl mercury mass balances for export to San Francisco Bay are biased high.

Methyl mercury concentrations

Sources

All unfiltered methyl mercury concentration data for the Delta are summarized in Table 2. This summary includes information collected during the first CALFED study (March 2000 to October 2001), information collected between April and September

2003 with TMDL funds, and results from the present study (October 2004 to June 2006). Methyl mercury concentrations collected before and after April 2003 were compared for each of the three major Delta water inputs (Sacramento River, San Joaquin River, and Prospect Slough) to determine whether there might be inter study differences. No significant difference was noted between the two periods for any of the three inputs ($P>0.25$). Therefore, concentration data for both time periods were combined for each watershed in Table 2.

The combined data set was evaluated to determine whether unfiltered methyl mercury concentrations changed in a predictable fashion as a function of season, flow, or suspended sediment concentration. Evidence for seasonal patterns was evaluated by comparing methyl mercury concentrations between irrigation (April-September) and non irrigation (October-March) seasons and between spring, summer, fall, and winter. No significant seasonal difference was found for any of the three water sources ($P>0.10$, Kruskall-Wallis test). Next, methyl mercury concentration was regressed against flow at each site to ascertain whether there might be flow-related effects. Methyl mercury concentration was independent of flow in both the Sacramento and San Joaquin Rivers ($P>0.1$). In contrast, methyl mercury concentration increased with increasing flow at Prospect Slough ($R^2=0.30$, $P<0.05$, Figure 3). Finally, methyl mercury was regressed against suspended sediment to ascertain whether increasing turbidity might be associated with more methyl mercury. Methyl mercury was found to be independent of suspended sediment concentration in both the San Joaquin River and Prospect Slough ($P>0.1$). Unfiltered methyl mercury concentrations did increase with increasing suspended sediment in the Sacramento River at Freeport ($R^2=0.33$, $P<0.01$, Figure 4). A similar relationship was observed in the Sacramento River during the first CALFED study (Foe, 2003).

Unfiltered methyl mercury concentrations for the Sacramento and San Joaquin Rivers at the legal boundary of the Delta are presented in Figure 5 and Table 2. Data for the Sacramento River before June 2003 were collected at Greene Landing and thereafter at Freeport. Freeport is 8 miles upstream of Greene Landing. Mean and 95 percent confidence limits for methyl mercury in the Sacramento and San Joaquin Rivers are 0.11±0.1 and 0.18±0.03-ng/l, respectively. Elevated methyl mercury concentrations in the San Joaquin River in June 2005 and April to June 2006 are outside the upper 95 percent confidence limit. In both instances the elevated methyl mercury (0.25 to 0.75 ng/l) was associated with the release of large volumes of spill water from Millerton and/or Pine Flat Reservoirs in the upper San Joaquin and Kings Rivers. The release of a large water volume in a short time caused downstream flooding on the valley floor. This flooding, as will be discussed later, appeared to result in the production of large amounts of methyl mercury downstream.

The Mokelumne and Cosumnes Rivers drain two small watersheds located to the east of the Delta. The Cosumnes is the only major watershed in the Central Valley with no substantial reservoirs. In the first CALFED study methyl mercury samples were collected only in the Mokelumne River below its confluence with the Cosumnes River and so represent an integrated sample. The Mokelumne and Cosumnes

Rivers were monitored separately after May 2003 as the highest fish tissue levels observed in the Delta were collected in the lower Cosumnes River (Davis *et al*., 2008; Slotton *et al*., 2007). At present there are only 18 data points for the Cosumnes River and 22 data points for the Mokelumne River. No seasonal or flow related methyl mercury patterns are evident but the data set is too small for robust conclusions. The mean and 95 percent confidence limits for the Cosumnes and Mokelumne Rivers are 0.38±0.12 and 0.11±0.01 ng/l methyl mercury, respectively (Table 2). The methyl mercury concentrations in the Cosumnes River are the highest of any tributary to the Delta ($P<0.01$, Kruskall-Wallis test) consistent with the fish tissue data.

A subset of all the water samples collected in the Delta were filtered through a 0.45 micron filter and analyzed for methyl mercury. Mean filter passing methyl mercury concentrations in the Delta varied between 0.03 and 0.07-ng/l (Table 3). Positive correlations were observed between filter passing and unfiltered methyl mercury at all source and export sites ($P<0.05$). Average filtered to unfiltered methyl mercury concentrations varied between 26 and 59 percent. This data was used in Task 5.1 to estimate methyl mercury photodemethylation rates (Gill *et al*., 2008) and in Task 5.3 to estimate methyl mercury losses associated with sediment deposition (Stephenson *et al*., 2008)

Exports

The three major water export sites from the Delta are the DMC and SWP pumping plants in the South Delta and the channel to San Francisco Bay off Mallard Island (Figure 2). Water for methyl mercury analysis was collected at the two pumping facilities by both CALFED studies (Table 2). Concentrations were compared between the two study periods to ascertain whether there were differences. Concentrations increased by 40 and 115 percent in the second study at the SWP and DMC, respectively. Both increases were statistically significant ($P<0.05$, t-test). The results were unexpected as concentrations were not different in any of the three major water sources to the Delta during the same periods.

Methyl mercury concentration at both pumping plants was regressed against flow (Table 1) and methyl mercury concentration (Table 2) of all tributary inputs for both study periods. The purpose of this analysis was to determine whether any suite of variables might explain the unexpected increase in methyl mercury at the pumping plants. A stepwise forward multiple regression demonstrated that methyl mercury concentration at the DMC was positively correlated with methyl mercury concentration and flow on the San Joaquin River at Vernalis ($R^2=0.80$, $P<10^{-6}$, Figure 6). The DMC exports water that mostly comes from the San Joaquin River (Stephenson *et al*., 2008). Methyl mercury concentrations at the SWP were best described by a combination of methyl mercury concentrations on the Sacramento River at Freeport and on the San Joaquin River at Vernalis and the sum of all tributary inflows to the Delta ($R^2=0.56$, $P<10^{-5}$, Figure 7). The SWP exports a combination of Sacramento and San Joaquin River water (Stephenson *et al*., 2008). The unexpected finding from both multiple regressions was that there was a positive correlation between river flow and concentration at the export sites. In both cases increased flow into the Delta resulted in an increase in methyl mercury concentration at the export sites. There was no relationship between pumping rate and methyl mercury concentrations at either facility ($P>0.3$).

The last major water export site is through the channel off Mallard Island to the San Francisco Bay. Methyl mercury concentrations during the first CALFED study were measured at X2 to estimate transport to San Francisco Bay. X2 is defined as the location in the estuary with 2-o/oo bottom salinity. X2 moves spatially in the estuary as a function of both tidal cycle and freshwater outflow. During the first CALFED study X2 was as far seaward as Martinez during high flow and as far landward as Sherman Island later in the summer. The two locations are about 10 miles below and above Mallard Island, respectively. X2 was sampled within 3 miles of Mallard Island more than half the time in the first CALFED study.

The definition of export from the Delta to San Francisco Bay was changed in the second CALFED study. The new definition was net seaward movement of methyl mercury past Mallard Island. Water samples were taken at both X2 and Mallard Island on 12 occasions in the second CALFED study (October 2004 to November 2005) to ascertain whether there might be site specific differences (Table 2). During this time, X2 was again located between Martinez and Sherman Island. No difference in methyl mercury concentration was observed between the two locations ($P=0.50$, two tailed paired t-test). Therefore, both sites are assumed to have a similar concentration and the two data sets were combined and called Mallard Island in Table 2.

Methyl mercury concentration at Mallard Island was regressed against the flow (Table 1) and the concentration (Table 2) of all upstream tributary inputs to ascertain whether any combination of these might explain Mallard Island concentrations. The stepwise forward regression determined that methyl mercury concentrations at Mallard Island were best explained by methyl mercury concentrations from the Sacramento River at Freeport and Yolo Bypass at Prospect Slough and the Sacramento River flow ($R^2=0.63$, $P< 10^{-6}$, Figure 8). The Sacramento River and Prospect Slough (when flooding) are the primary sources of water at Mallard Island.

The multiple regressions for methyl mercury at each of the three export sites share common features. First, export methyl mercury concentrations are positively correlated with the methyl mercury concentration in the source water. Second, the partial methyl mercury correlation coefficient for each source is always less than one, indicating that methyl mercury concentration decreases as water flows across the Delta. The magnitude of the correlation coefficient reflects the average efficiency of the transport of methyl mercury during the 41-month period. For example, the partial correlation coefficient for methyl mercury at the DMC from Vernalis is 0.46 (Figure 6). This indicates that, on average, methyl mercury concentrations at the DMC will be 46 percent of the Vernalis value after correcting for flow. Finally, all three multiple regressions include positive terms for river flow. This finding was unexpected. Higher incoming river flows result in higher concentrations at the export sites. As previously mentioned, the second CALFED study period was wetter than the first. The positive correlation with flow explains why methyl mercury concentrations increased at the export sites during the second period. The reason for a positive relationship between export concentrations and incoming flow is not known. A hypothesis is that incoming water volume is inversely correlated with travel time across the estuary. Higher flows result in shorter residence times. The positive correlation between flow and methyl mercury may indicate that the sum of all methyl mercury production and decay processes in the Delta are negative. Decreasing residence time results in less time for each process to act, and thus causes a smaller overall net loss.

Methyl mercury Loads

Sources

Methyl mercury loads to the Delta for both CALFED study periods are summarized in Table 4. The Sacramento is the largest watershed in the Central Valley and exported the most water and methyl mercury through either the channel at Freeport or the Yolo Bypass at Prospect Slough. The only exception was when Millerton and/or Pine Flat Reservoirs were spilling flood water and discharged down the San Joaquin River (June, 2005 and April to June 2006).

The San Joaquin River drains the second largest watershed in the Central Valley (Table 5). Overall, the San Joaquin River exported 21 percent of the methyl mercury load entering the Delta but only 14 percent of the water. It is important to note that over 60 percent of the methyl mercury exported by the San Joaquin River was delivered in just 4 of the 42 month study period (June 2005 and April to June 2006, Table 4). All four months were during an exceptionally wet period with upstream flooding. More detailed information on methyl mercury production during flooding is presented later in Task 2B.

Prospect Slough drains two mercury enriched watersheds, Cache and Putah Creeks. The Slough exported 32 percent of the methyl mercury and 43 percent of the inorganic mercury (Table 5). Seventy-six percent of the Prospect Slough methyl mercury load was exported during 3 of the 44 study months (March 2000, January and April 2006). The Yolo Bypass was under water during these 3 months and acted as a flood conveyance system. The results, like for the San Joaquin watershed, emphasize the importance of episodic upstream flooding in the Central Valley on downstream methyl mercury loadings to the Delta. A more detailed study on methyl mercury production and transport in the Yolo Bypass is presented later in Task 2C.

The Mokelumne and Cosumnes watersheds are much smaller than the Sacramento and San Joaquin basins and have minor influences on methyl mercury loads to the Delta. Local flooding, like in the San Joaquin and Prospect Slough watersheds, produced elevated methyl mercury concentrations and loads in export water in December 2005 and again in May and June 2006 (Table 2). The two watersheds produced 4 percent of both the methyl mercury and water entering the Delta (Table 5). Although the Cosumnes River exports a minor load, it does have the highest methyl mercury concentrations of any Delta tributary and the highest observed fish tissue concentrations (Davis *et al*, 2008; Slotton *et al*., 2007).

A key objective of this study was to update the TMDL methyl mercury mass balance model (Figure 1) with data collected over a longer period that includes wetter years. The TMDL model was developed with 18 months of data while the revised load estimate is for a 44-month period. Tributary inputs have increased from 8.2 to 16.6 g/day[4] (Figure 9). The increase results from higher flows as methyl mercury concentrations in the incoming water did not change between the two periods.

Exports and Sinks

There are three major exports for Delta water. These are the Sacramento River channel at Mallard Island to San Francisco Bay and the SWP and DMC pumping plants in the South Delta.

Eighty percent of the water exported from the Delta during the two CALFED studies was to San Francisco Bay through the channel off Mallard Island (Table 1). Mallard Island was the only methyl mercury sampling site in the study located in the tidal prism. Methyl mercury transport in the tidal prism is computed from the sum of advective (river discharge) and dispersive (tidal) flux. The study evaluated dispersive flux at Mallard Island by simultaneously measuring methyl mercury concentrations in mid channel off Collinsville and Port Chicago on ten occasions (August 2005 to June 2006, Table 2). The two sites are about 6 miles east and west of Mallard Island, respectively. The purpose of the sampling was to determine whether there was a consistent methyl mercury gradient in the western Delta that could result in net tidal pumping. Methyl mercury concentrations were higher on 6 occasions at Collinsville and on 4 occasions at Port Chicago. The difference was not significant (P=0.7, two-tailed t-test). While the sample size is small, there is no evidence of a consistent methyl mercury gradient in the western Delta centered at Mallard Island. Therefore, the preliminary conclusion of this study is that dispersive methyl mercury flux is negligible on an annual basis at Mallard Island and that export loads can be estimated for the Delta by only calculating an advective term. Further study may be warranted to determine whether there are consistent seasonal methyl mercury gradients in the western Delta that might result in dispersive flux.

Advective flux calculations suggest that eighty-seven percent of the methyl mercury was exported from the Delta to San Francisco Bay (Table 4). This translates, when averaged over the 44-month study period, to 9.8 g/day (Figure 9). This is an increase over what was previously estimated (4.7 g/day) in the TMDL mass balance model (Figure 1).

The SWP and DMC pumping plants are minor exports and account for 6 and 7 percent of total methyl mercury exports, respectively (Table 4). On a daily basis

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[4] Tributary inputs were estimated at 21,904 g for the 44 month or 1320 day period (Table 4). This translates to 16.6 g/day.

this translates to a combined export rate of 1.5 g/day in the revised box model (Figure 9).

An unexpected finding of the first CALFED grant was a consistent loss of methyl mercury as water traveled across the Delta (Foe, 2003). This pattern has persisted with the collection of more data, including mass balance information in some very wet months. The sum of incoming methyl mercury loads exceeded the sum of exports in 42 of the 44 months studied (Table 4). The cause of the loss is not known, although as previously mentioned, the magnitude of the loss may be related to water residence time.

The loss of methyl mercury in the Delta was evaluated as a function of tributary inflow. The ratio of the sum of methyl mercury exports was divided by the sum of incoming loads for each study month. The ratio was regressed against Delta inflow to ascertain whether the ratio was a function of incoming water volume (Figure 10). The ratio increased (amount of methyl mercury successfully transported across the Delta) as flow increased ($R^2=0.39$, $P<0.05$). Months when either the Yolo Bypass and/or San Joaquin River discharged flood water are indicated by squares in Figure 10. These five events were not incorporated into the regression as they appear to alter net methyl mercury dynamics. Methyl mercury losses still occur then but the loss rate appears to be independent of flow. The conclusion that the loss of methyl mercury loads decreases with increasing flow is consistent with observations that methyl mercury concentrations at the SWP, DMC, and Mallard Island also are positive functions of flow (Figures 6, 7, and 8).

A cumulative frequency distribution of monthly flow rates for the period between October1983 and September 2003 was computed to determine expected annual methyl mercury loss rates in the Delta (Figure 11). The period was selected as it has a similar number of wet and dry water year types as the 100-year precipitation record for the Central Valley (Wood *et al*., 2008). Incoming flow rates as low as 600,000 or as high as two million acre-feet per month each happen less than 10 percent of the time. Discharge rates up to a million acre-feet per month are more common and occur about 55 percent of the time. The estimated methyl mercury loss is about 30, 60, and 80[5] percent at 2 million, 1 million and 600,000 acre-feet per month, respectively (Figure 10). The TMDL methyl mercury mass balance study was conducted during a relatively dry period. Average methyl mercury losses were 53[6] percent for the 18-month period (Figure 1). The present study was during a wetter period. The average 44-month loss rate was 46 percent[7] (Figure 9).

A revised methyl mercury box model is presented for the Delta in Figure 9. New methyl mercury values were developed in this study for tributary source loads (16.8 g/day), exports to southern California (1.5 g/day) and exports to San Francisco Bay (9.8 g/day). No changes have been made to the methyl mercury contributions from urban runoff, municipal wastewater treatment plants, and Delta island

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[5] (1-ratio) X 100

[6] Calculated by dividing the sum of exports (6.7-g/d) by the sum of inputs (14.31-g/d).

[7] Calculated from the sum of sedimentation, unknown loss, and photodemethylation (10.51 g/day) divided by the sum of all inputs (22.71 g/day)

agricultural returns. These values were all calculated from separate studies summarized in the TMDL report (Wood *et al*., 2008). Improved estimates of methyl mercury flux from wetlands and open water are from task 5.3 by Heim *et al*. (2008). Loads from wetlands and open water habitats in the Delta have decreased from 2.7 to 0.15 g/day and from 2.4 to 0.48 g/day, respectively. The revised sum of all methyl mercury inputs to the Delta has increased from 14.3 to 18.2 g/day. The increase is primarily the result of more methyl mercury entering the Delta from rivers draining the Central Valley. Increased river loads are the result of the present study being conducted in a wetter period. Exports to San Francisco Bay doubled (4.7 to 9.8 g/day). This results from a combination of: (1) more methyl mercury entering the Delta and (2) greater flows that result in a smaller loss rate. Two additional loss processes have been added to the box model. They are photo demethylation (-2.5 g/day) and sedimentation (-4.9 g/day). Measurements of photo demethylation and sedimentation[8] are described in Tasks 5.1 and 5.2 by Gill (2008) and Stephenson *et al*. (2008). Finally, a new error term (1.4 g/day) is calculated from the difference of the sum of all sources and sinks. The new error term is about 8 percent of the sum of all methyl mercury sources to the Delta. In comparison, the relative percent difference of duplicate laboratory measurements of the same field sample was 9 percent (Appendix A, Tables 3). The new error term is within the analytical precision of replicate laboratory measurements suggesting that, perhaps, all major Delta source, export and sink terms have been quantified.

Methyl mercury box models are presented for January and August 2005 to illustrate seasonal changes in the relative magnitude of source and export processes (Figure 12a and b). A comparison of the mass balance for the two months reveals that the sum of all inputs decreased in magnitude between January and August by over 60 percent, from 19.6 to 5.9 mg/day. Tributary River inputs are the major source of methyl mercury in both months but the magnitude of their loads decrease in summer because of reductions in flow. As a result, the contribution of *in situ* Delta sources increases in summer to 27 percent of the total load.

The relative importance of the different methyl mercury loss processes is more complicated and is a function of season (Figure 12a and b). Sedimentation and the associated loss of attached methyl mercury is the major removal process in January (Stephenson *et al*. 2008). Sedimentation is estimated to have removed 37 percent of the total incoming load in January (-7.2 g/day) but only 20 percent in August (-1.2 g/day). In contrast, photo demethylation is the principal removal process in summer (Gill, 2008). Photo demethylation is estimated to have removed 53 percent of the incoming load (-3.1 g/day) in August but only 5 percent in January (-1.0g/day). Photolysis is more important in summer because solar radiation is greatest then and water travel times slowest allowing more time for photolysis to occur. Exports to southern California are a function of water pumping rates. Methyl mercury exports to southern California increased from 21 percent in January (-4.1 g/day) to 41 percent in August (-2.4 g/day). Finally, exports to San Francisco Bay

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[8] Phytoplankton herbivory by clams, zooplankton and fish is included at present in the estimate for “sedimentation”. A separate estimate for phytoplankton consumption would be useful as it could lead to estimates of methyl mercury uptake in the aquatic food chain.

were 24 percent of the incoming load in January (-4.1 g/day) but only 12 percent in August 2005 (-0.7 g/day).

Biotic Significance

Unfiltered aqueous methyl mercury concentrations are hypothesized to be an important factor controlling methyl mercury bioaccumulation in the aquatic food chain (Wood *et al.,* 2008). An increase in aqueous methyl mercury is predicted to cause an increase in fish tissue levels. Physical processes occurring in the Central Valley that result in changes in aqueous methyl mercury concentrations provide an opportunity to evaluate the bioaccumulation hypothesis. Flooding in the spring and summer of 2006 produced elevated methyl mercury concentrations in the Yolo Bypass and San Joaquin and Cosumnes Rivers (Table 2). Biosentinel sampling was conducted with juvenile silverside fish in the Delta in the fall of 2005 and spring and summer of 2006 (Slotton *et al*., 2007). Elevated concentrations of methyl mercury were observed in juvenile fish in the Yolo Bypass and the San Joaquin and Cosumnes Rivers several months after the 2006 flooding. As an example, methyl mercury concentrations in water and juvenile silversides are presented in Figure 13 at Vernalis on the San Joaquin River. Unfiltered methyl mercury concentrations in San Joaquin River water increased 6-fold in May 2006 but returned to baseline conditions several months later. Mercury concentrations in silversides increased by a similar amount two months later. Fish born after May 2006 had lower concentrations comparable to pre May 2006 levels. The water biotic mercury results at Vernalis support the bioaccumulation hypothesis that unfiltered aqueous methyl mercury concentrations are an important factor controlling fish tissue levels.

Conclusions and Recommendations

Conclusions

This is the second CALFED methyl mercury mass balance study in the Delta. This study was conducted during a wetter period than the first. There are 7 major conclusions from the two studies.

- Average methyl mercury concentrations in the three major water sources—Sacramento and San Joaquin Rivers and Yolo Bypass—were not different between the two study periods.
- In contrast, concentrations were higher in the present study at two of the three export sites—DMC and SWP.
- Stepwise multiple regressions demonstrate that methyl mercury concentrations at all three export sites—Mallard Island, DMC and SWP—are positive functions of both methyl mercury concentration and flow in the source water. The present study was conducted during a wetter period and this is believed to explain the increase in methyl mercury concentrations at export sites.
- An unexpected finding of the first CALFED study was there appeared to be a consistent, unexplained loss of methyl mercury in the Delta. The pattern has

persisted. The sum of incoming loads exceeded the sum of exports in 42 of 44 months.

- The loss of methyl mercury loads was found to be an inverse function of incoming Delta flow. Smaller losses in loads were observed at higher flows.
- Increases in methyl mercury concentration were observed in water downstream of the Cosumnes and San Joaquin Rivers and in Prospect Sloughs after upstream flooding in 2005 and 2006. The increases in water concentrations were associated with increases in silverside tissue concentrations in studies by Slotton and others (2007).
- Finally, a revised methyl mercury box model is presented for the Delta. Major changes are that net tributary inputs and the export rate to San Francisco Bay have doubled from previous studies. In addition, two new loss processes, sedimentation and photo demethylation are included from work done in Task 5 of this contract. The revised methyl mercury mass balance model is now balanced within 8 percent, suggesting that all major Delta sources, export and sink terms may have been quantified.

Recommendations

- Use RMA model in conjunction with measured methyl mercury rate processes developed in this grant to develop a predictive computer simulation model of methyl mercury concentrations and transport in the Delta. Conduct transects along the major flow paths of water across the Delta during high and low flow and measure methyl mercury concentrations. Use methyl mercury concentration data collected in transects to evaluate performance of simulation model and identify processes needing additional refinement.

Subtask 2b

The goal of Task 2B is to characterize tributary and regional input sources of methyl and total mercury in the Sacramento and San Joaquin Basins. This report describes the methyl mercury portion of the study. An accompanying report (Louie e*t al*., 2008) summarizes the inorganic mercury monitoring results. For convenience, the methyl mercury discussion has been divided into separate sections for the Sacramento and San Joaquin Basins. Each includes a brief description of the watershed and then a discussion of concentrations and loads and transport downstream to the Bay-Delta Estuary.

Sacramento Basin

Watershed Description

The Sacramento River is the primary source of water to the Delta. The water balance for the 31-month study is summarized in Tables 6 and 7. Six rivers systems, each with its own set of dams, feed the Sacramento River. These are the upper Sacramento, Trinity, Feather, Yuba, Bear, and American Rivers. Each river was monitored below the last major dam before entering the floor of the Central Valley. Ten smaller creeks and sloughs discharge to the Sacramento River from both the east and west side of the Valley above Colusa (tributary inputs “A”, “B” and “C” in Table 6). These were only monitored during the last six months of the study when it became apparent that their methyl mercury loads might be significant. Water is diverted out of the Sacramento River for agricultural use at a series of pumping stations located between Keswick and Colusa (Table 6). Unused agricultural return water drains back into the river from the east and west side of the Valley via Sacramento Slough and Colusa Basin Drain, respectively (Table 7). There are five weirs that divert storm water out of the Sacramento River mainly during high flows in winter and spring. These are the Moulton, Colusa, Tisdale, Fremont and Sacramento Weirs. The Moulton, Colusa and Tisdale Weirs return water through Sacramento Slough and the lower Feather Rivers. The Fremont and Sacramento Weirs discharge to Prospect Slough through the Yolo Bypass. Prospect Slough discharges to the Delta upstream of Rio Vista.

The water balance for the Sacramento River has been separated into budgets for the upper and lower Sacramento River, upstream and downstream of Colusa, respectively. The water and methyl mercury mass balances were divided in two parts to better identify sources and uncertainties in the budget. Each budget was calculated by summing gauged sources and diversions. Shasta Dam (Sacramento River at Keswick) was the largest source of water to the upper river and contributed 66 percent of the flow at Colusa (Table 6). The sum of tributary inputs “A”, “B” and “C” provided the remaining 34 percent of the water. Agricultural diversions and weirs removed 10 and 13 percent of the water, respectively. The water budget, for reasons that are unclear, over predicts water volumes at Colusa in late summer and fall (June through November) and under predicts water at Colusa in winter and early spring. Overall, the water budget for the upper river is balanced within 95 percent.

The lower Sacramento River between Colusa and Freeport has five major sources of water (Table 7). These are the upper Sacramento River, Feather River (including Yuba and Bear River inputs), American River, Sacramento Slough, and Colusa Basin Drain. The upper Sacramento River, Feather River, and American River contribute 41, 28, and 13 percent of the flow at the Sacramento River at Freeport, respectively. The two agricultural drains, Sacramento Slough and Colusa Basin Drain, together provided 19 percent of the water at Freeport. There are no agricultural diversions from the Sacramento River between Colusa and Freeport. The Tisdale, Fremont, and Sacramento Weirs diverted 19 percent of the flow from the Sacramento River, mostly during winter storm events. The water budget for the lower river, like for the upper river, over predicts water volumes at Freeport in summer and fall and under predicts them at other times of the year. Overall, the water budget for the lower river also balanced within 95 percent.

The Sacramento Basin is a 17.4-million acre watershed. Primary land uses in the Coastal Range and Sierra Nevada are forestry and animal grazing while the valley floor is extensively farmed. Major crops are rice, alfalfa, tomatoes, wheat, barley and fruit and nut orchards. Many of the rice fields are managed as seasonal wetlands in winter for duck hunting. Historically, extensive gold mining occurred in the Klamath-Trinity and Sierra Nevada Mountains on the northern and eastern borders of the basin (Figure 2). Mercury was used as an amalgam in gold mining and beads of elemental mercury are still found in river beds. This, at least in part, may have resulted in nine water bodies in the Sacramento basin being placed on the Federal Clean Water Act 303(d) list because of elevated mercury concentrations in fish tissue[9]. The number of mercury listings could increase as additional fish sampling occurs and the magnitude of mercury contamination is better defined.

The results and discussion section for the Sacramento Basin have been separated in upper and lower river reaches. The upper section is defined as the 150-mile reach between Redding and Colusa while the lower is the 90-miles between Colusa and Freeport, the legal boundary of the Delta (Figure 2).

Upper River Methyl Mercury Concentrations

Methyl mercury concentrations increase 3-fold in the Sacramento River between Redding and Colusa (Table 8, Figure 14). The increase is statistically significant ($P<0.0001$, Kruskal-Wallis Test). Ten creeks (tributary inputs “A”, “B” and “C” Table 6) discharge to the Sacramento River in this reach. Overall, these creeks contributed 34 percent of the flow at Colusa. The creeks were monitored monthly between December 2005 and June 2006 to ascertain how much of the overall increase in river mercury concentration they might explain. Eighty water samples were collected (Table 9). Sixty-five percent of these had higher mercury values

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[9] 303(d) listed water bodies include the Sacramento River between Redding and Freeport, lower Feather, and American Rivers and Sacramento Slough. Lakes and reservoirs include Black Butte, Camp Far West, Combie, Englebright, Natomas and Rollins Reservoir.

than were measured in the Sacramento River above their confluence. The frequency is greater than expected by chance ($P<0.05$, chi-square test) confirming that the tributaries are, at least partially, responsible for the overall increase in mercury observed as river water moves downstream.

Storm events were the only exception to the pattern of a 3-fold increase in methyl mercury down the Sacramento River. Methyl mercury concentrations were measured during three storms (February 2004 and March and December 2005). On each occasion several sites in the upper river had higher concentrations than downstream at Colusa (Table 8). The monitoring apparently caught a pulse of more contaminated storm runoff in transit down river. The source of all the material in the Sacramento River is not known but methyl mercury concentrations were measured in the ten tributaries during the December 2005 event. All ten creeks had higher concentrations than did the Sacramento River at Redding, suggesting that each was contributing to the overall river increase during the storm. Methyl mercury concentrations in Mill and Thomes Creek were 0.59 and 0.88-ng/l, respectively (Table 9). These are among the highest levels ever measured in the Sacramento watershed.

Upper River Methyl Mercury Loads

Thomes and Cottonwood Creeks[10] were the two most significant tributary sources and accounted for about 65 percent of the methyl mercury load from the ten small creeks (Table 10). Overall, the mass balance calculations during the 7-month period account for about 88 percent of the water volume at Colusa but only 45 percent of the increase in methyl mercury load between Redding and Colusa. This suggests that additional unidentified methyl mercury sources exist in the upper Sacramento River that are not associated with the direct input of water. The sources likely include both riparian and in-stream sediment methyl mercury production. Future studies will need to identify these if a successful TMDL control program is going to be developed for the upper Sacramento River.

Lower River Methyl Mercury Concentrations

Four watersheds drain into the lower Sacramento River (Figure 2). These are Colusa Basin Drain, Sacramento Slough, and the Feather (including the Bear and Yuba Rivers) and American Rivers. The Yuba and Bear Rivers are tributary to the Feather River.

Unfiltered methyl mercury concentrations were evaluated in each of these watersheds to determine whether levels changed in a predictable fashion as a function of season, flow or suspended sediment concentration. Evidence for a seasonal pattern was evaluated by comparing methyl mercury levels between irrigation (Apr-Sept) and non irrigation (Oct-Mar) seasons and between spring, summer, fall and winter. No significant seasonal difference was found for any

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[10] The northern half of the Cottonwood watershed drains an area in the Trinity Mountains with widespread gold mining (placer, hardrock, and dredging). The southern half of the Cottonwood Creek watershed and the Thomes Creek watershed drain areas in the Coastal Range with only a few gold mines.

watershed (P>0.10, Kruskall-Wallis test). As an example, concentrations for the Sacramento River at Colusa and Freeport are presented in Figure 15. The highest values were observed during winter storms at Colusa (February 2004 and December 2005) but adjoining months (March 2004 and November 2005) have some of the lowest values suggesting that it was the storm, not the season, that is responsible for the elevated level. Similar high values were also observed in other watersheds during storms suggesting that episodic storm related increases in methyl mercury are a common phenomenon.

Next, methyl mercury concentration was regressed against flow at each site to ascertain whether there might be a flow-related effect. Methyl mercury concentration was independent of flow at all locations (P>0.25). Finally, methyl mercury was compared to suspended sediment concentrations in each watershed to determine whether there might be a pattern. Positive relationships were observed in about half the watersheds, if samples collected during storms were omitted (Table 12). More suspended sediment resulted in more methyl mercury. The sample size was small in all the watersheds that were not statistically significant. Increasing the sample size might have made more of the watershed correlations statistically significant. The relationship between methyl mercury and suspended sediment for the Sacramento River between Redding and Freeport is presented in Figure 16. The main stem Sacramento River is shown as it had the most data and, unlike other basins, was best fit by a power function. The underlying physical mechanism is not clear although the relationship suggests that the additional sediment mobilized at higher storm flow has lower concentrations of attached methyl mercury.

The relationship between filter passing and unfiltered methyl mercury was evaluated in each watershed during the first year of the study. The ratio of filter passing to unfiltered methyl mercury was estimated from the slope of the regression between the two variables after forcing the correlation to pass through zero. Statistically significant correlations were observed in many watersheds after omitting samples collected during storms (Table 13). The relationship for the Sacramento River between Redding and Freeport is presented in Figure 17. Overall, filter passing methyl mercury appears to account for between 30 and 50 percent of the total methyl mercury in the basin. The Bear River was an exception. In the Bear over 70 percent of the methyl mercury was in a dissolved state.

The relationship between the proportion of filter passing and unfiltered methyl mercury and suspended sediment was compared to determine whether changes in suspended sediment might alter the ratio. Sufficient data were available for a statistical analysis only for the Sacramento River (Figure 18). A significant inverse power relationship was observed (P<0.0001). Increasing concentrations of suspended sediment were associated with a decrease in the ratio of filter passing to unfiltered methyl mercury. The underlying physical mechanism is unclear but higher flows are usually associated with more turbid water. As demonstrated previously, this suspended sediment has less methyl mercury per gram sediment and more of the methyl mercury appears bound to sediment.

Upstream and downstream methyl mercury concentrations were compared in each watershed to determine whether there was evidence for in-basin production. No change in methyl mercury concentration was apparent in the 90-miles between Colusa and Freeport on the Sacramento River (P>0.4, paired t-test). This is in contrast to the upper 150-miles of river, where there was a statistically significant three-fold increase in methyl mercury concentration (Figure 14). The lower Sacramento River channel, unlike the upper river, is deeper and its sides are armored with rock. These physical factors may make the river channel less conducive to in-stream methyl mercury production.

Methyl mercury concentrations in the lower American River between Nimbus Dam and Discovery Park increased from 0.04 to 0.06-ng/l (Table 8). The increase was statistically significant (P<0.001, paired t-test). The cause of the increase is not known but runoff from about 40,000-acres of urban development in the City and County of Sacramento discharge to the river in the 20-miles reach. Mean wet and dry weather methyl mercury concentrations in storm drains in Sacramento and other cities in the Central Valley average 0.24 and 0.36-ng/l, respectively (Wood *et al*., 2008). Also, 4 NPDES permitted facilities discharge to this 20-mile stretch of river. The Central Valley Water Board has requested that each permitted facility monitor methyl mercury concentrations in their discharge for one year. Detailed mass balance calculations for the lower American River are beyond the scope of this report but this segment of the American River is on the Federal Clean Water Act 303(d) list and a TMDL report is required by the U.S. EPA. Detailed mass balance calculations will be made to determine how much of the overall increase can be ascribed to urban runoff, permitted facility discharges and riparian and in stream production.

Methyl mercury concentrations on the Feather River between Gridley (downstream of Lake Oroville) and Nicholas increased from 0.05 to 0.09-ng/l (Table 8). The increase was again statistically significant (P<0.0001, paired t-test). Both the Yuba and Bear Rivers enter the Feather River between Gridley and Nicholas (Figure 2). Average methyl mercury concentrations in each river are 0.08 and 0.13-ng/l, respectively. A simple mass balance calculation was made to determine whether these drainages might account for the increase in the Feather River. The two rivers are estimated to cause about one quarter of the increase observed in the Feather River. Other potential sources are non point source runoff in ungauged Jack Slough and Honecut Creek and urban runoff and municipal wastewater from Marysville and Yuba City.

Lower River Methyl Mercury Loads

The three largest reservoirs—Shasta, Oroville, and Folsom—discharged 73% of the water during the study (Table 7) but only 24% of the methyl mercury (Table 11) entering the Delta at Freeport. This is because the reservoirs discharge water with a low methyl mercury concentration. Mean concentrations from Shasta, Oroville, and Folsom Reservoirs are 0.03, 0.05, and 0.04-ng/l, respectively (Table 8). For comparison, the average concentration at Freeport is 0.11-ng/l. The analysis demonstrates that most of the methyl mercury exported to the Delta from the Sacramento River is produced on the Valley floor below the major reservoirs.

The magnitudes of methyl mercury and water exports from watersheds downstream of Colusa are compared in Figure 19. No watershed exported a disproportionate amount of methyl mercury in comparison to its water volume. The Sacramento River at Colusa was the primary source of both methyl mercury (43 percent) and water (51 percent). The American and Feather River watersheds, both major gold mining areas, together discharged 33 percent of the methyl mercury and 41 percent of the water. This was unexpected and suggests that elemental mercury from historic gold mining may not be as important a source of methyl mercury as previously hypothesized. In contrast, methyl mercury loads from Sacramento Slough (15 percent) were twice as great as the agricultural return flow (7 percent). It is important to note that the sum of upstream methyl mercury loads underestimated the average export at Freeport by about 5 percent while the water budget overestimated it by 2 percent. Some of the unexplained increase in methyl mercury may be caused by discharge from municipal sewage treatment plants and urban runoff. The TMDL mass balance for the Delta (Figure 1) estimated that about 5 percent of its methyl mercury originated from these two sources.

Methyl Mercury Transport

An important management question is whether methyl mercury is transported in a conservative fashion in the Sacramento River. If yes, then upstream control actions will have beneficial results in both the upper river where they occur and downstream in the Delta. Methyl mercury loads at Freeport were regressed against the sum of methyl mercury sources and diversions below Colusa after excluding 3 storm events (February 2004, March and December 2005). The regression is significant ($P<0.0001$, $R^2=0.63$, $N=29$, Figure 20). Higher loads in the upper river always result in greater exports to the Delta at Freeport. The regression is still significant if all three storm events are included ($P<0.001$, $R^2=0.46$, $N=31$). The regressions are consistent with the hypothesis that methyl mercury is being transported in a conservative fashion in the Sacramento River between, at least, Colusa and Freeport[11]. This conclusion is different than the one obtained for the Delta. In the Delta methyl mercury loss was found to be inversely proportional to flow. Higher flows resulted in a lower loss rate. The difference between the Sacramento River and Delta emphasize the complex nature of methyl mercury transport and the need to understand the underlying processes responsible for such different results. Finally, conservative transport in the Sacramento basin implies that all the major sources and sinks of methyl mercury have been identified in the Sacramento River.

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[11] 90-mile river reach

Conclusions and Recommendations

Conclusions

This study presents results from the first comprehensive methyl mercury monitoring in the Sacramento River Basin. There are five major conclusions from the present study.

- The Basin is the largest source of both water and methyl mercury to the Sacramento-San Joaquin Delta Estuary.
- The three largest reservoirs—Shasta, Oroville, and Folsom—discharged 73% of the water but only 24% of the methyl mercury at Freeport (Delta boundary).
- Methyl mercury concentrations increase 3-fold in the 150 river miles between Redding and Colusa. Ten tributary creeks account for about 40% of this increase.
- The Sacramento River at Colusa (43 %), Feather River (22 %), Colusa Basin Drain (3 %), Sacramento Sough (15 %) and American River (11 %) watersheds are the main sources of methyl mercury at Freeport. Five percent of the methyl mercury measured at Freeport is unaccounted for.
- The Feather and American River watersheds were the site of extensive gold mining but do not contribute a disproportionate amount of the methyl mercury load at Freeport on a flow weighted basis.
- A positive correlation exists between the sum of monthly upstream methyl mercury loads from the Sacramento River at Colusa, Feather River, Colusa Basin Drain, Sacramento Slough and American River and the downstream load at Freeport ($R^2 = 0.63$, $P < 0.0001$). The correlation is consistent with these being the primary sources in the basin and that methyl mercury is transported in a conservative fashion down river to Freeport.

Recommendations

The study has one major recommendation.

- Conduct additional loading studies in the upper Sacramento River between Redding and Colusa, in the Feather River between Gridley and Nicholas, and in the American River between Nimbus and Discovery Park to identify the remaining sources of methyl mercury.

San Joaquin Basin

Background

The San Joaquin is the second largest river discharging to the Delta. The San Joaquin River drains a 10.7-million acre watershed (Figure 2). Primary land uses are silviculture and grazing in the mountains and irrigated agriculture and dairies on the valley floor. Primary agricultural crops are tomatoes, alfalfa, cotton, wheat, vegetables, and orchards. The largest contiguous block of remaining wetlands in the Central Valley (33,000 acres) is located in and around Mud and Salt Sloughs. Placer and hydraulic gold mining occurred in all east side rivers draining from the Sierra Nevada Mountains. In addition, mercury mining occurred along the Coastal Range to the west of the San Joaquin River. None of the gold or mercury mines are still operational. The watershed also receives mercury from atmospheric deposition, but this has not yet been well characterized. The result is sediment mercury contamination in Sierra and Coastal Range creeks and the major rivers draining the valley. Mud Slough, the lower Merced and Stanislaus Rivers and the San Joaquin River between Mud Slough and Vernalis are on the 2006 Federal Clean Water Act 303(d) list because of elevated concentrations of mercury in fish tissue. Other water bodies may be added to the list later as additional fish samples are collected and the spatial extent of mercury contamination better defined.

The hydrology of the San Joaquin River basin is complicated because it is one of the most man altered systems in the world. The natural headwaters of the San Joaquin are in the Sierra Nevada Mountains above Millerton Reservoir and Friant Dam. From here, the San Joaquin River originally descended to the Valley floor and flowed north 150 miles to discharge into the Delta. However, the headwaters of the San Joaquin were cut off from the downstream river with the construction of Friant Dam, and the majority of the water is transported out of the basin in the Friant-Kern Canal system. Often water does not flow continuously from the upper to the lower San Joaquin River. However, in wet years water released from Friant Dam to the San Joaquin Channel does flow downstream to the Delta. In addition, in unusually wet years, water from the Tulare Basin (south of the San Joaquin Basin) spills from Pine Flat Reservoir down the Kings River and into the San Joaquin River. When this occurs, there is insufficient capacity in the river channel, and localized flooding occurs on the San Joaquin valley floor around Mud Slough. Friant Dam spilled in June 2005, and both Friant and Pine Flat had uncontrolled releases in the spring and summer of June 2006.

The construction of Friant Dam and loss of water from the upper San Joaquin Basin led the federal government to provide “exchange” water to downstream west side agricultural interests in the Basin. The exchange water is carried south in the Delta Mendota Canal (DMC) from the southern Delta. The DMC provides water to farmers along the west side of the Valley between the southern Delta and Mendota Pool. West side water users also have riparian water rights and pump water from the San Joaquin River. Agricultural return flow from the west side is returned to the San Joaquin River in Salt and Mud Sloughs and in many small non metered agricultural drains and creeks between Mud Slough and Vernalis. During the present study the San Joaquin River between Friant Dam and Lander Avenue was at flood stage, a series of stagnant pools, or dry. However, below Lander Avenue the San Joaquin River always had continuous flow because of agricultural discharge from Salt Slough. Monitoring emphasized the characterization of methyl mercury concentrations in tributaries and the San Joaquin River between Lander Avenue and Vernalis.

Three large rivers -- Merced, Tuolumne and Stanislaus -- drain the east side of the Valley north of Friant Dam. These now discharge most of the flow in the San

Joaquin River. Each eastside river is dammed and runoff from winter precipitation is captured and released in summer for downstream use. East side farmers also have riparian water rights and divert water from the three eastside rivers for agricultural use. Unused agricultural return flow is returned to the San Joaquin and to eastside Rivers in a series of small non metered drains. The presence of many small non gauged agricultural diversions and drains complicate construction of a water and methyl mercury balance for the San Joaquin Basin.

Water

This study makes use of a new TMDL model under development for the San Joaquin River Basin. Watershed Analysis Risk Management Framework (WARMF) is a proprietary watershed model with a hydrologic component (EPRI, 2001). The hydrologic algorithms for WARMF divide the basin into a network of land catchments and stream segments. The physical dimensions of each catchment are prescribed by U.S Geological Survey digital elevation maps. A time series of meteorological data, point source discharges, rainfall volumes, and reservoir releases are used to drive the model. All the necessary input data for the San Joaquin River WARMF model have been collected for the period between October 1999 and September 2005. Input and output data have been promised for the model through September 2006 by the winter of 2008. A potential advantage of WARMF is that it may provide better hydrologic information on both water sources and discharge volumes in the San Joaquin Basin than is currently available from the traditional approach of relying upon discharge information from upstream river segments alone.

This study evaluated the accuracy of both WARMF and the traditional method of computing downstream flows by comparing predicted and measured flow at four gauged sites in the San Joaquin River -- Fremont Ford, Crows Landing, Patterson, and Vernalis -- monthly between October 1999 and September 2005. For the traditional method, the difference between predicted and measured flow at the four river sites ranged between 2 and 25 percent with an average difference of 13 percent. In contrast, the difference between predicted and measured flow with WARMF ranged between 1 and 5 percent with a mean difference of 2.7 percent. WARMF was the more accurate hydrologic model and was therefore used in this study. A potential problem with using WARMF is that output is only available for October 1999 to September 2005 while methyl mercury data were collected between April 2003 and June 2006. Predicted water volumes from WARMF were used to calculate methyl mercury loads for the period between April 2003 and September 2005 and gauged flow data afterwards (Table 14). It is anticipated that the conclusions of this report will be reviewed and updated, if necessary, when WARMF hydrologic data are made available for the entire study period.

The winters of 2003 and 2004 were dry while 2005 was very wet. The primary sources of water to the San Joaquin River at Vernalis were the Merced, Tuolumne, Stanislaus, upper San Joaquin and Kings Rivers. Together they contributed over 90 % of the flow (Table 14). Mud and Salt Sloughs provided about 6% of the remaining water. Agricultural diversions and return flows transported much smaller water volumes.

Methyl Mercury Concentration

Methyl mercury concentrations decrease down the San Joaquin River between Fremont Ford and Vernalis, the legal boundary of the Delta (Figure 21, Table 15). Average methyl mercury concentrations in the San Joaquin River between Fremont Ford and Patterson ranged between 0.30 and 0.27-ng/l. Concentrations at Vernalis decreased to 0.19-ng/l. The decrease is significant ($P<0.0001$, Kruskal-Wallis test). The concentrations of methyl mercury on the San Joaquin at Vernalis (0.19 ng/l) is more than twice as high as on the Sacramento River at Freeport (0.11 ng/l, Table 2), the other major tributary to the Delta. The primary sources of water in the upper basin are the San Joaquin River at Lander Avenue and Salt and Mud Sloughs (Table 14). All tributary inputs, except Mud Slough, have methyl mercury concentrations similar to the San Joaquin River. Mud Slough had the highest average methyl mercury concentration (0.92-ng/l) of any tributary in the Basin. Discharge from these three sub basins (San Joaquin River at Lander Avenue, and Salt and Mud Sloughs) likely explains the elevated methyl mercury concentrations in the upper River. In contrast, the primary sources of water to the lower San Joaquin River are the Merced, Tuolumne and Stanislaus Rivers (Table 14). Together these three provided more than 70 percent of the flow at Vernalis. Methyl mercury concentrations in the three eastside rivers were the lowest of any water source measured in the Basin (0.09 to 0.12-ng/l, Table 15). The decrease in methyl mercury concentrations in the San Joaquin River between Patterson and Vernalis is most easily explained as dilution by the Tuolumne and Stanislaus Rivers.

The Merced, Tuolumne and Stanislaus Rivers all experienced extensive historic gold mining. The average methyl mercury concentrations in each of the three river was the lowest recorded for any waterway in the Basin (Table 15). The Feather and American River watersheds in the Sacramento Basin were also sites of extensive historical gold mining. The two River had about half the average methyl mercury concentration of the Sacramento River at Colusa (Table 8). The Sacramento River at Colusa drains a watershed with some but not as much gold mining as the Feather and American River watersheds. Apparently, watersheds with historical gold mining do not necessarily produce elevated methyl mercury concentrations.

The only exception to the pattern of decreasing methyl mercury concentrations down the San Joaquin River was when Millerton Reservoir in the upper San Joaquin Basin and/or Pine Flat Reservoir on the Kings River had uncontrolled spills that reached the lower San Joaquin at Lander Avenue. This occurred during four months (June 2005 and April to June 2006). The additional water caused extensive flooding in the 20 mile segment Lander Avenue and Crows Landing and was associated with large increases in methyl mercury levels as far downstream as Vernalis (Tables 15).

Turlock Irrigation District Lateral #5 (TID 5) and Orestimba Creek were monitored as representative of the many small agricultural return flows from the east and west side of the Valley, respectively. Average methyl mercury concentrations were 0.19±0.07 and 0.17±0.03[12]-ng/l, respectively (Table 15). The two average concentrations were used to calculate methyl mercury loads in agricultural return water. Interestingly, methyl mercury concentrations in the two main agricultural drains in the Sacramento Basin (Colusa Basin Drain and Sacramento Slough) were similar to concentrations in agricultural return flow in the San Joaquin Basin (Kruskall-Wallis test, P>0.1). Average methyl mercury concentration in water samples from Colusa Basin Drain and Sacramento Slough were 0.21±0.06 and 0.18±0.04, respectively (Table 8).

The relationship between filter passing and unfiltered methyl mercury was evaluated in the first year of the study (Table 16). Positive correlations were observed between filter passing and unfiltered methyl mercury at all sites except TID 5, Orestimba Creek and the San Joaquin River at Patterson. Only a small number of samples were collected at these three locations and it is possible that significant relationships would have been observed if more data had been obtained. On average, 30 to 60 percent of the aqueous methyl mercury existed in a filter passing form. Unlike in the Sacramento Basin, no relationship was observed at Vernalis between filter passing methyl mercury and suspended sediment or flow. Also, no relationship was apparent at Vernalis between the ratio of filter passing to total methyl mercury and either of the above two variables. Insufficient data are available to evaluate whether similar relationships might exist at other locations in the basin.

Methyl Mercury Loads

Methyl mercury loads are presented in Table 17. Loads were calculated by multiplying monthly water volumes by average methyl mercury concentrations. Water volumes for calculations between May 2003 and September 2005 were from the WARMF model while values after that date were estimated from gauged flow data.

The methyl mercury mass balance for the San Joaquin Basin demonstrates that methyl mercury production is not strongly correlated with water delivery (Figure 22). A disproportionate amount of the methyl mercury load at Vernalis is produced in three sub watersheds located upstream of the confluence of the Merced River. The San Joaquin River at Lander Avenue and Salt and Mud Sloughs produced 45 percent of the methyl mercury while only delivering 19 percent of the Vernalis flow. Mud Slough is particularly interesting. Mud Slough discharged 15 percent of the methyl mercury but only 3 percent of the flow. In contrast, the Merced, Tuolumne and Stanislaus Rivers provided 75 percent of the water but only 49 percent of the methyl mercury at Vernalis. Agricultural diversions and return flows account for about 6 percent of both the water and methyl mercury. Finally, it is important to note that the water budget is balanced to within a percent, suggesting that there are no large unaccounted for sources or diversions. In contrast, there is about 4 percent more methyl mercury at Vernalis than would be expected from summing

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[12] Mean ± 95 percent confidence limits.

upstream sources and diversions (Figure 22). The methyl mercury and water mass balance calculations have been repeated for irrigation (March to September) and non irrigation (September to March) seasons and the results are similar to those for the entire year.

Both methyl mercury concentration (Table 15) and load (Table 17) data demonstrate that the Merced, Tuolumne, and Stanislaus Basins are not large sources of methyl mercury. This was surprising as all three basins, like the American and Feather River watersheds in the Sacramento Basin, had extensive historic gold mining. The results suggest that gold mining may not be as important a source of methyl mercury to the Central Valley as was initially hypothesized. In contrast, the major source of methyl mercury in the San Joaquin River appears to originate upstream of Crows Landing.

The methyl mercury mass balance presented in Figure 22 does not include months when Millerton and/or Pine Flat Reservoirs spilled floodwater into the San Joaquin River channel. The winter and spring of 2006 were very wet and extensive flooding occurred on the Valley floor from upstream Reservoir releases. A preliminary mass balance for the four flood months (June 2005 and April to June 2006) demonstrates a very different methyl mercury source pattern (Figure 23) than was observed during non flooding periods (Figure 22). The sum of the loads during floods from Salt and Mud Sloughs and the Merced, Tuolumne and Stanislaus Rivers only accounted for 18 percent of the Vernalis load, while in dry periods they were greater than 70 percent. The majority of the methyl mercury during floods appears to originate upstream of Lander Avenue and from sources that were not monitored.

A second analysis was made to identify river reaches contributing a disproportionate amount of the methyl mercury load during floods. The percent of San Joaquin River at Vernalis load not accounted for by summing tributary inputs was graphed against River location in Figure 24. The analysis suggests that 30 to 60 percent of the methyl mercury was produced upstream of Lander Avenue while most of the remainder originated in the 18-mile reach between Fremont Ford and Crows Landing. These two reaches correspond to areas with the most extensive flooding.

Transport

Two analyses were undertaken to evaluate methyl mercury transport in the San Joaquin River (Figure 25A). First, the sum of upstream loads and diversions (Table 17) was regressed against the observed downstream load at Vernalis. The analysis only employed loads calculated with water volumes from the WARMF model. WARMF data is only available at present for the period of April 2003 through September 2005. The analysis also does not include loads for the June 2005 flood event. A positive correlation was observed between the sum of monthly upstream loads and diversions and the downstream monthly load at Vernalis. More methyl mercury in the upper basin results in more export at Vernalis. The slope of the regression is one, implying that little methyl mercury production or decay is occurring in transit down channel. The second analysis divided the river into three reaches[13] (Fremont Ford to Crows Landing, Crows Landing to Patterson, and Patterson to Vernalis) and compared the sum of upstream methyl mercury loads and diversions to the downstream load exported at the end of each segment. Again, the analysis only used WARMF data and excluded the June 2005 flood event. A positive correlation was again observed between the sum of upstream and downstream loads (Figure 25B). The slope of the relationship was again close to one suggesting that conservative transport is occurring in each river segment[14]. Finally, both regressions imply that all the major methyl mercury sources and sinks have been identified.

The load analysis has not been repeated for flood events as most of these occurred in 2006 when no WARMF data is available. High flows in June 2005 and April to June 2006 produced local flooding upstream of Lander Avenue and between Fremont Ford and Crows Landing. This apparently resulted in the inundation of the river flood channel and significant local methyl mercury production that was not associated with any of the monitored tributary inputs. The load analysis will be repeated when hydrologic data from WARMF becomes available. However, it is anticipated that the new regression will have a positive slope greater than one indicating significant methyl mercury production in the San Joaquin channel or on the adjoining unmonitored flood plain.

Conservative methyl mercury transport in the San Joaquin River is similar to the finding of conservative transport in the Sacramento River between Colusa and Freeport (Figure 20). Conservative transport in both river systems occurred over a wide range of flows and during each season of the year. However, the conclusions for both rivers are at variance with observations of non conservative transport in the Delta. Methyl mercury losses in the Delta are an inverse function of the sum of incoming water volumes (Figure 10). Stephenson *et al.* (2008) and Gill (2008) investigated methyl mercury loss processes in the Delta in Task 5.3. Stephenson *et al.* concluded that on an annual basis sedimentation might be responsible for up to -4.9 g/day or 27 percent of the sum of all methyl mercury inputs (Figure 9). Louie *et al*, (2008) and Wright and Schoellhamer (2005) have estimated that 50 to 66 percent of incoming sediment is being deposited in the delta. In contrast, both the Sacramento and San Joaquin Rivers are erosional (Louie *et al*. 2008). Lack of sediment deposition may help explain why methyl mercury is transported conservatively in both river systems. Gill (2008) evaluated the role of photo demethylation and concluded that on an annual basis photo demethylation was responsible for the loss of up to -2.5 g/day or 14 percent of the sum of all incoming methyl mercury loads in the Delta. Photo demethylation rates are an inverse function of turbidity. The higher sediment loads in the two rivers may have reduced photo demethylation rates enabling the river to transport the methyl mercury in a conservative fashion.

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[13] The distances between Fremont Ford, Crows Landing, Patterson and Vernalis are 53, 35, and 28 river miles, respectively.

[14] Travel times between Fremont Ford and Vernalis at low flow may be as long as four days while at high flows may decrease to 2 days.

Conclusions and Recommendations

Conclusions

This study represents the first comprehensive methyl mercury monitoring in the San Joaquin Basin. The study has five main conclusions.

- Methyl mercury concentrations decrease down the San Joaquin River. Average concentrations at Fremont Ford are about 35 percent higher than 55-miles downstream at Vernalis.
- The San Joaquin River at Lander Ave and Salt and Mud Sloughs discharged 45 percent of the methyl mercury at Vernalis but only 19 percent of the flow.
- In contrast, the Merced, Tuolumne and Stanislaus Rivers discharged 49 % of the methyl mercury but over 75% of the flow. The methyl mercury findings were unexpected as the three rivers were sites of extensive gold mining.
- Uncontrolled spills from Friant Dam and Pine Flat Reservoir produce local flooding above Lander Avenue and between Fremont Ford and Crows Landing. The flooding is associated with up to a six-fold increase in methyl mercury concentrations downstream at Vernalis.
- A positive correlation exists between the sum of upstream methyl mercury sources and diversions and the downstream load at Vernalis. The result is consistent with the conclusion that most of the methyl mercury is produced in the upper basin and is transported in a conservative fashion down river.

Recommendations

The study has two recommendations.

- Conduct detailed studies in the San Joaquin Basin above Crows Landing to identify landscape features responsible for the disproportionate amount of methyl mercury production.
- Update the methyl mercury mass balance calculations when WARMF hydrologic data is released for the period between October 2005 and June 2006.

Task 2c.

The purpose of Task 2C was to conduct sub watershed studies of tributaries or source regions to define regional sources of methyl mercury. Study results are provided for the Yolo Bypass and Cache Creek Settling Basin.

Yolo Bypass

Background

The Yolo Bypass is a 59,000-acre flood conveyance system designed to divert storm water from the Sacramento River around the City of Sacramento (Figure 26). Storm water completely floods the Bypass about every other year for two months (Yolo Bypass Working Group, 2001). Storm flows enter through the Fremont and Sacramento Weirs and are discharged down Shag Slough and the Toe Drain/Prospect Slough to enter the Delta above RioVista. The Bypass also receives water from Colusa Basin Drain via the Knights Landing Ridge Cut and from Cache and Putah Creeks. Extensive historical mercury mining occurred in both the Cache and Putah Creek watersheds and these may have resulted in elevated concentrations of inorganic mercury in soil in the Yolo Bypass. Major land uses in the Bypass are irrigated agriculture, animal grazing and wetlands. Two flooded islands—Liberty and Little Holland—are located at the bottom of the Bypass. The two islands total about 4,450-acres and have been purchased for restoration to tidal wetlands.

There are three general hydraulic conditions in the Yolo Bypass: low flow when all the water moving through the Bypass is contained in existing channels, mini-floods when flow from Cache and/or Putah Creeks are greater than the carrying capacity of their channels resulting in local flooding and, finally, diversion of Sacramento River water across the Fremont Weir which results in the entire Bypass flooding.

Water exiting the Bypass at Prospect Slough has the second highest average unfiltered methyl mercury concentration of any channel in the Delta (0.26-ng/l, Table 2). All but four monthly measurements were made with no water spilling over the Fremont Weir. Average monthly methyl mercury concentrations increase statistically when the Bypass is used for flood conveyance (0.25 to 0.70-ng/l, $P<0.01$). More importantly, the Yolo Bypass can become the single largest source of methyl mercury to the Delta (Table 4). Not known is the origin of the methyl mercury leaving the Bypass during different hydrologic conditions and whether it is being transported in a conservative fashion through the flooded Liberty Island and Little Holland Tract to the Delta at Rio Vista.

The purpose of the special study was two-fold. First, determine the source of the methyl mercury discharged down Prospect Slough and how much of it was produced *in situ* in the Yolo Bypass. Second, determine whether the flooded Liberty Island and Yolo Bypass are net sinks or sources for methyl mercury.

Production Studies

The methyl mercury production studies occurred over multiple years but emphasize winter months. Production was estimated by measuring the difference in loads entering and leaving the Yolo Bypass. The main sources of water during non flood conditions are the Knights Landing Ridge Cut and Cache and Putah Creeks. The main export point is the Toe Drain at Lisbon Weir. Water was collected for methyl mercury analysis from the Ridge Cut at the County Road 16 Bridge, from Cache Creek at the exit from the Settling Basin and from Putah Creek at the Mace Boulevard Bridge. Flow measurements for Cache Creek are from the gauge at Yolo and for Putah Creek from the gauge at the town of Winters. Flow for the Knights Landing Ridge Cut was estimated as the flow of the Colusa Basin Drain (CBD) near Knight's Landing minus the flow of the CBD to the Sacramento River (CBD at Knights Landing gauge). CBD near Knights Landing flow was estimated to be equal to the flow at the CBD at Highway 20 gauge, if no rain had occurred in the previous two days. If it rained, then the flow at the Highway 20 gauge was multiplied by 1.21 as recommended by the Yolo Bypass Working Group (2001). Flow at Lisbon is from the gauge located at the Lisbon Weir, if the stage at Lisbon Weir was below 10 feet. No operational gauges exist for the Bypass at high flow. Therefore, if the stage at Lisbon Weir was above 10 feet, then the sum of inputs to the Yolo Bypass was used as an estimate of water exports. During flood flows the two-mile long Fremont Weir becomes the major water source and Shag Slough becomes an additional export site. The water from Fremont Weir was collected by boat on the Sacramento River from three locations along the outside of the Weir (upper, mid, and lower weir) and daily averages were used in subsequent calculations. Shag Slough was sampled from the Liberty Island Bridge. Finally, water samples also were taken during low flow from the Yolo Bypass at ½ Lisbon to determine the contribution from the Bypass area located below Lisbon. Also, at high flow samples were taken from the Sacramento River upstream of the confluence with the Yolo Bypass at Isleton to compare Bypass and River methyl mercury production rates.

Low Flow Methyl mercury production was estimated for the Yolo Bypass during three low flow events (Table 18). Production estimates are provided for the area above the Lisbon Weir and between the Lisbon Weir and the stair step dredging canal at ½ Lisbon (Figure 26). Production was positive on all occasions except 13 December 2004 when methyl mercury was lost between Lisbon and ½ Lisbon. In general, about as much methyl mercury was produced above as below the Lisbon Weir. Net low flow *in situ* production in the Bypass ranged between 27 and 64 percent of the load exported to Prospect Slough. The source of the majority of the remaining methyl mercury at Prospect Slough was from the Knights Landing Ridge Cut canal.

Mini Floods Methyl mercury production was estimated for the Yolo Bypass during two mini flood events (Table 19). Net production was positive on both occasions above Lisbon and between Lisbon and ½ Lisbon. *In situ* production in the Bypass ranged between 36 and 39 percent of the load exiting to Prospect Slough. Cache

Creek and the Ridge Cut canal were the two other major sources of methyl mercury to the downstream Delta.

Average methyl mercury concentrations increased about 15% in the 12-miles of Toe Drain between Lisbon and ½ Lisbon (Figure 27). The increase is statistically significant (two-tailed t-test, P=0.05). The spikes in methyl mercury in the Toe Drain on 28 May 2005 and for several months in 2006 were associated with the discharge of Sacramento River storm water over the Fremont Weir. At least 29 constructed drains are located in the reach between Lisbon and ½ Lisbon and appear to predominately discharge water from seasonal and permanent wetlands (Figure 28). Methyl mercury was measured in water discharging from these drains on four low flow occasions (Table 20). Concentrations ranged between 0.2 and 5.2-ng/l. Twenty-seven of the 32 measurements were greater than the methyl mercury concentration at Lisbon suggesting that the drains were responsible, at least on these days, for some of the increase in methyl mercury between Lisbon and ½ Lisbon.

Fremont Weir Storm Flows The winter and spring of 2005/2006 were very wet and the Yolo Bypass flooded on three occasions for a total of 95 days (Figure 29). All major water input and export sites were sampled on 15 occasions during the last major flooding event. An initial assumption was that water leaving the Bypass would be well mixed and that methyl mercury concentrations at Shag Slough and at the Toe Drain would be similar. However, water samples collected from the two discharge points on the same date demonstrated that methyl mercury concentrations in Shag Slough were twice as high as in the Toe Drain (P<0.01 paired t-test, Figure 30). Sommer et al., (2008) observed four distinct hydrologic bands down the length of the Yolo Bypass associated with inputs from the Sacramento River, Ridge Cut, Cache and Putah Creeks during a March 1998 flooding event. This complicated the monitoring and suggested that water leaving the Bypass is not well mixed and that an accurate estimate of net export will require information about both the concentration and water volume discharged down each channel.

Water samples were taken on three occasions from all input and export channels and analyzed for a suite of conservative elements by inductively coupled plasma analysis (ICP). The purpose of the ICP analysis was to determine the source and volume of water leaving the Bypass at Shag Slough. A comparison of unfiltered sodium, magnesium and chloride concentrations in source and discharge water demonstrate that Cache and Putah Creeks mainly exit through Shag Slough while Fremont Weir water is discharged down the Toe Drain (Figure 31). Instantaneous discharge rates were calculated for both export sites by assuming conservation of water and the mass of magnesium, sodium, chloride, and boron. The analysis suggests that, on average, about 19 percent of the water entering the Bypass exited down Shag Slough while 81 percent went down the Toe Drain (Table 21). All subsequent export load calculations were made using the 19/81 flow split.

Methyl mercury production in the Bypass was estimated from the difference between incoming (Putah, Cache, Ridge Cut and Fremont Weir) and export (Shag

Slough and Toe Drain) loads. Exports were always greater than incoming loads on the same date (Figure 32a). The difference between the two curves is a measure of net methyl mercury production in the Bypass (Figure 32b). Bypass production increased as a function of increasing flow to at least 110,000-cfs, the highest discharge rate monitored. The reason why net production is a positive function of flow is not known. Two possible hypotheses are that the increased flow increases erosion of particles, some of which have attached methyl mercury. Alternatively, increased flow may facilitate diffusion of methyl mercury from porewater.

The methyl mercury production rate of the Sacramento Basin was calculated by summing the exports from both the Bypass and the Sacramento River at Isleton and comparing this value with *in situ* production from just the Bypass. *In situ* methyl mercury production from the Bypass averaged 40 percent of the production rate for the entire Sacramento watershed (Figure 33). This is surprising as the Yolo Bypass is only 59,000-acres while the Sacramento Basin is 16,765,000-acres or 285 times larger.

Transport

Liberty and Little Holland Islands are flooded tracts at the base of the Yolo Bypass undergoing passive restoration to wetlands. Mean water depth in the flooded islands at lower low tide is between one and five feet with a tidal range of about 2 feet. The hydrology of the islands is complicated by the fact that there are multiple levee breaks allowing water to enter from both the Toe Drain and from the Sacramento River. The shallow depth precludes complete mixing.

The quality of the water leaving the Yolo Bypass was characterized by monitoring at Prospect Slough. Prospect Slough is a composite of water discharged down the Toe drain from ½ Lisbon, Toe Drain water entering and moving through the two flooded islands and water from the Sacramento River at Rio Vista being tidally pumped upstream. Probably the largest water source in Prospect Slough is from the two flooded islands. It was not known at the beginning of the study whether the flooded islands were net methyl mercury sources or sinks.

Methyl mercury concentrations were compared on twenty-two occasions (between December 2004 and June 2006) at both ½ Lisbon in the Toe Drain and five miles downstream at Prospect Slough. Average methyl mercury concentrations decreased 20 percent between the two sites (Figure 34, $P<0.0002$, paired t-test). It was unclear whether the decrease was caused by tidal dilution of Sacramento River water or whether the two flooded islands were acting as net methyl mercury sinks.

Eleven surveys were made between Rio Vista and ½ Lisbon and electrical conductivity and unfiltered methyl mercury were measured at about eight sites between the two locations. Methyl mercury and electrical conductivity were both consistently greater at ½ Lisbon. Half the monitoring sites were located in channels and the other half on the two flooded islands. The surveys were made during ebb and flood tide, during windy and calm periods, and during high and low flow events. Methyl mercury and electrical conductivity were compared at each site with a simple mixing model to determine whether the change in methyl mercury was similar to the change in electrical conductivity and could be explained by dilution or whether the islands were a net methyl mercury sink. Overall, 79 water samples were collected during the eleven surveys. Results for 14 March, a typical run, are presented in Figure 35. Methyl mercury concentrations were consistently less at sites along the transect (plotting below the EC-methyl mercury line) than would be predicted from the electrical conductivity measurements alone. Overall during the eleven surveys, fifty-eight samples plotted above the line, 10 on it and 4 below. The distribution is unlikely to have occurred by chance ($P<0.01$, Chi square test) indicating that the decrease was not caused by dilution and that the two flooded islands must be net methyl mercury sinks. The mechanism(s) responsible for the methyl mercury loss are not known but may be some combination of photo demethylation and sedimentation as Stephenson *et al*. (2008) and Gill (2008) have proposed for other locations in the Delta. Average water depths on the islands are less than 5-feet which should facilitate photolysis. Also, the upper portion of each island is now densely colonized by tules and cattails which may decrease water velocity and facilitate sediment deposition.

Biological Significance

Spatial and temporal methyl mercury patterns in water in the Yolo Bypass are similar to the pattern observed in fish tissue. Slotton *et al*. (2007) collected and measured mercury in juvenile silverside fish for several years at multiple locations in the Yolo Bypass. Mercury concentrations in silversides at Prospect Slough increased several months after water concentrations rose with flood flows from Fremont Weir in the spring of 2006 (Figure 36). Mercury levels declined in fish hatching after methyl mercury levels in water returned to baseline levels. This association of increases and subsequent decreases in methyl mercury in water and fish after flooding is similar to the pattern previously described for the San Joaquin River (Figure 13). Slotton *et al*. also reported that average mercury concentrations in silversides were about 25 percent lower at Prospect Slough than at ½ Lisbon in both 2005 and 2006. Similarly, methyl mercury concentrations in water declined on average by about 20 percent values between the two locations (Figure 34). In conclusion, the spatial and temporal similarity between the changes in methyl mercury concentrations in fish and water in the Bypass are consistent with the hypothesis that unfiltered methyl mercury measured is biologically available and being incorporated into the aquatic food chain.

Cache Creek Settling Basin

Background

The Cache Creek Settling Basin is located at the base of Cache Creek (Figure 2 and 25). The 3,600-acre structure was constructed by the U.S. Army Corps of Engineers to capture sediment from Cache Creek and prevent a debris dam forming downstream in the Yolo Bypass and reducing the Bypass's ability to carry flood water. Cache Creek is a mercury enriched watershed and transports about 226-kg of inorganic mercury per year (20-yr average, Louie et al., 2008). About half the mercury is trapped with sediment in the Settling Basin and the rest (99-kg/yr) exported to the Yolo Bypass. Some of the exported mercury is hypothesized to deposit in the Bypass where it contributes to the disproportionate amount of methyl mercury production there. The Central Valley Water Board staff hypothesizes that reducing inorganic mercury export loads from the Cache Creek Settling Basin may be one way to reduce methyl mercury production in the Bypass and subsequent bioaccumulation in the food chain.

Studies are underway to evaluate options for increasing the inorganic mercury trapping efficiency of the Settling Basin. These include increasing the volume of the Settling Basin by increasing the acreage, raising the high flow weir, and/or dredging. However, no information exists about present methyl mercury production or transport in the Basin or how changes in Basin hydrology might alter these processes.

Production and Transport

The Cache Creek Settling Basin has a low flow channel rated for up to 400-cfs. At higher flow rates water fills the Settling Basin and once the Basin is full discharges across the high flow weir. Paired sampling at the entrance and exit of the Settling Basin demonstrates that average methyl mercury concentrations double from in to out during low flow (Figure 37A). The increase is statistically significant (two tailed paired t-test, $P<0.01$). There is no relationship between net methyl mercury production and flow through the low flow channel. In contrast, average methyl mercury concentrations decrease 27 percent when the Settling Basin is full and water is spilling over the high flow weir (Figure 37B). The loss rate is inversely proportional to flow with an inflection point around 2,800-cfs. Net methyl mercury production is positive at flows less than 2,800-cfs and negative at higher flow.

The processes responsible for a decrease in methyl mercury concentration with increasing discharge across the high flow weir are not known. It is hypothesized that two dominant processes may control methyl mercury concentrations discharged from the Basin over the high flow weir: particle settling and *in situ* sediment methyl mercury production. Water residence time in the Settling Basin is about a day at flows of 4,000-cfs. Paired filter-passing and unfiltered samples of the incoming water demonstrate that about 75±10 percent of the methyl mercury is bound and potentially available to be settled. Sedimentation may be the dominate process at water residence times of a day or less (4,000 or higher cfs). This would result in a net loss of methyl mercury. In contrast, *in situ* sediment methyl mercury production may become the dominant process when residence times are greater than a day (4,000 or lower cfs). In this case, production would gradually replace the methyl mercury lost to sedimentation and, if allowed to act long enough, would result in a net increase in export concentrations.

A conceptual model of competing deposition and methyl mercury production may help inform future improvements to the Settling Basin. Preferred options for increasing sediment deposition is to either increase the volume of the basin by increasing the acreage of the basin, raising the high flow weir, and/or dredging. All options would increase sediment deposition by similar amounts and, if the conceptual model is correct, would result in similar amounts of methyl mercury loss. However, enlarging the surface area of the Settling Basin would increase the area available for methyl mercury production while raising the high flow weir or dredging would not change surface area. Therefore, it seems that raising the high flow weir in combination with dredging might be the preferred option to minimize methyl mercury exports.

Conclusions and Recommendations

Conclusion

- The Yolo Bypass is a flood conveyance system designed to divert storm water from the Sacramento River around the City of Sacramento. Storm water is discharged across the Fremont Weir and down the Bypass about every other year for two months. Water exits the Bypass at Prospect and Shag Sloughs.
- Water leaving the Yolo Bypass at Prospect Slough has the highest average annual methyl mercury concentration in the Delta (0.27-ng/l).
- Mass balance studies when the Fremont Weir is not spilling indicate that 27 to 66 percent of the methyl mercury at Prospect Slough is produced in the Bypass. Most of the rest comes from Colusa Basin Drain via the Knights Landing Ridge Cut.
- Mass balance studies when the Fremont Weir is spilling indicate that the Bypass, on average, produces about 40 percent of all the methyl mercury exported from the Sacramento Basin. This is surprising as the Bypass is only 59,000 acres while the Sacramento Basin is 16,765,000 acres or 285 times larger.
- The flooded Liberty and Little Holland Islands downstream of the Yolo Bypass are net methyl mercury sinks.
- The Cache Creek Settling Basin is a methyl mercury source at flows less than 400-cfs when discharging through the low flow weir.
- In contrast, a negative relationship exists between flow and production when the Settling Basin is full and discharging over the high flow weir. The inflection point is at about 2,800-cfs with production being positive at lower flows and negative at higher ones.

Recommendations

- Detailed studies need to be undertaken in the Yolo Bypass under normal and flood conditions to determine the land use practices responsible for the disproportionate amount of methyl mercury production. These studies should be followed by the development of management practices to reduce methyl mercury production.
- Follow up studies need to be conducted in the Cache Creek Settling Basin at flows less than 400-cfs to determine where the methyl mercury is made and whether changes can be made to minimize production.
- Studies need to be conducted in the Settling Basin during high flow to evaluate the conceptual model that methyl mercury concentrations is the result of two competing processes, *in situ* production and sedimentation. The information would be used to inform the design of an improved Settling Basin.

Citations

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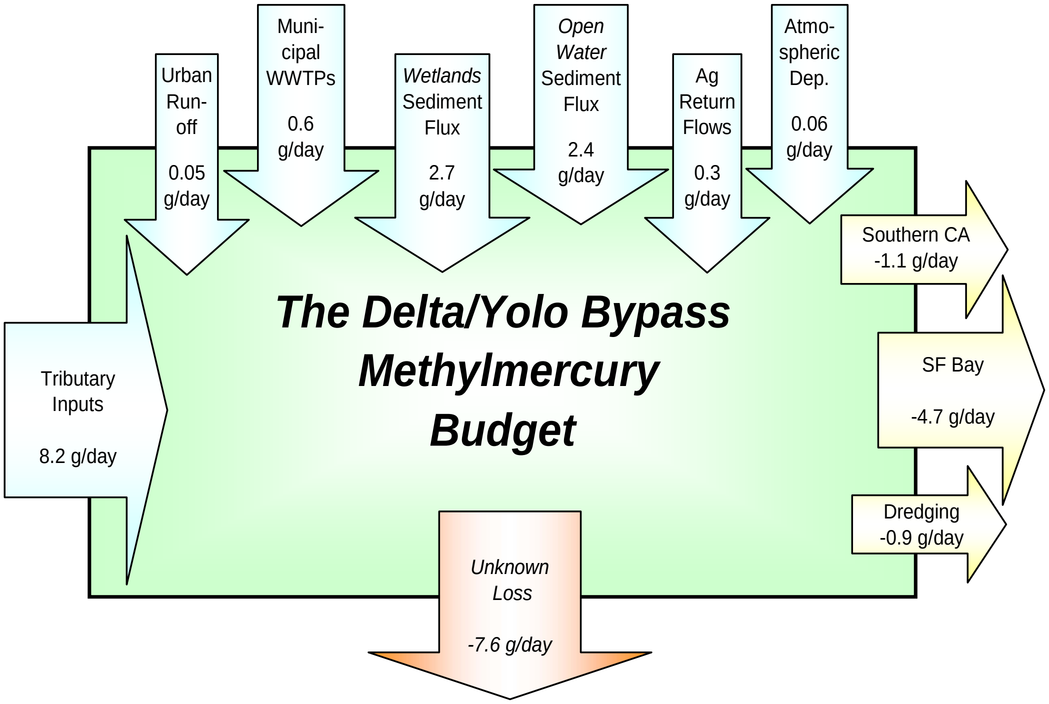


Figure 1. Methyl mercury mass balance model for the Delta based on a relatively dry period (March 2000 to October 2001). The figure is from the methyl mercury TMDL report to the U.S. EPA (Wood *et al*., 2008)

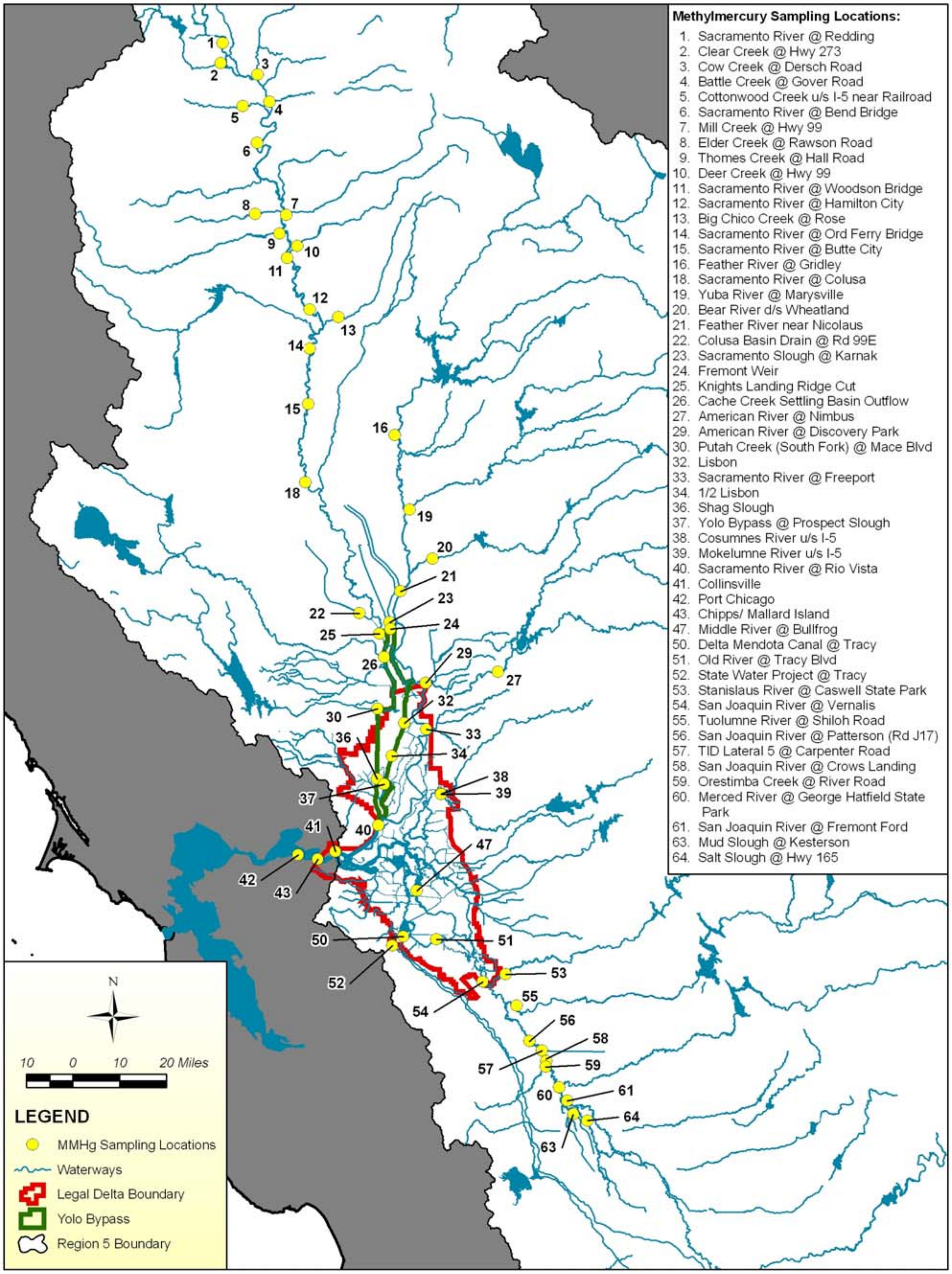


Figure 2. Map of methyl mercury sampling sites in the Central Valley and Delta.

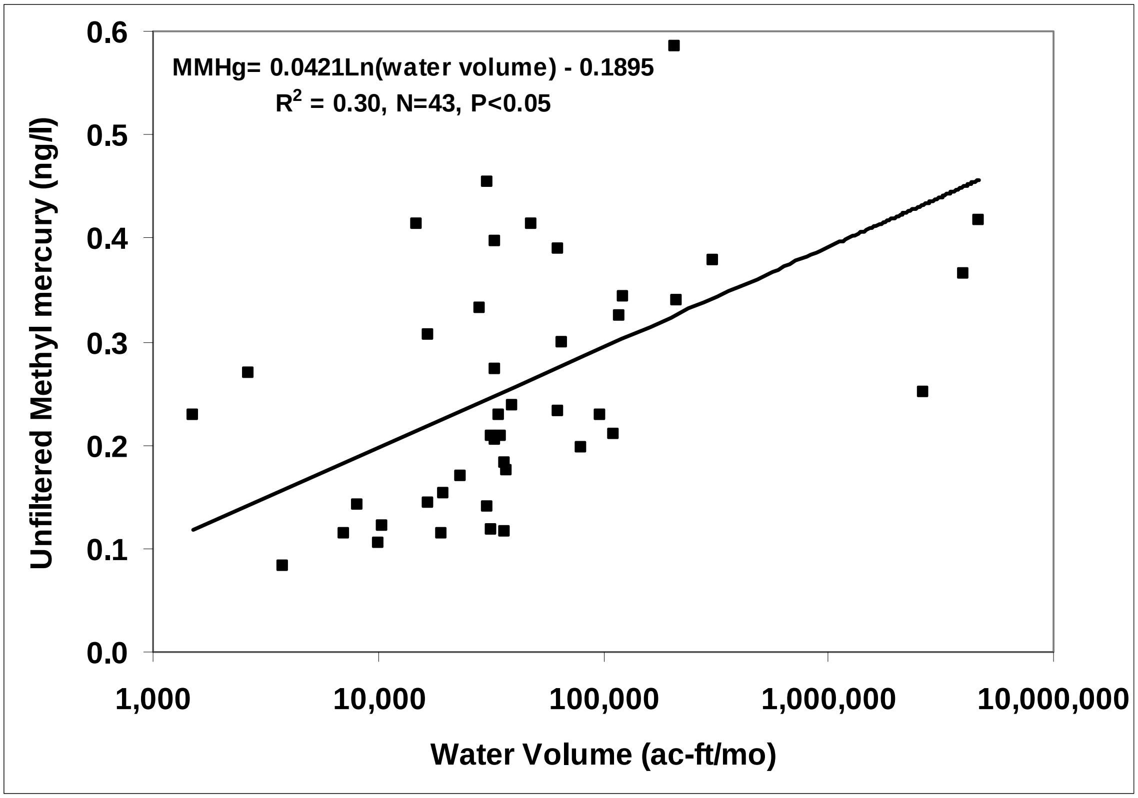


Figure 3. Unfiltered methyl mercury concentrations as a function of water volume in Prospect Slough. Note the X-axis is on a log based 10 scale.

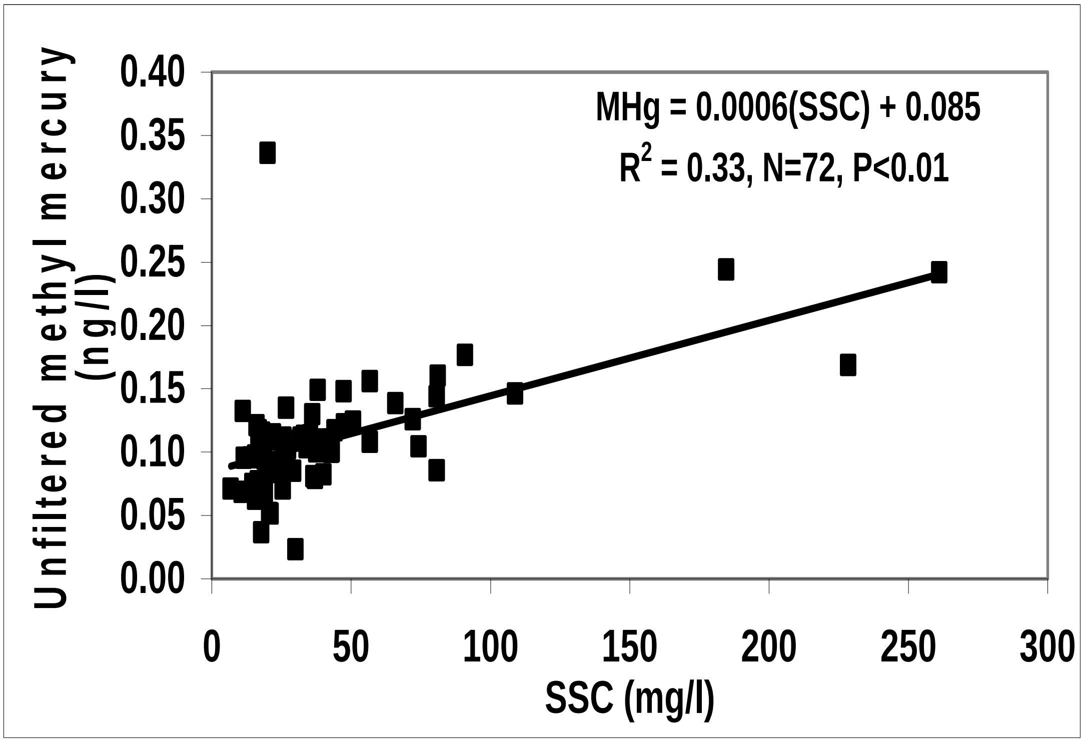


Figure 4. Unfiltered methyl mercury concentration (ng/l) as a function of suspended sediment concentration (SSC, mg/L) in the Sacramento River at Freeport.

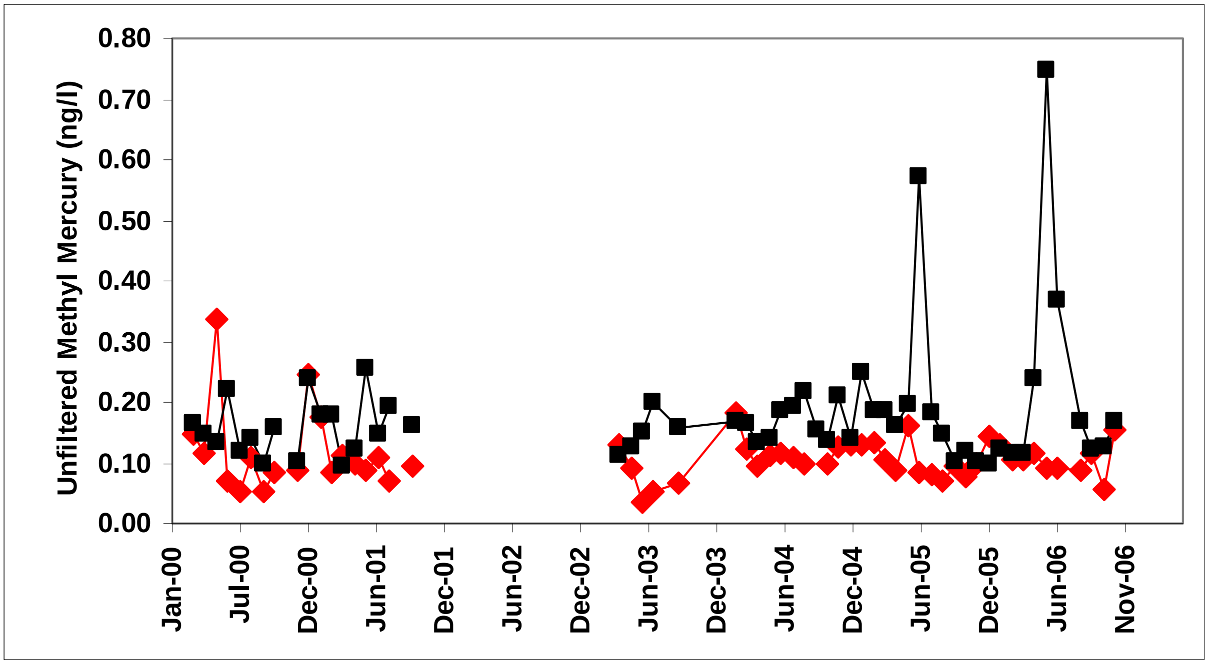


Figure 5. Unfiltered methyl mercury concentrations (ng/l) in the Sacramento (diamonds) and San Joaquin Rivers (squares) at the legal boundary of the Delta. The elevated methyl mercury concentrations in the San Joaquin River on June 2005 and April to June 2006 were associated with upstream flooding.

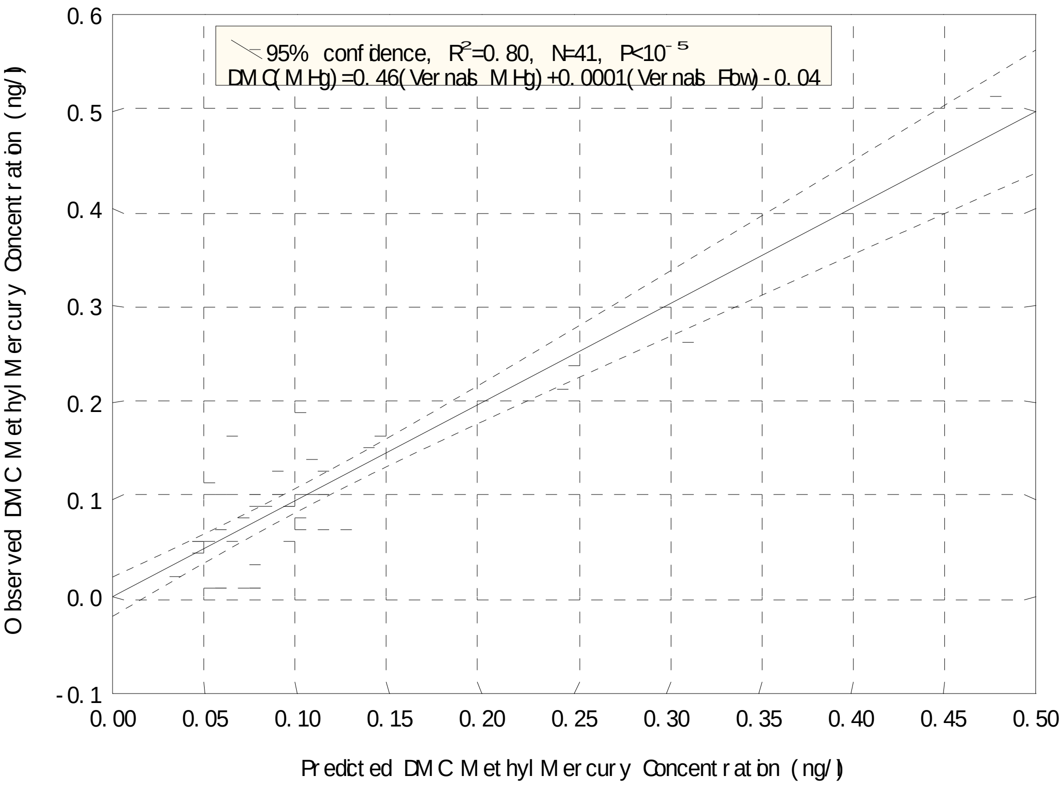


Figure 6. Predicted and observed methyl mercury concentrations (ng/l) at the Delta Mendota Canal (DMC). The units for unfiltered methyl mercury and flow in the equation in Figure 6 to calculate predicted DMC methyl mercury concentrations are ng/l and thousand acre-ft per month.

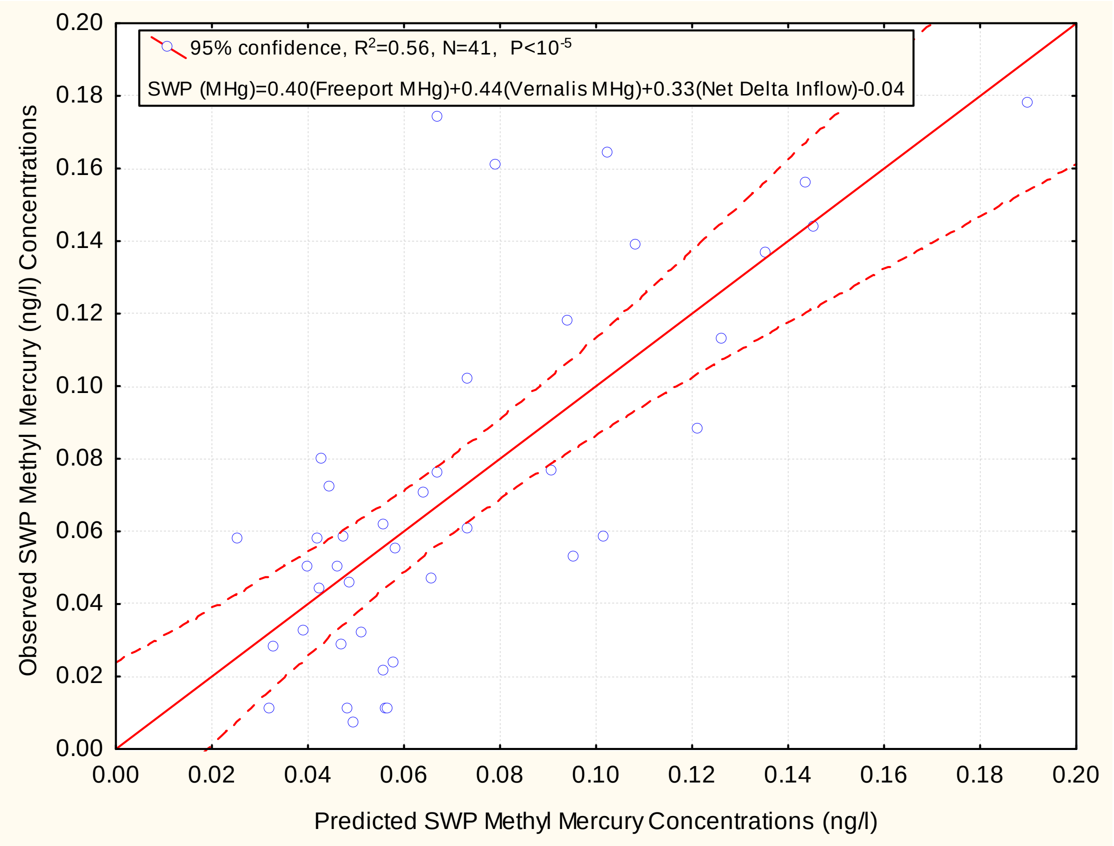


Figure 7. Predicted and observed methyl mercury concentrations at the State Water Project (SWP). The units for unfiltered methyl mercury and flow in the equation in the figure to calculate predicted SWP methyl mercury are ng/l and thousand acre-feet per month.

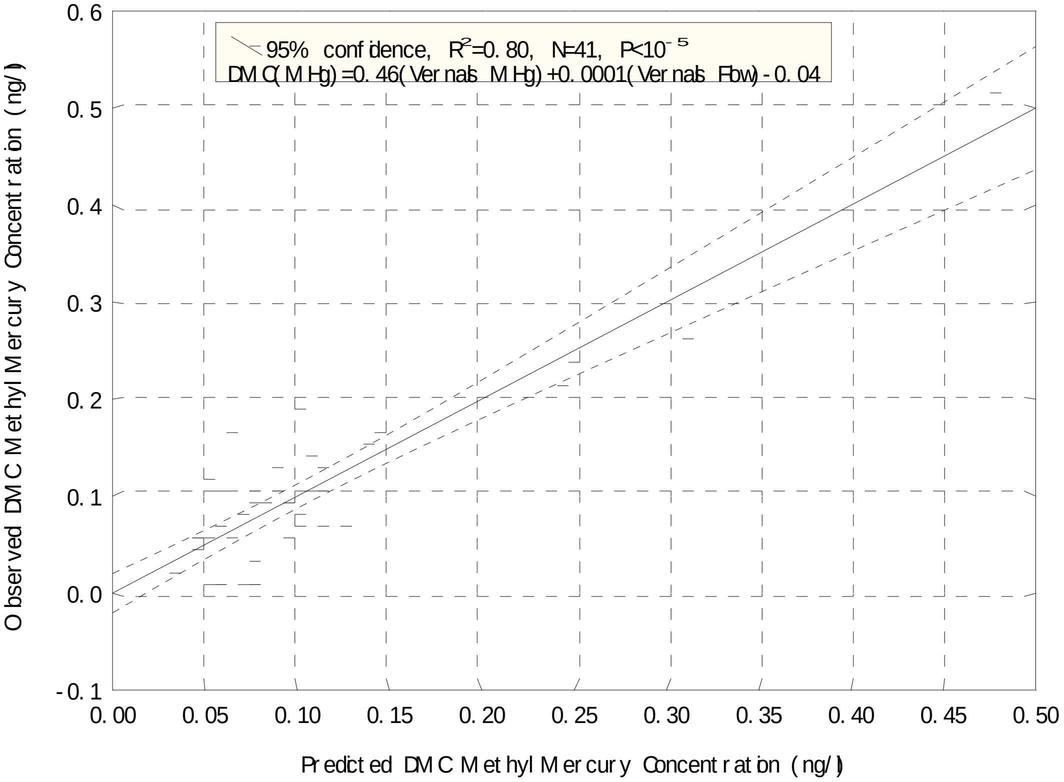


Figure 8. Predicted and observed methyl mercury concentrations (ng/l) at Mallard Island. The units for unfiltered methyl mercury and Sacramento River flow in the equation to calculate predicted Mallard methyl mercury concentrations are ng/l and thousand acre-feet per month.

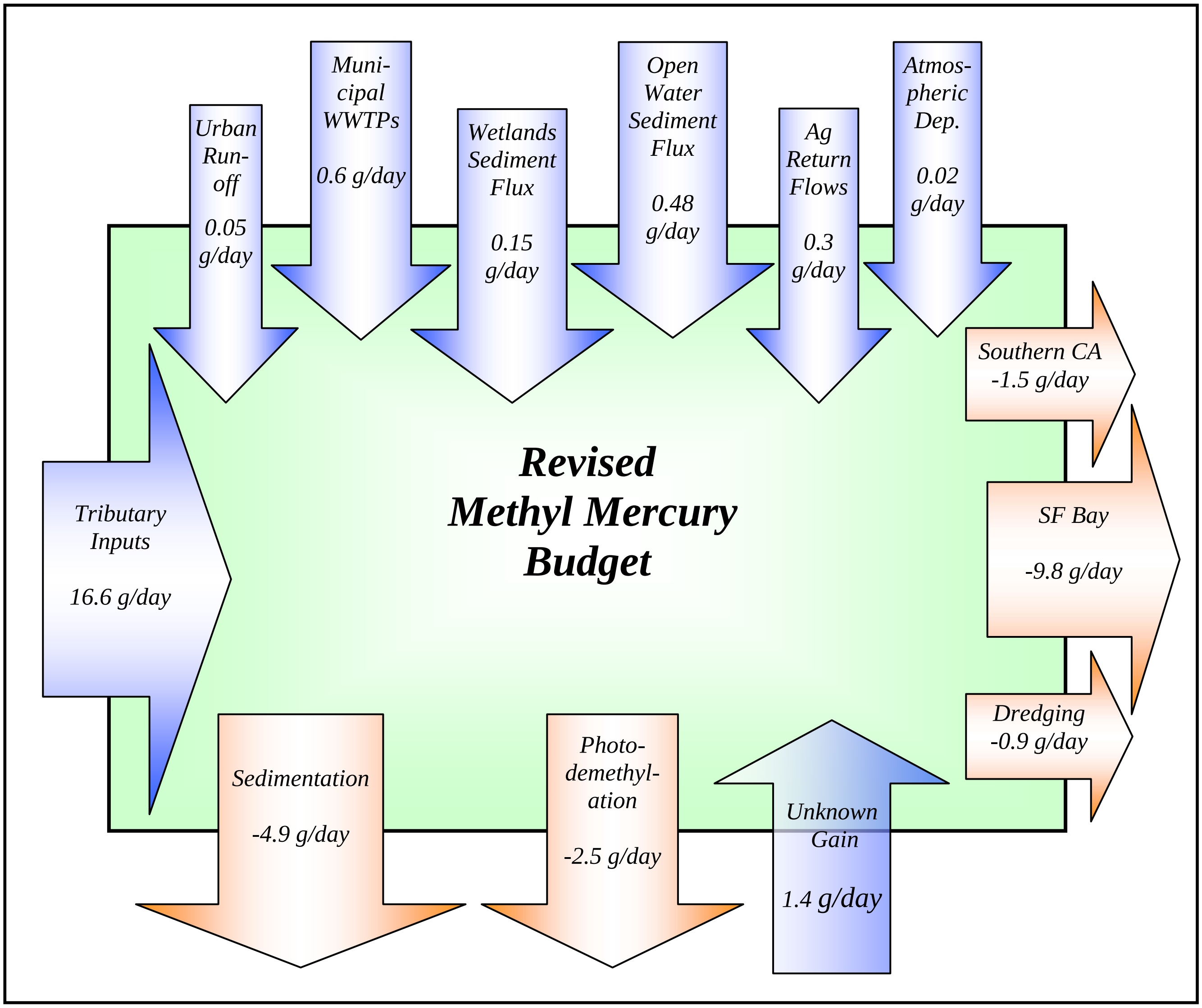


Figure 9. Revised methyl mercury mass balance model for the Delta. The revised model incorporates both some new rates for previously measured terms (tributary inputs and exports to southern California and San Francisco Bay) and rates for two previously unmeasured processes, (photo demethylation and sedimentation).

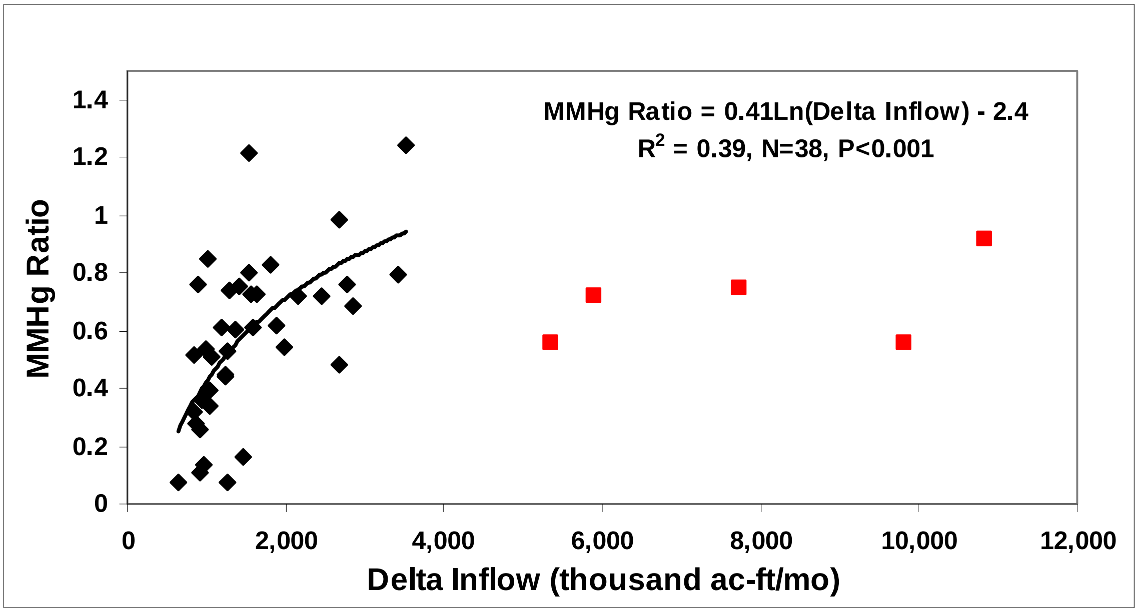


Figure 10. Ratio of the sum of monthly methyl mercury export loads divided by the sum of incoming loads as a function of tributary inflow. The load ratios were calculated from data in Table 4 while water volume is from Table 1. The five squares represent dates when the Yolo Bypass and/or San Joaquin River were flooding. These five were not included in the regression.

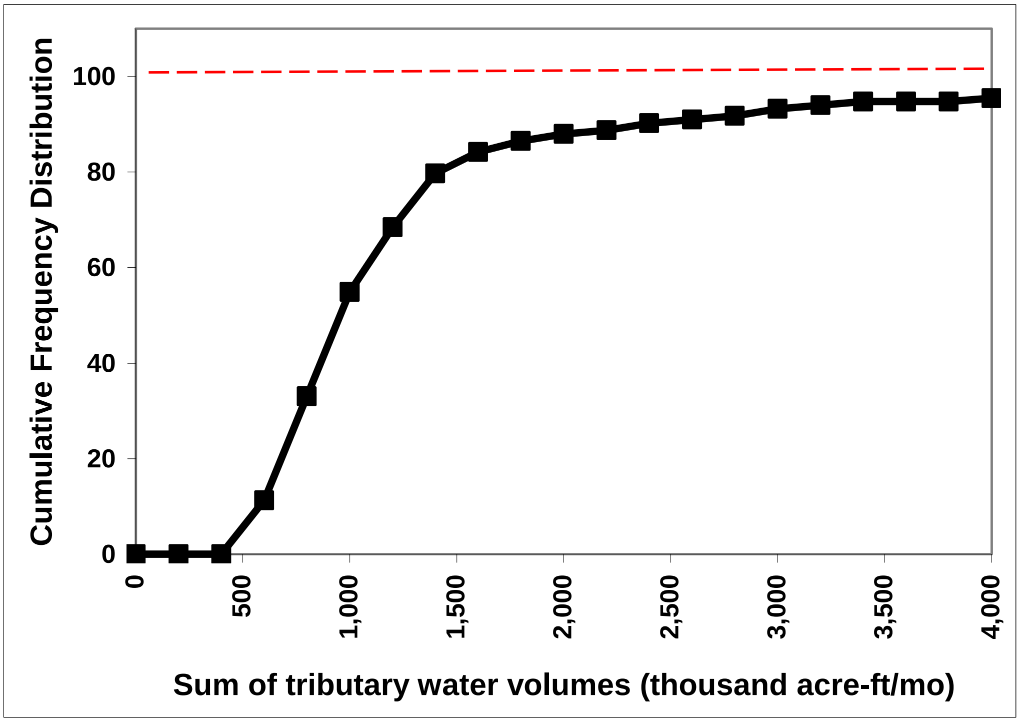


Figure 11. Cumulative monthly frequency distribution of Delta inflow for the 20-year period between October 1983 and September 2004. The flow data is from Louie *et al*., (2008). This period has a statistically similar distribution of water year types as the 100-year water record for the Central Valley (Wood *et al*., 2008).

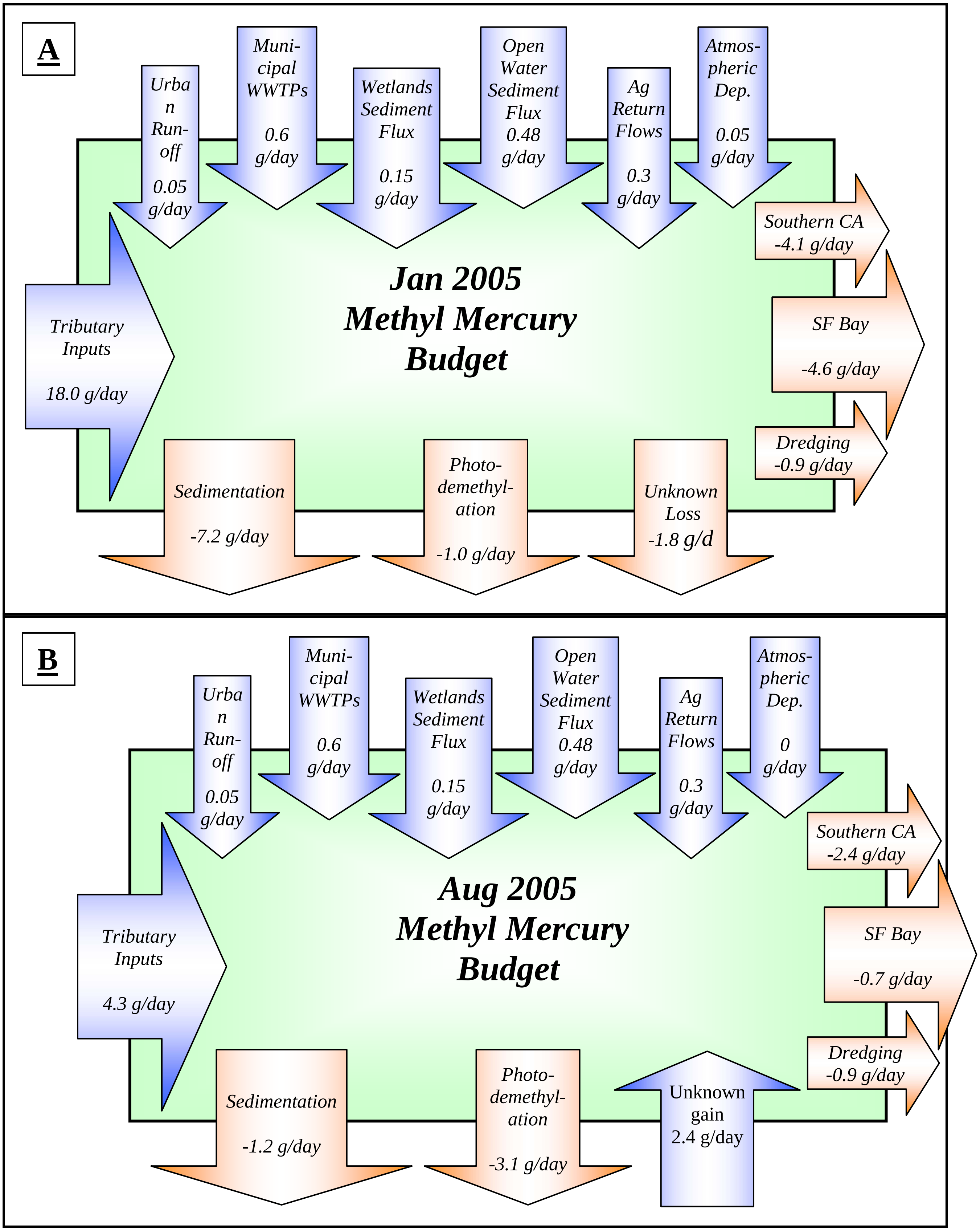


Figure 12. (A) Methyl mercury mass balance for the Delta for January 2005. (B) Same mass balance for August 2005. Note changes in the relative magnitude of the various processes.

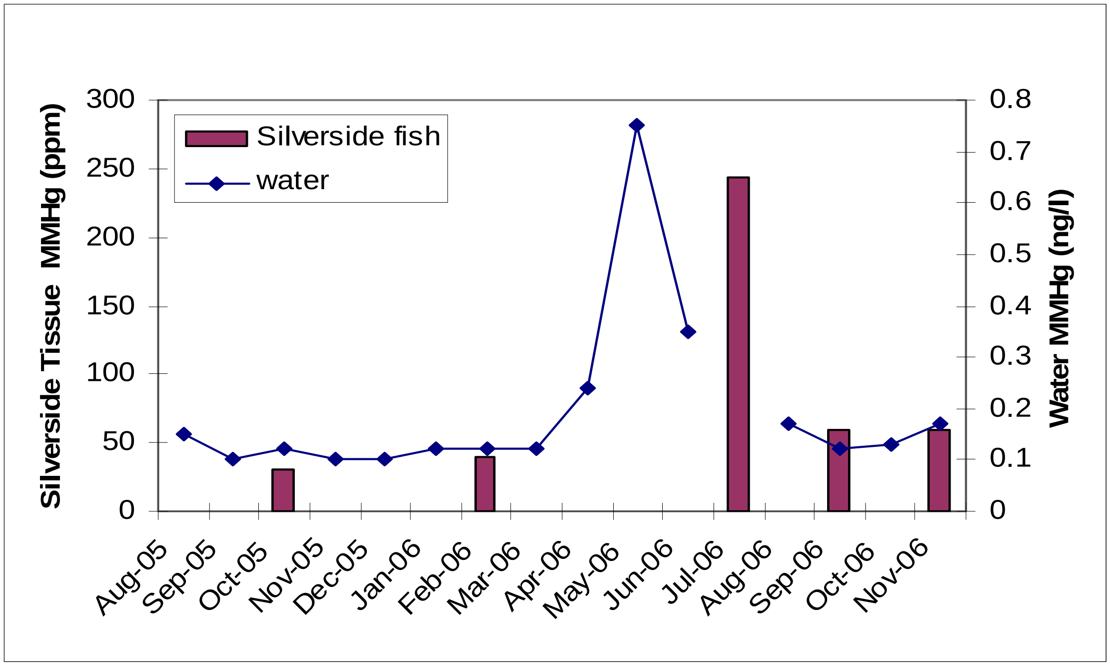


Figure 13. Methyl mercury concentrations in juvenile silverside fish and in water in the San Joaquin River at Vernalis. Unfiltered methyl mercury in water increased 6-fold in May 2006 but had returned to baseline concentrations by August. Mercury concentrations in silversides in July were 6 times higher than in fish caught earlier but had returned to baseline values by September 2006. The silverside data are from Slotton *et al*. (2008)

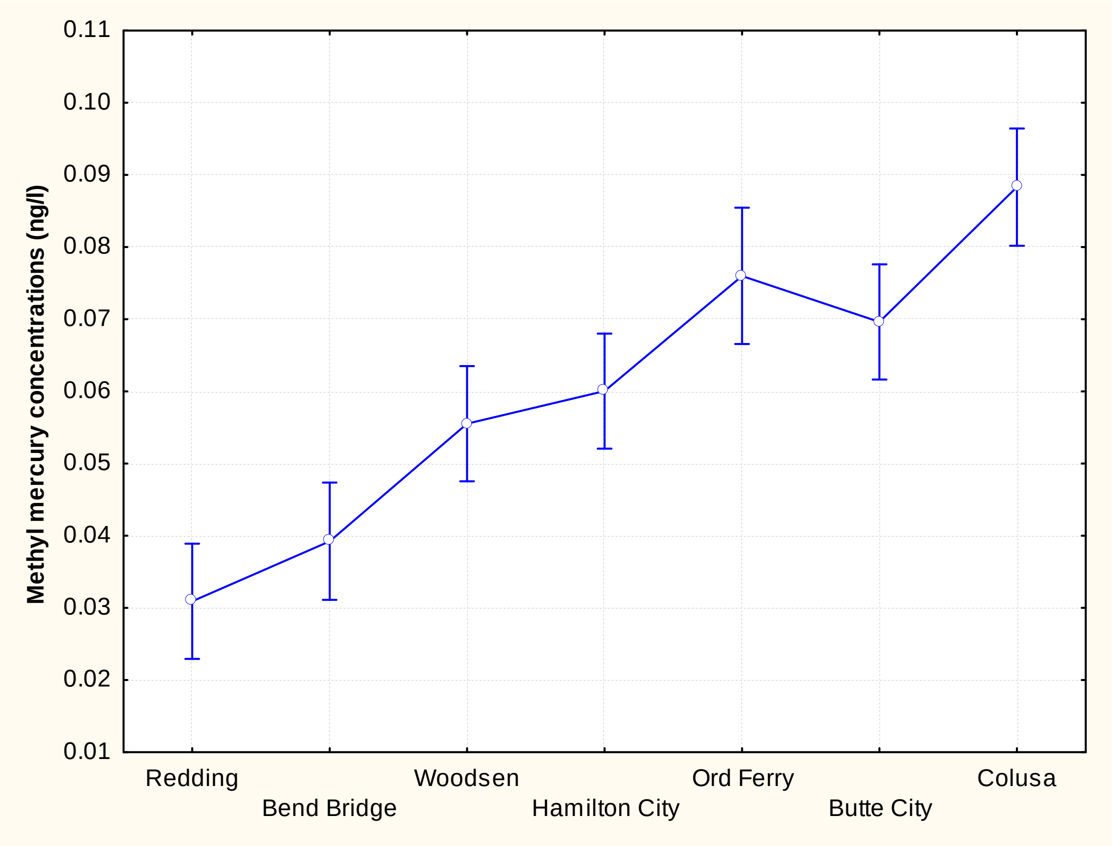


Figure 14. Mean and 95 percent confidence limits of monthly unfiltered methyl mercury concentrations (ng/l) in the Sacramento River between March 2003 and June 2006 (n=30). The graph does not include storm events.

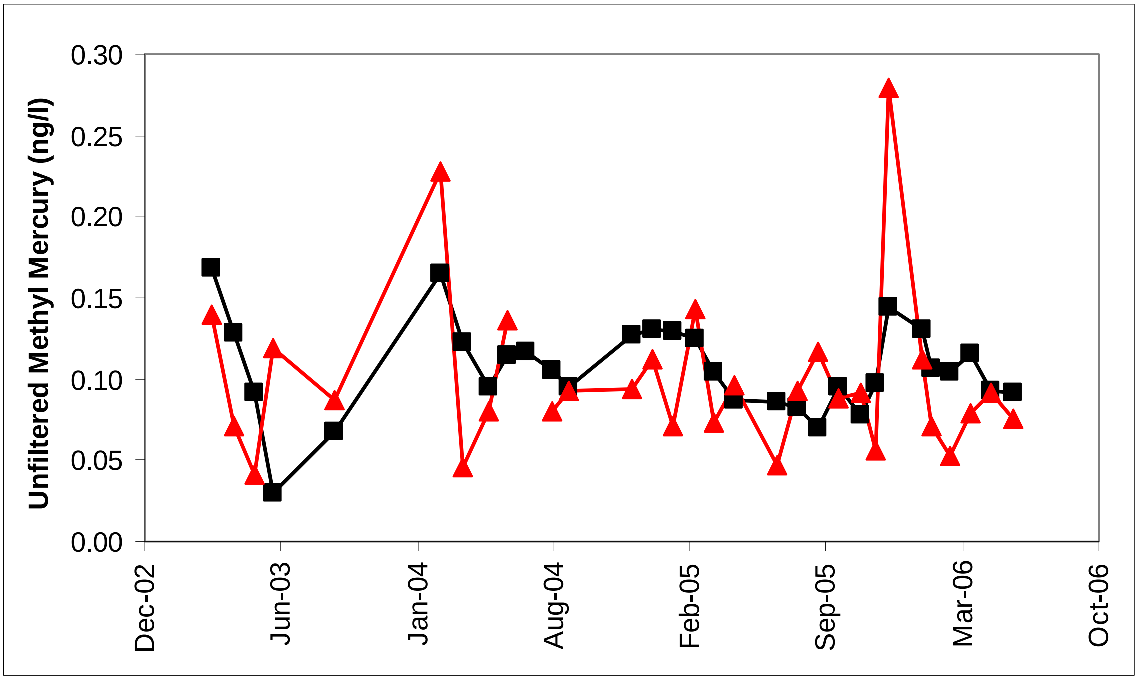


Figure 15. Unfiltered methyl mercury concentrations (ng/l) in the Sacramento River at Colusa (triangles) and Freeport (squares). No seasonal pattern was apparent. Elevated methyl mercury concentrations at Colusa in February 2004 and December 2005 were storm events.

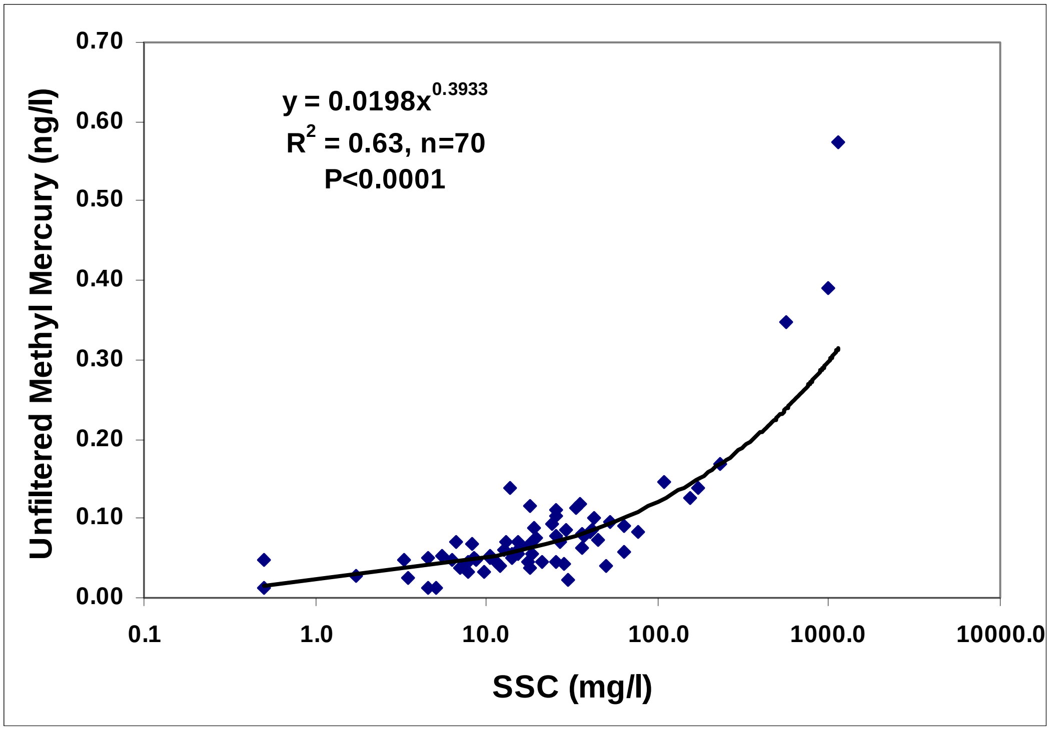


Figure 16. Relationship between unfiltered methyl mercury (ng/l) and suspended sediment concentration (SSC, mg/l) at all station in the Sacramento River between Redding and Freeport. Data includes samples collected during storms. The relationship is still significant if suspended sediment concentrations greater than 100 mg/l are omitted. Elevated suspended sediment values always occurred during storm events. Note the log base 10 scale on the X-axis.

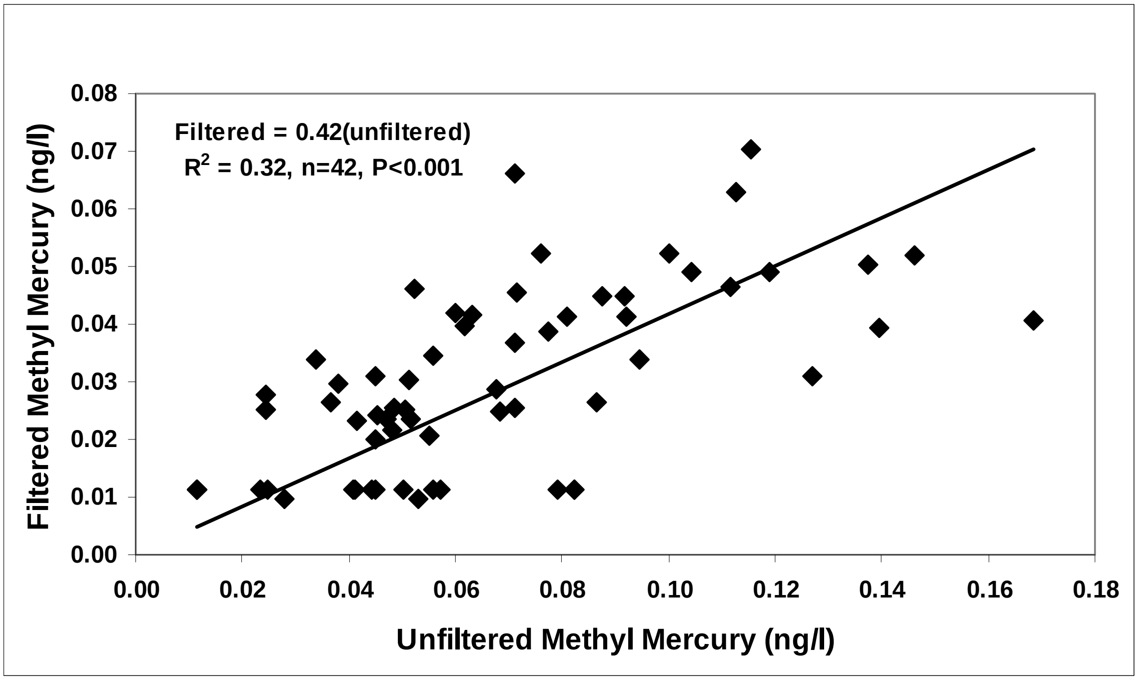


Figure 17. Relationship between filter-passing and unfiltered methyl mercury in the Sacramento River between Redding and Freeport. Data collected during storm events are not included.

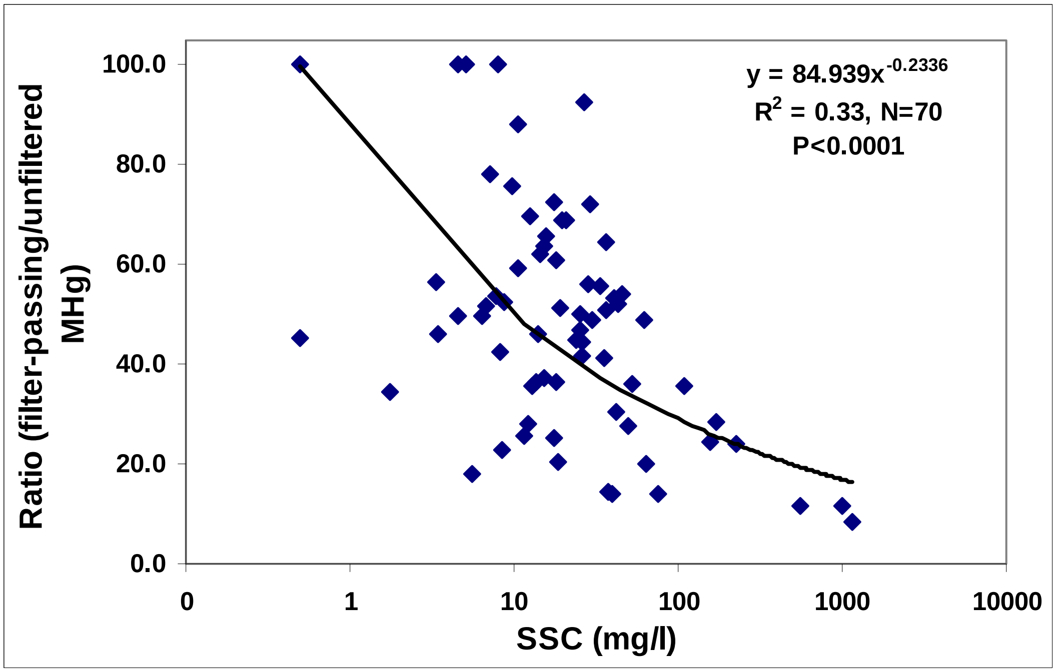


Figure 18. Relationship between the ratio of filter passing to unfiltered methyl mercury as a function of suspended sediment concentration (SSC). Data were collected between Redding and Freeport and include samples taken during storm events. Note the log base-10 scale on the X-axis.

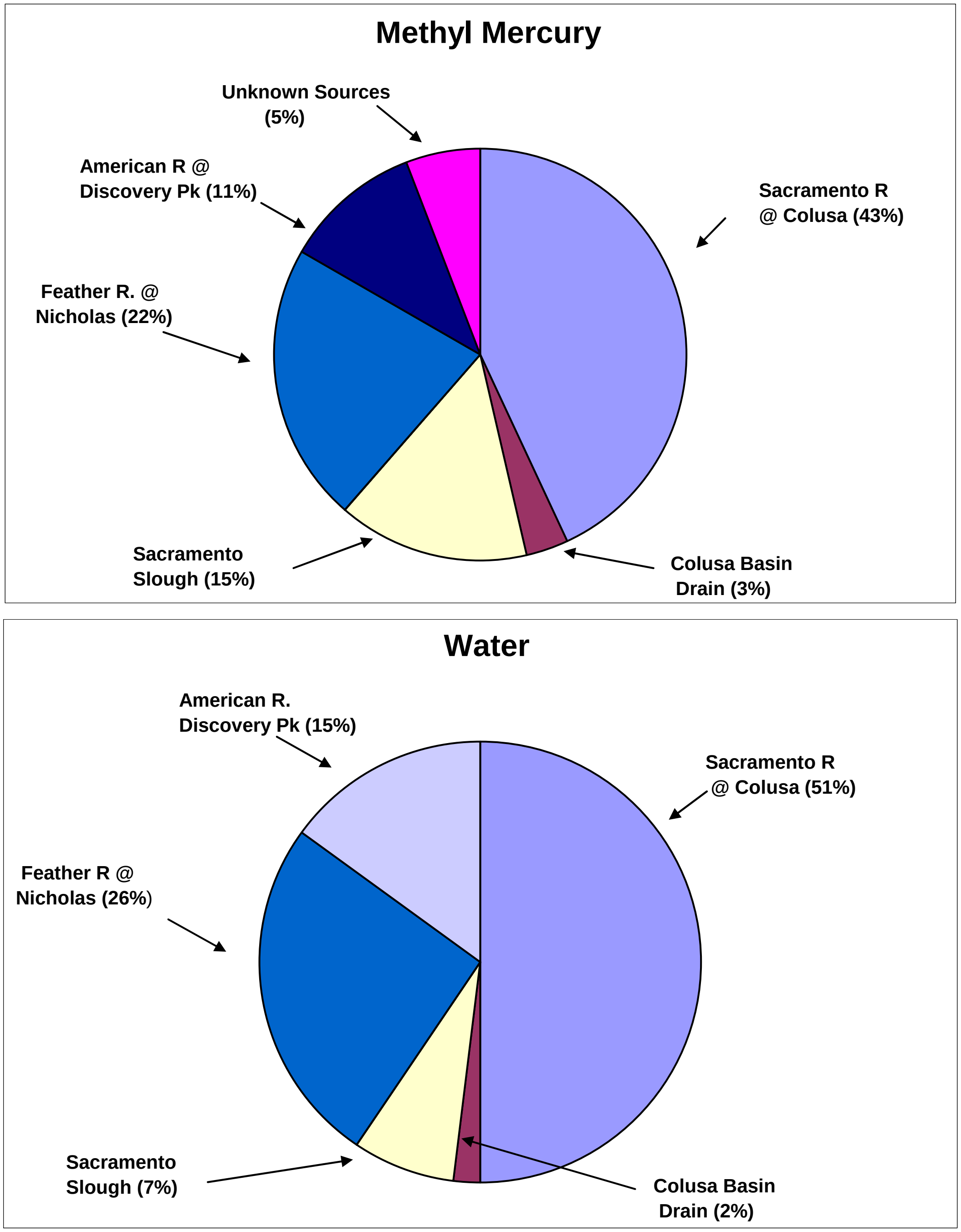


Figure 19. Pie charts comparing the magnitude of the sources of methyl mercury and water in the lower Sacramento River at Freeport. Charts do not include months when river water was diverted down the Fremont Weir. These were February and March 2004 and January through June 2006. The charts summarize 24 months of data. The methyl mercury budget underestimates the average load observed at Freeport by 5 percent while the water budget overestimates flows by 2 percent.

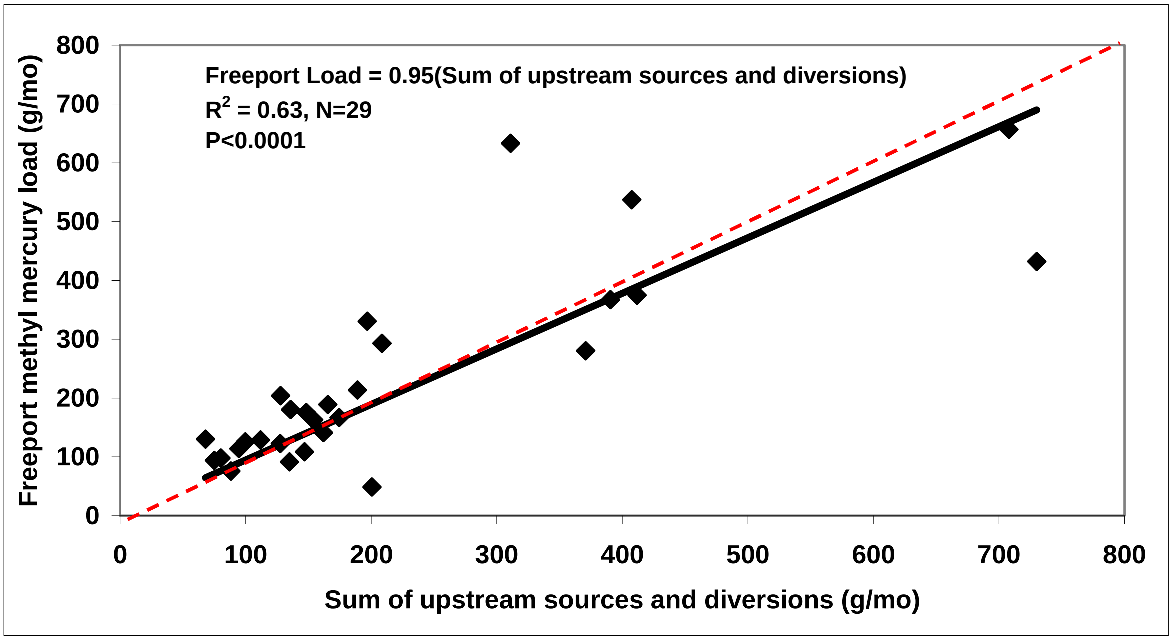


Figure 20. Methyl mercury loads for the Sacramento River at Freeport as a function of the sum of upstream sources and diversions downstream of Colusa. The regression does not include data from three storm events (February 2004, March 2005, and December 2005). The dashed line has a 1:1 slope with zero intercept.

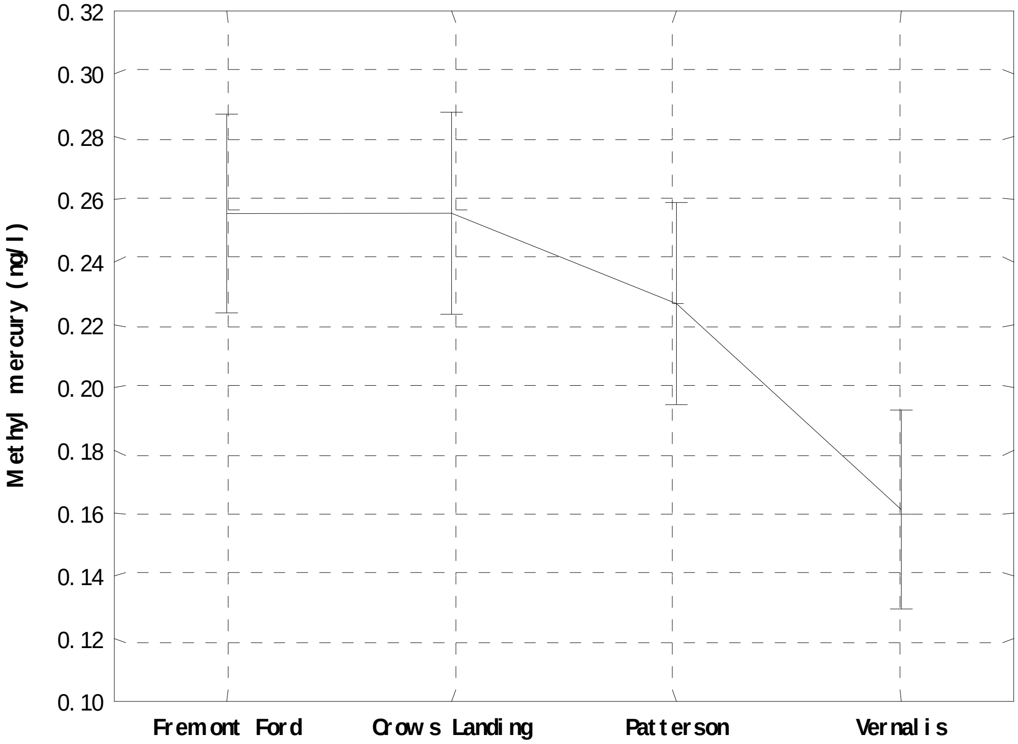
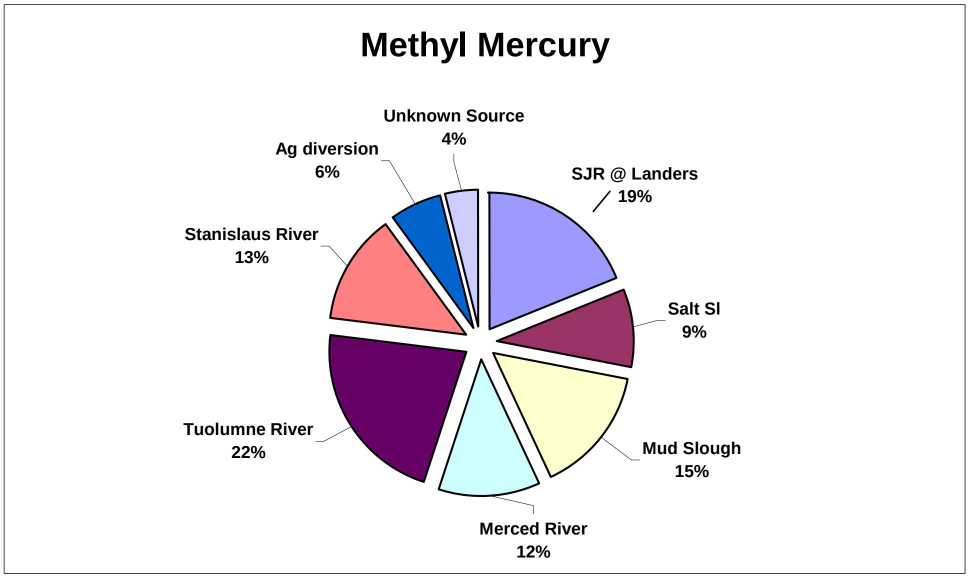


Figure 21. Mean and 95 percent confidence limits for monthly methyl mercury concentrations in the San Joaquin River between April 2003 and June 2006 (n=33). Fremont Ford is 55- river miles upstream of Vernalis. The graph does not include data for flooding events (June 2005, April, May and June 2006).



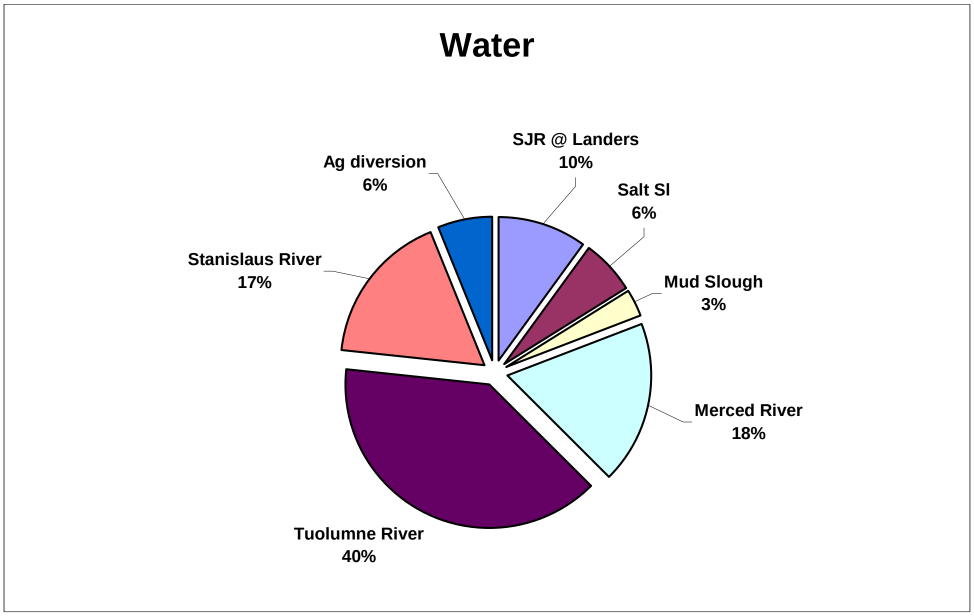


Figure 22. Comparison of methyl mercury and water mass balances for the San Joaquin River at Vernalis between April 2003 and June 2005. The mass balance calculations do not include storm events with upstream flooding.

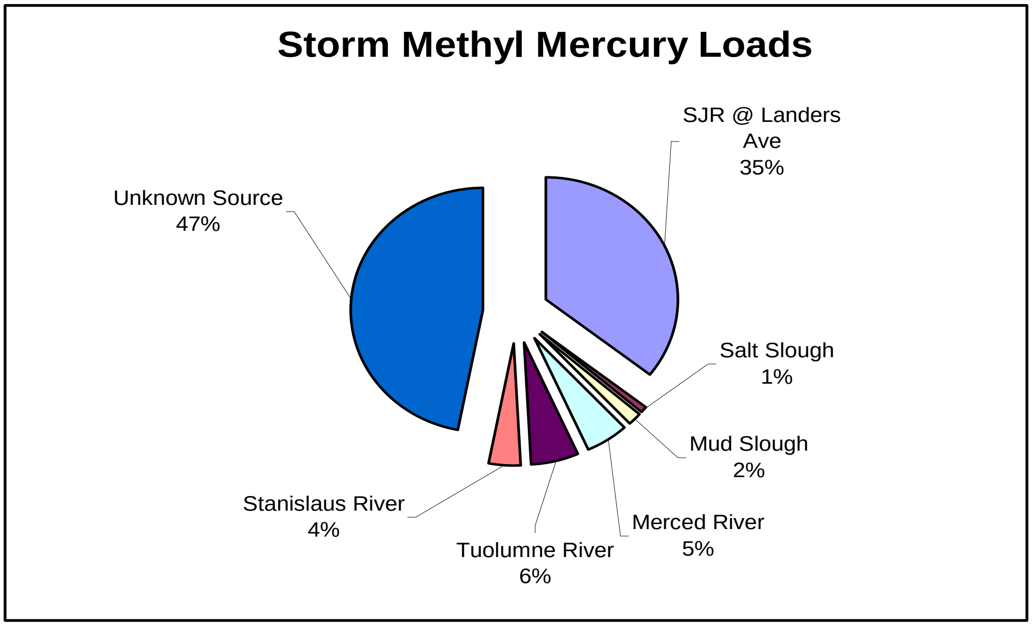


Figure 23. Methyl mercury loads during storms in the San Joaquin Basin as a percent of the Vernalis load. The four storm events were in June 2005 and April to June 2006.

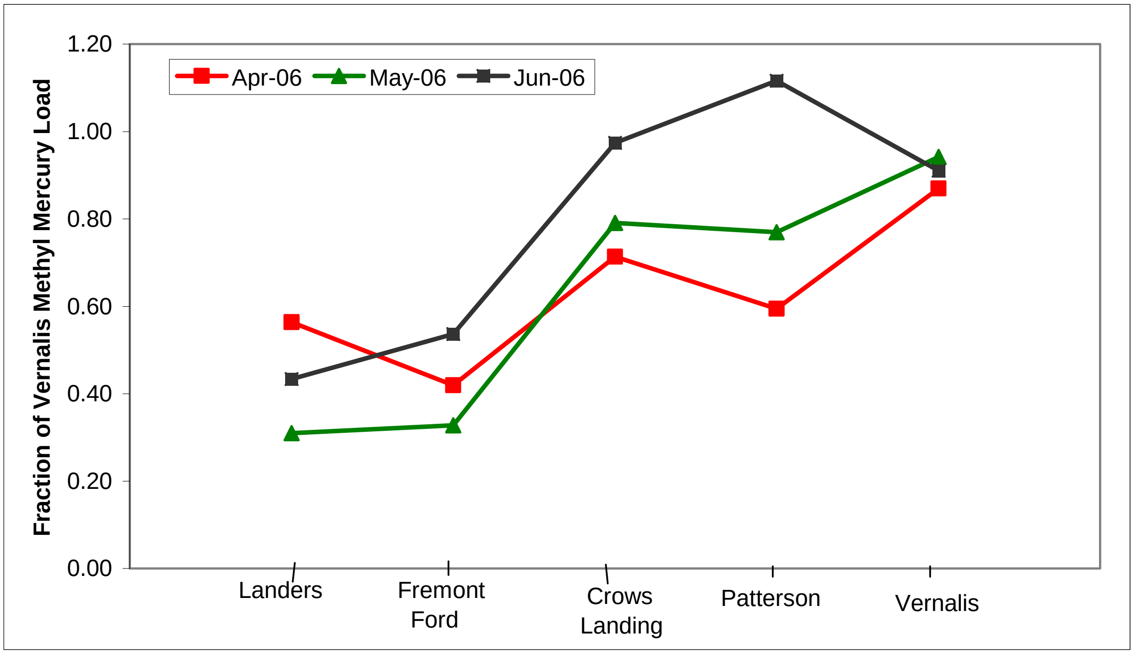


Figure 24. The fraction of the San Joaquin River at Vernalis methyl mercury load (g/mo) measured at each river site that could not be accounted for after subtracting all measured upstream tributary inputs and diversions. The results suggest that the majority of the methyl mercury during flooding is produced upstream of Lander Avenue and between Fremont Ford and Crows Landing. This corresponds to river reaches with the most extensive flooding.

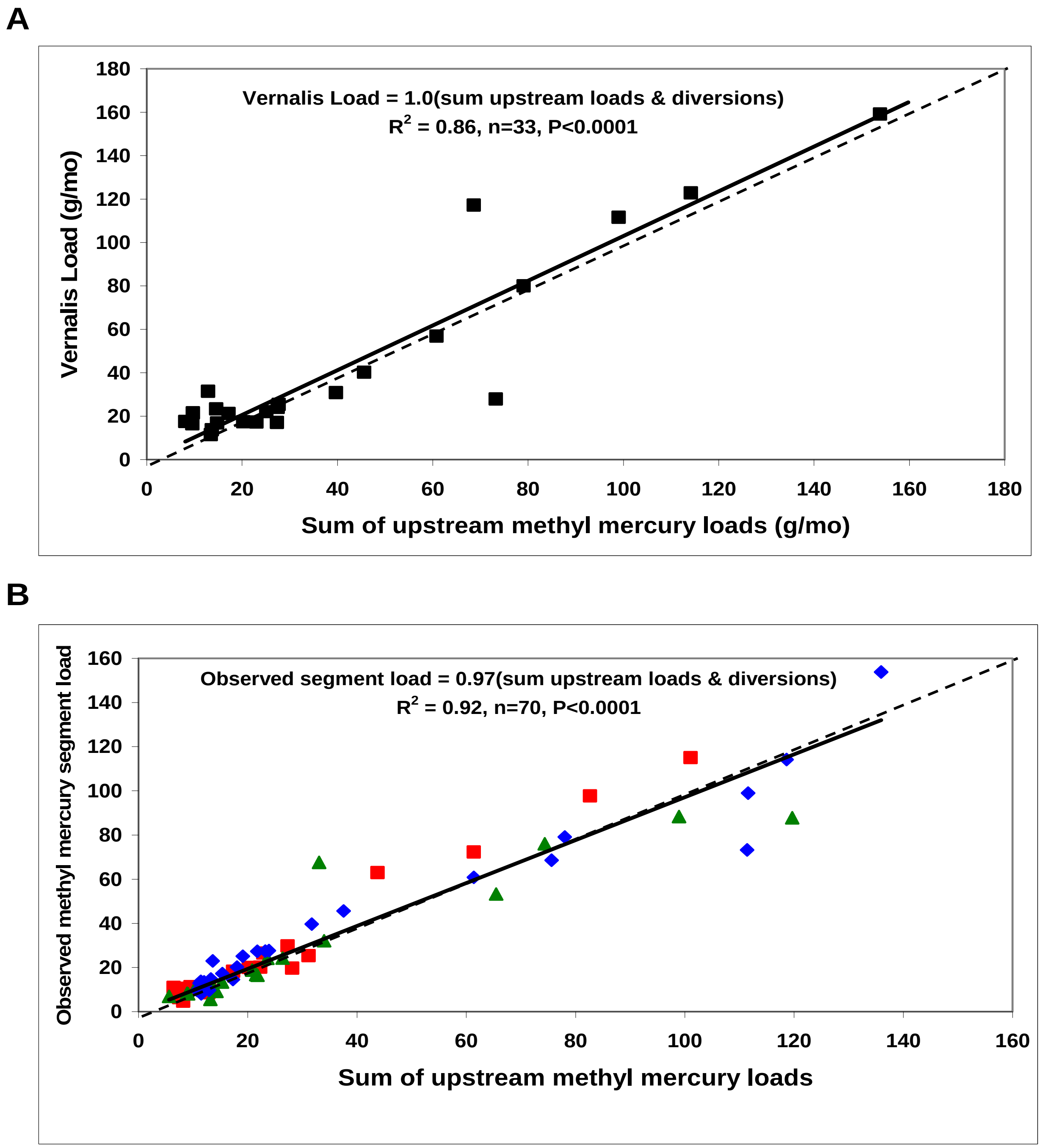


Figure 25 (A) Sum of upstream monthly methyl mercury loads and diversions between Fremont Ford and Vernalis as a function of the downstream load at Vernalis. (B) Sum of upstream monthly methyl mercury loads and diversions as a function of the downstream load at Crows Landing (squares), Patterson (triangles) and Vernalis (diamonds). The two regressions imply that all the major sources and sinks of methyl mercury have been identified in the San Joaquin Basin and that methyl mercury is being transported in a conservative fashion down river. A 1:1 dashed regression line has been added for comparison.

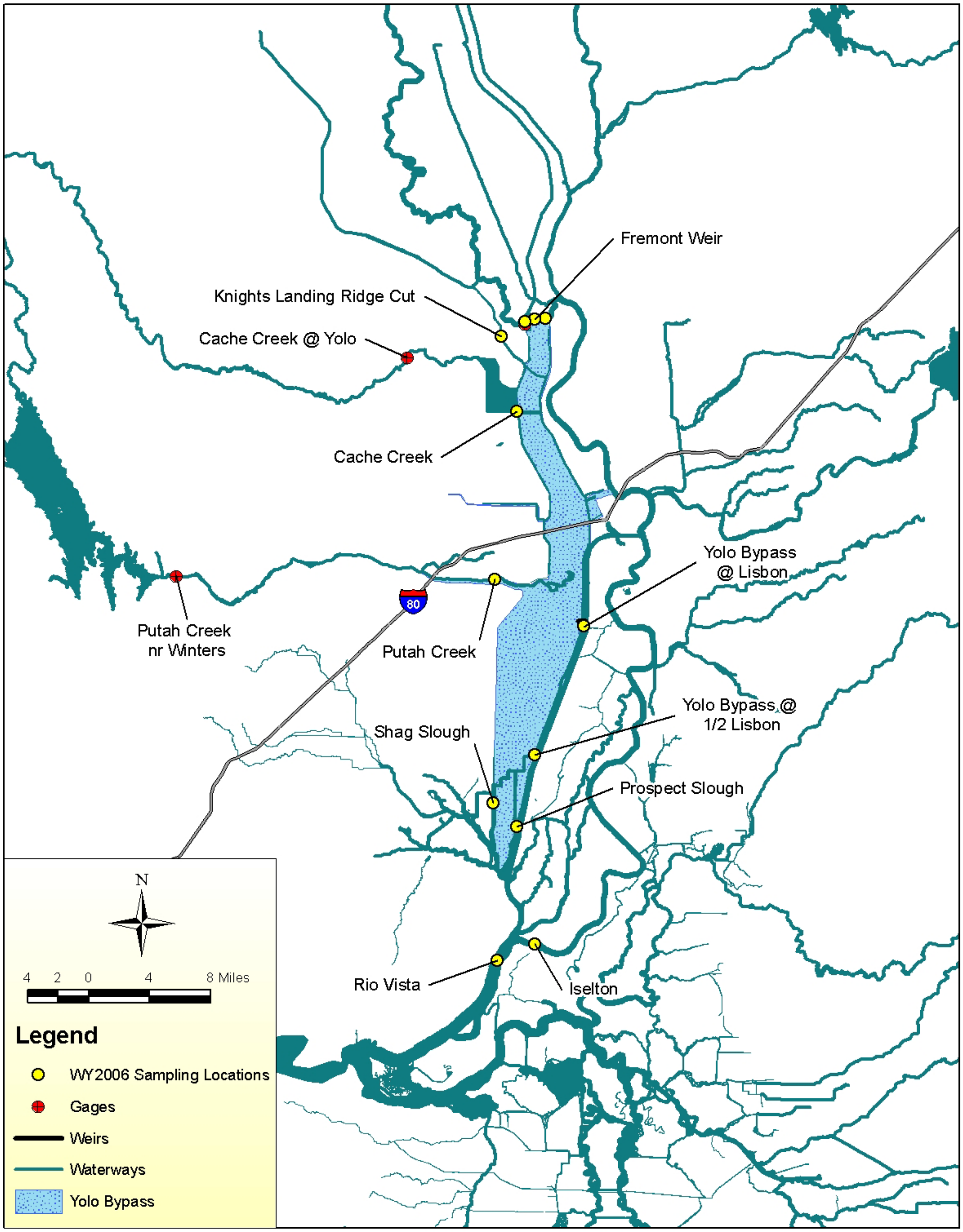


Figure 26. Map of the sampling sites in the Yolo Bypass.

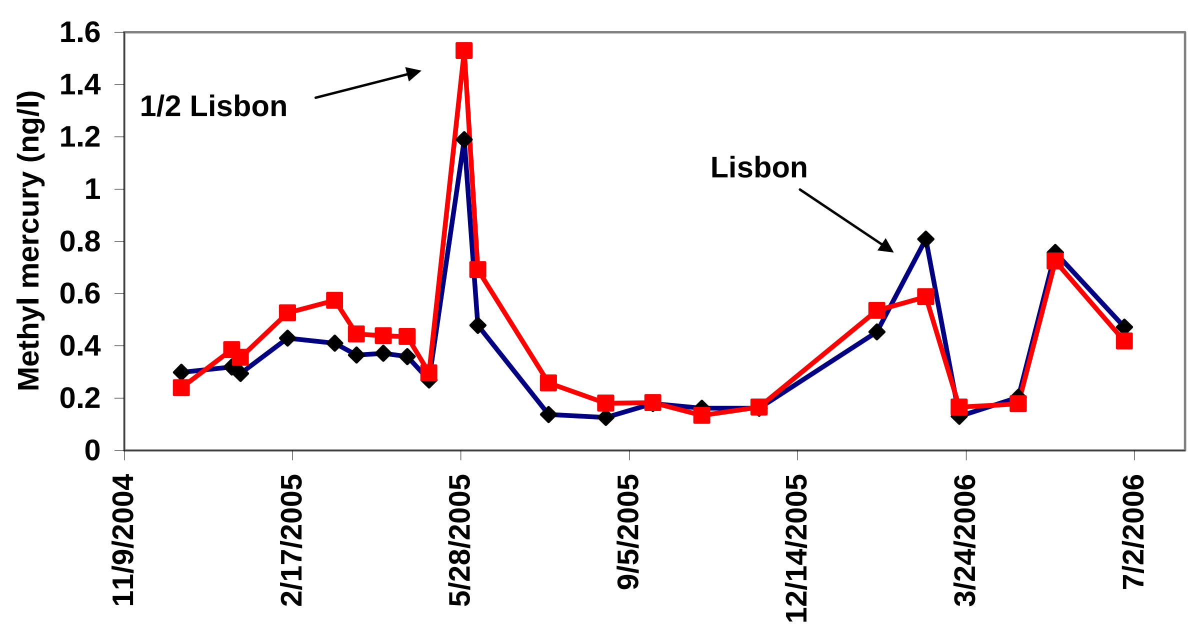


Figure 27 Comparison of methyl mercury concentrations (ng/l) at Lisbon (diamonds) and ½ Lisbon (squares). Elevated concentrations in May 2005 and for several months in 2006 coincide with flood water being spilled over the Fremont Weir.

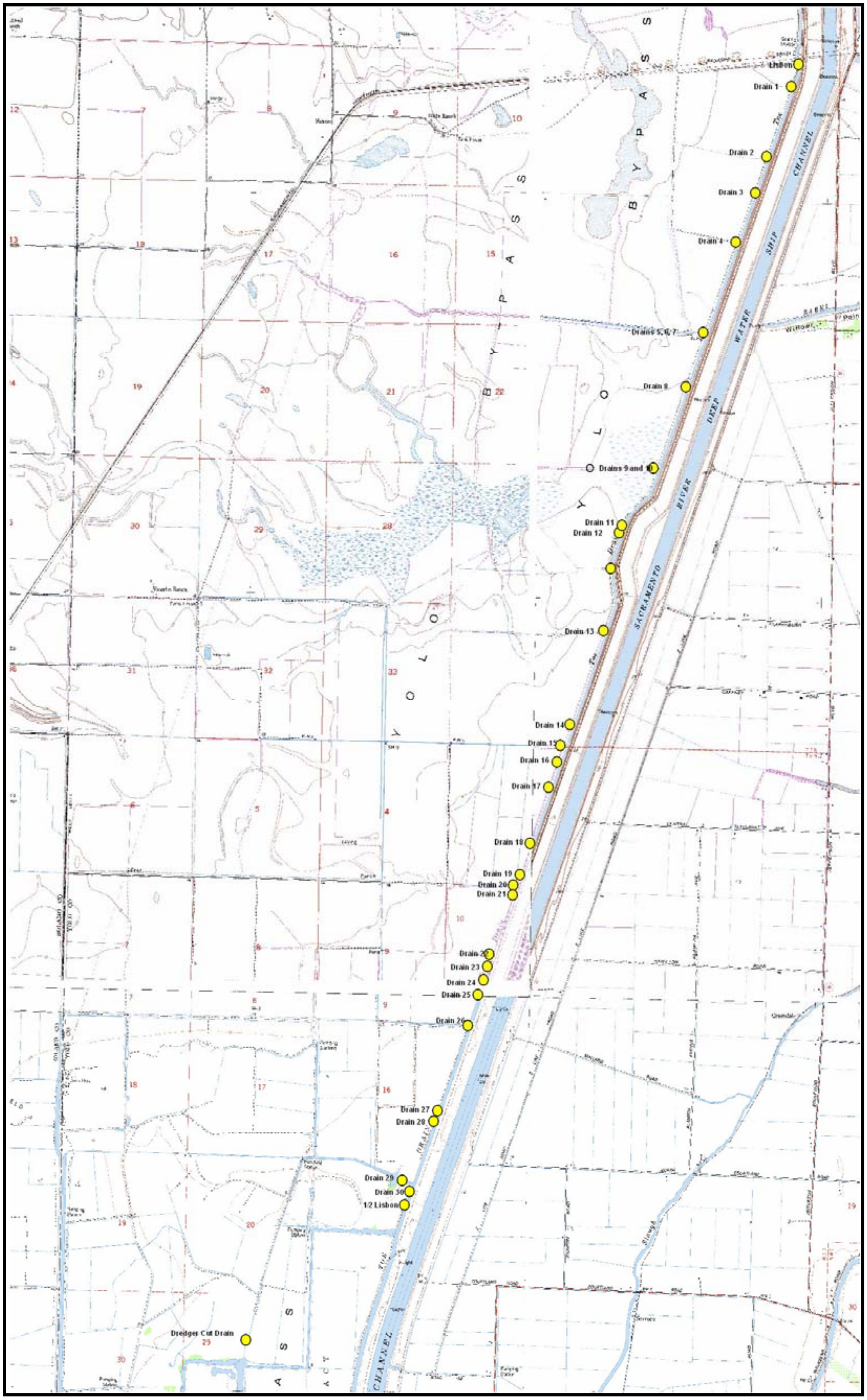


Figure 28. Map of the Toe Drain between Lisbon and ½ Lisbon in the Yolo Bypass. Dots are constructed drains.

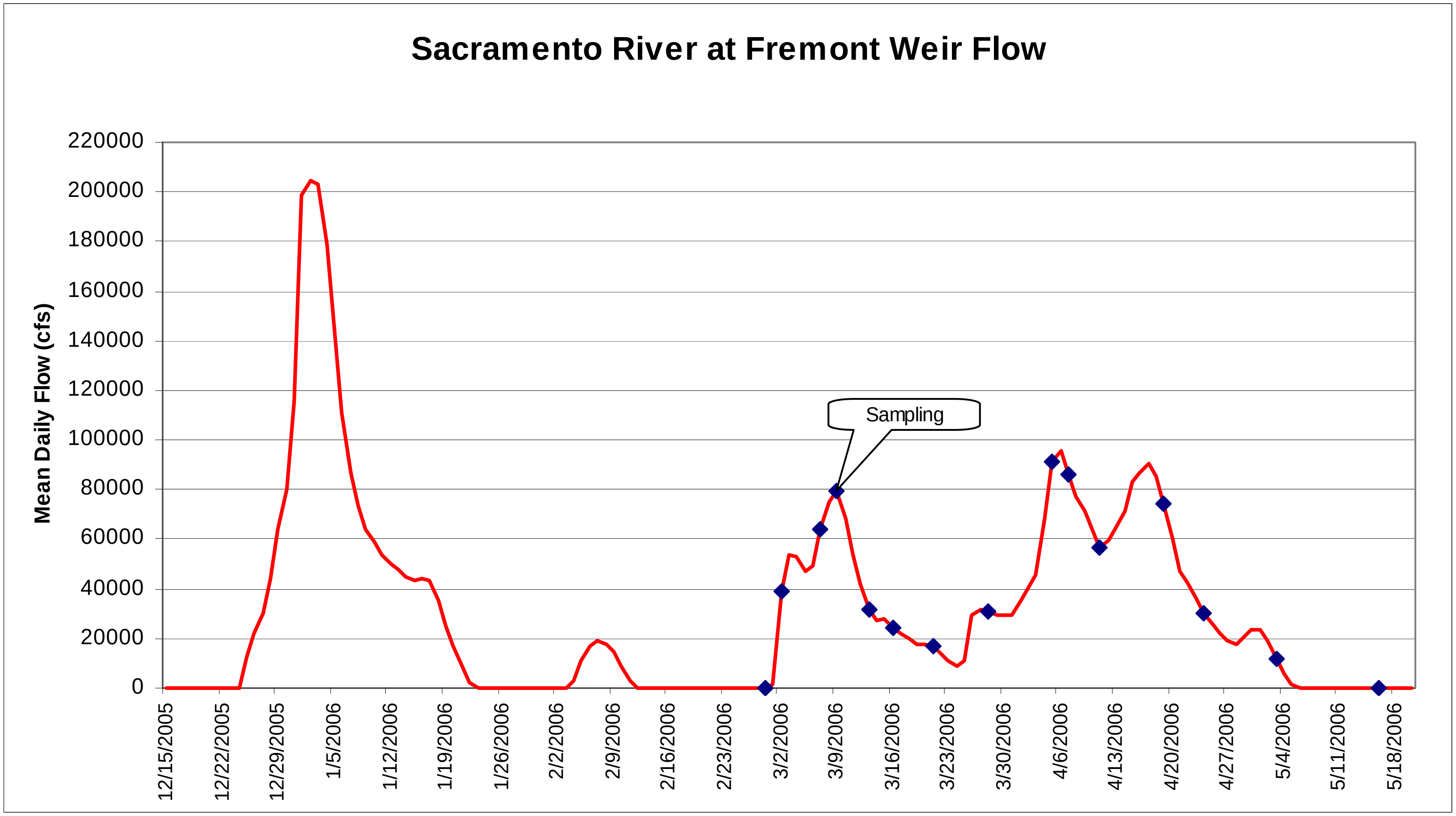


Figure 29. Mean daily flows over the Fremont Weir and into the Yolo Bypass from the Sacramento River between December 2005 and May 2006

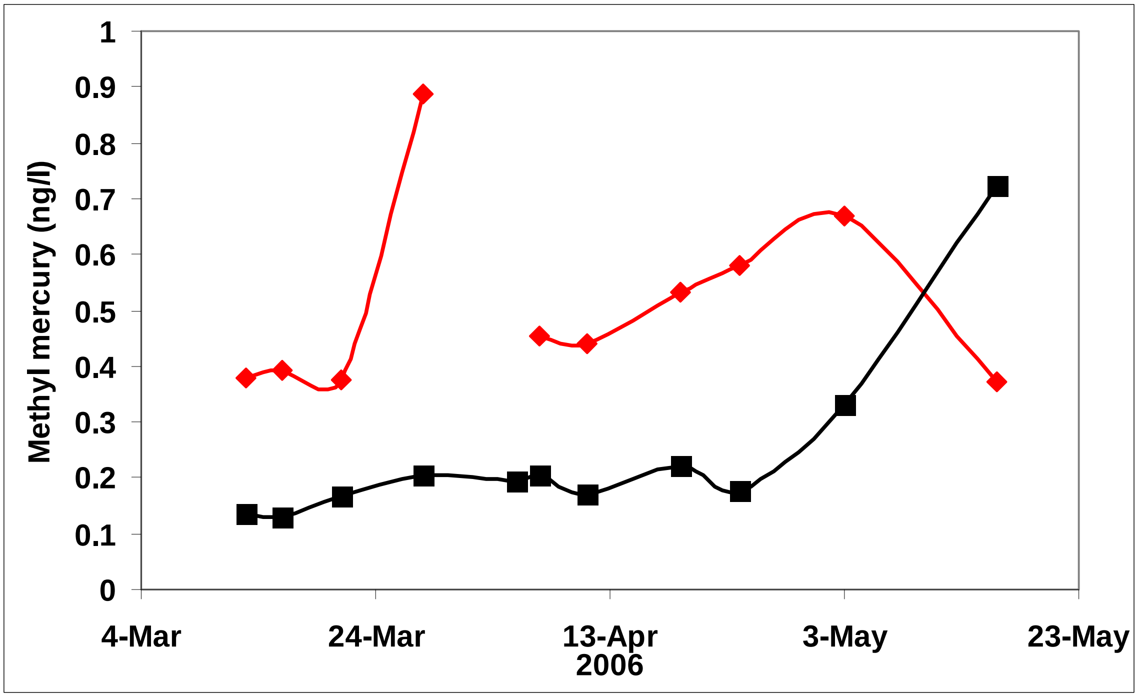


Figure 30. Comparison of methyl mercury concentrations in Shag Slough (diamonds) and the Toe Drain at ½ Lisbon (squares) during flood flow in 2005 and 2006.

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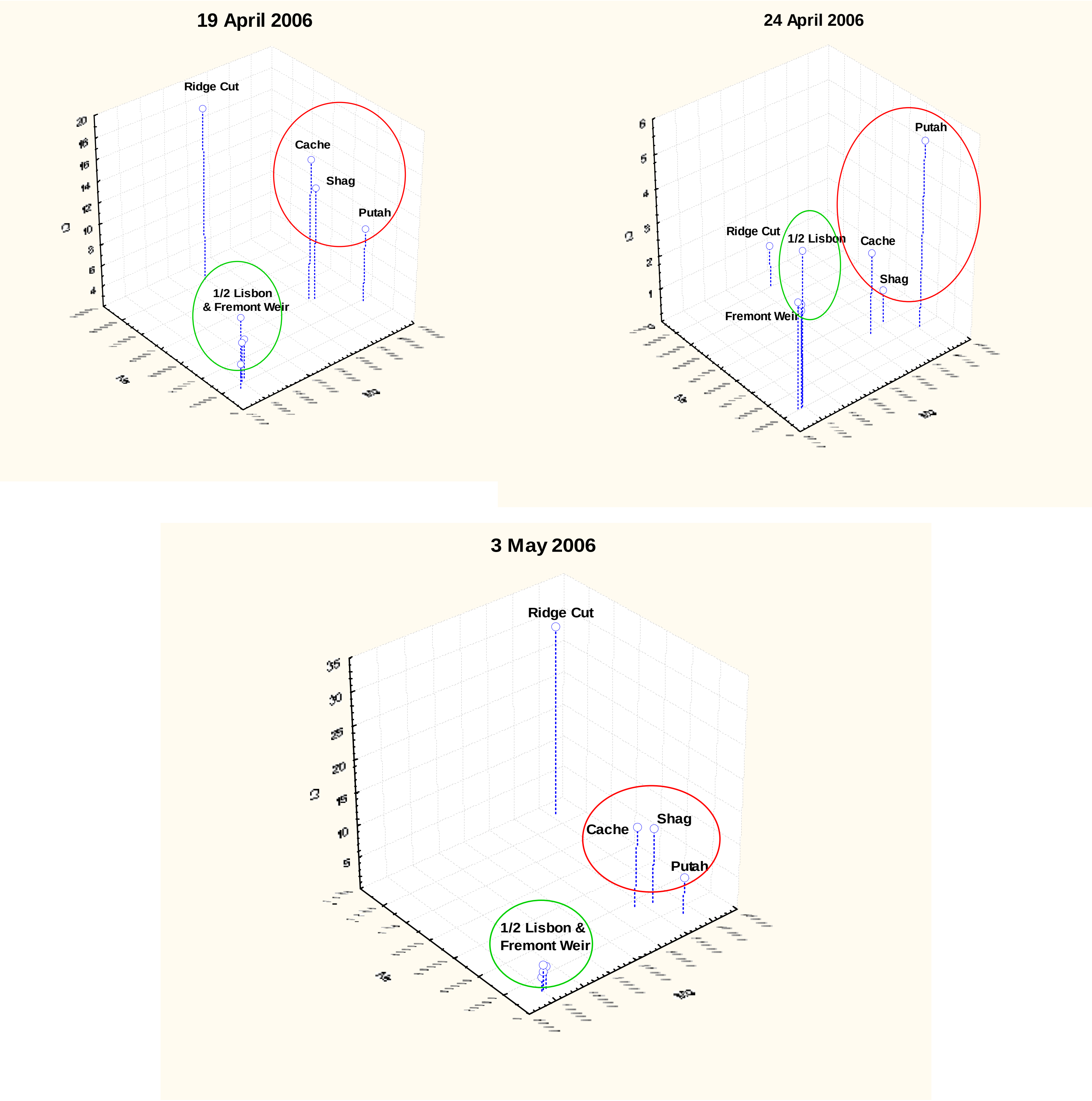

Figure 31. Comparison of sodium, chlorine, and magnesium concentrations (mg/l) in all major water source and export channels in the Yolo Bypass. Water quality in Shag Slough resembles Putah and Cache Creeks while the Toe Drain is similar to Fremont Weir.

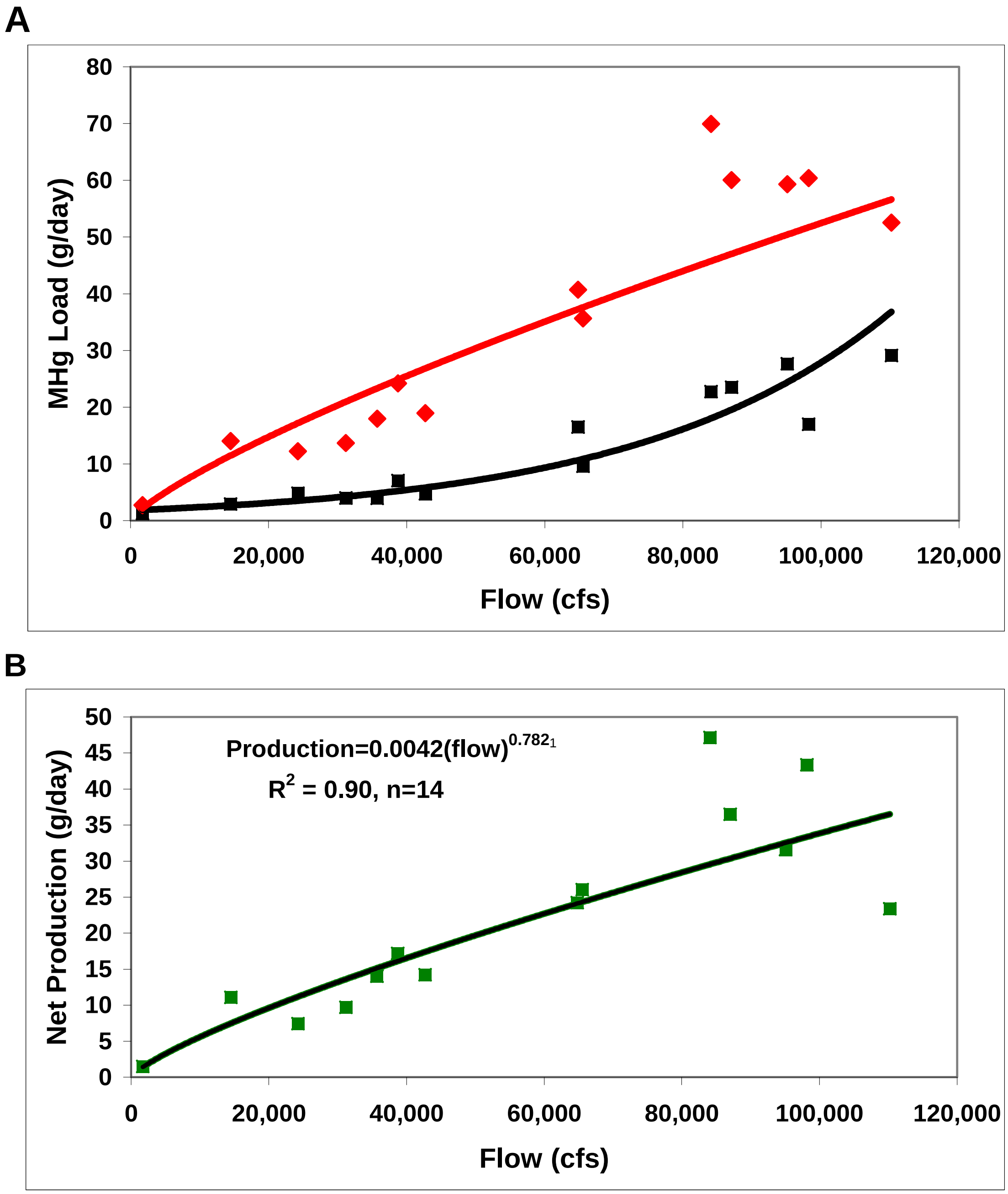

Figure 32. (A) Sum of methyl mercury loads (g/day) entering (squares) and leaving (diamonds) the Yolo Bypass as a function of flow. (B) Net production as a function of flow.

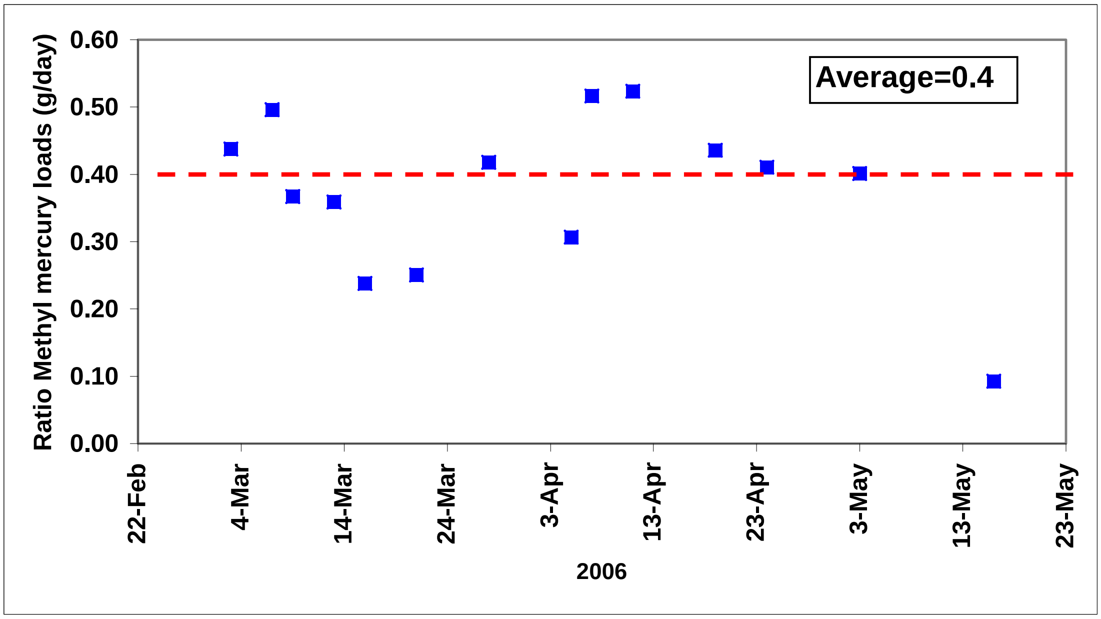

Figure 33. Ratio of *in situ* methyl mercury production in the Yolo Bypass to production for the entire Sacramento watershed, including the Bypass, on individual high flow days in 2006.

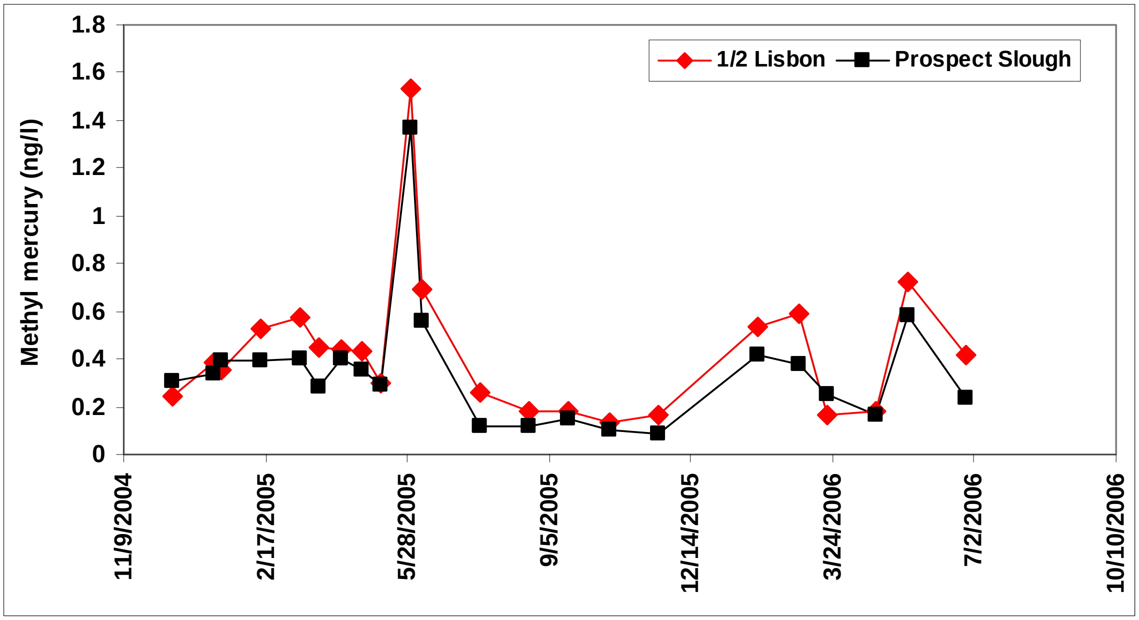

Figure 34. Methyl mercury concentrations at ½ Lisbon and 5 miles downstream at Prospect Slough. Average methyl mercury concentrations decrease 20 percent between the two monitoring locations.

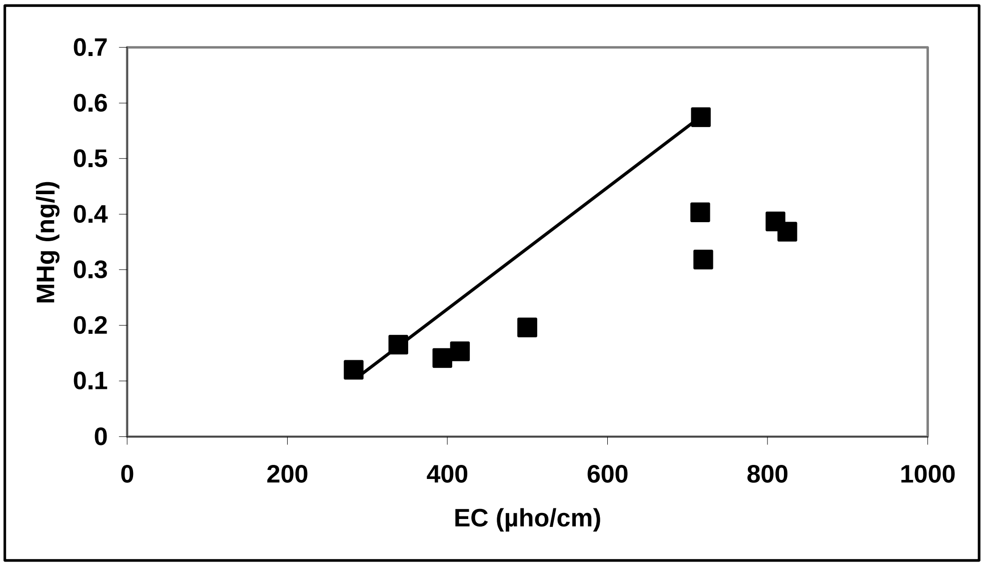

Figure 35. Ratio of electrical conductivity (EC) to methyl mercury (MHg) in a transect of sites located between ½ Lisbon and Rio Vista on 14 March 2005. The line connects Rio Vista (lower left) and ½ Lisbon (upper right), the two main water sources.

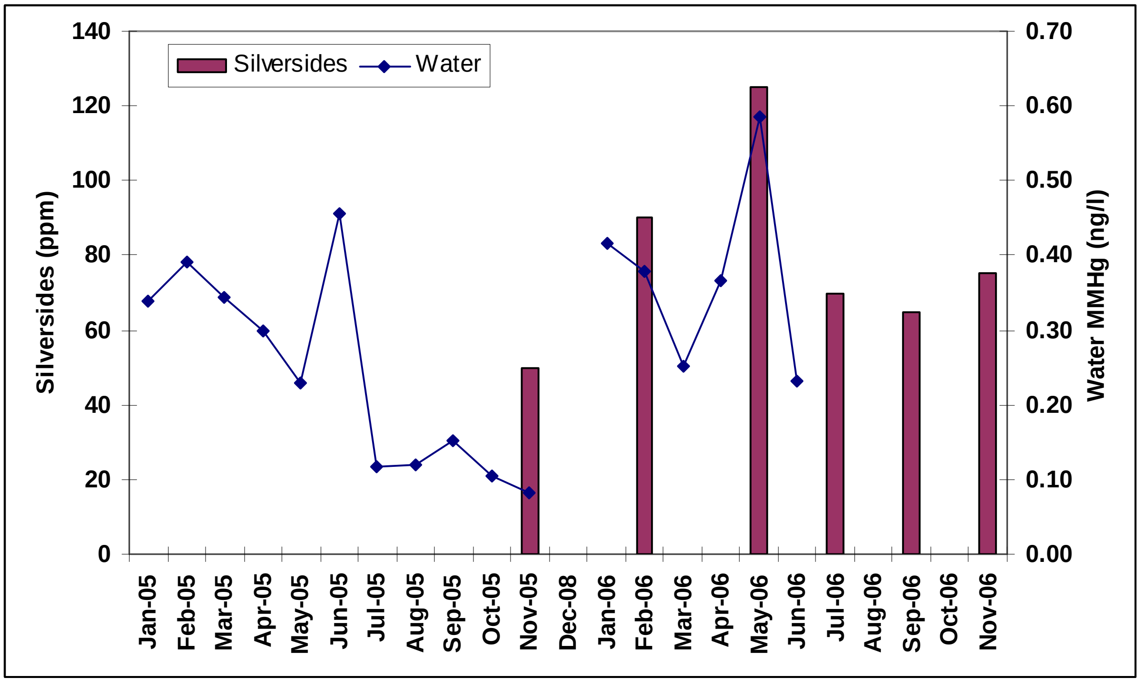

Figure 36 Methyl mercury concentrations in juvenile silversides and water in the Yolo Bypass at Prospect Slough. Fish data is from Slotton *et al*. (2007)

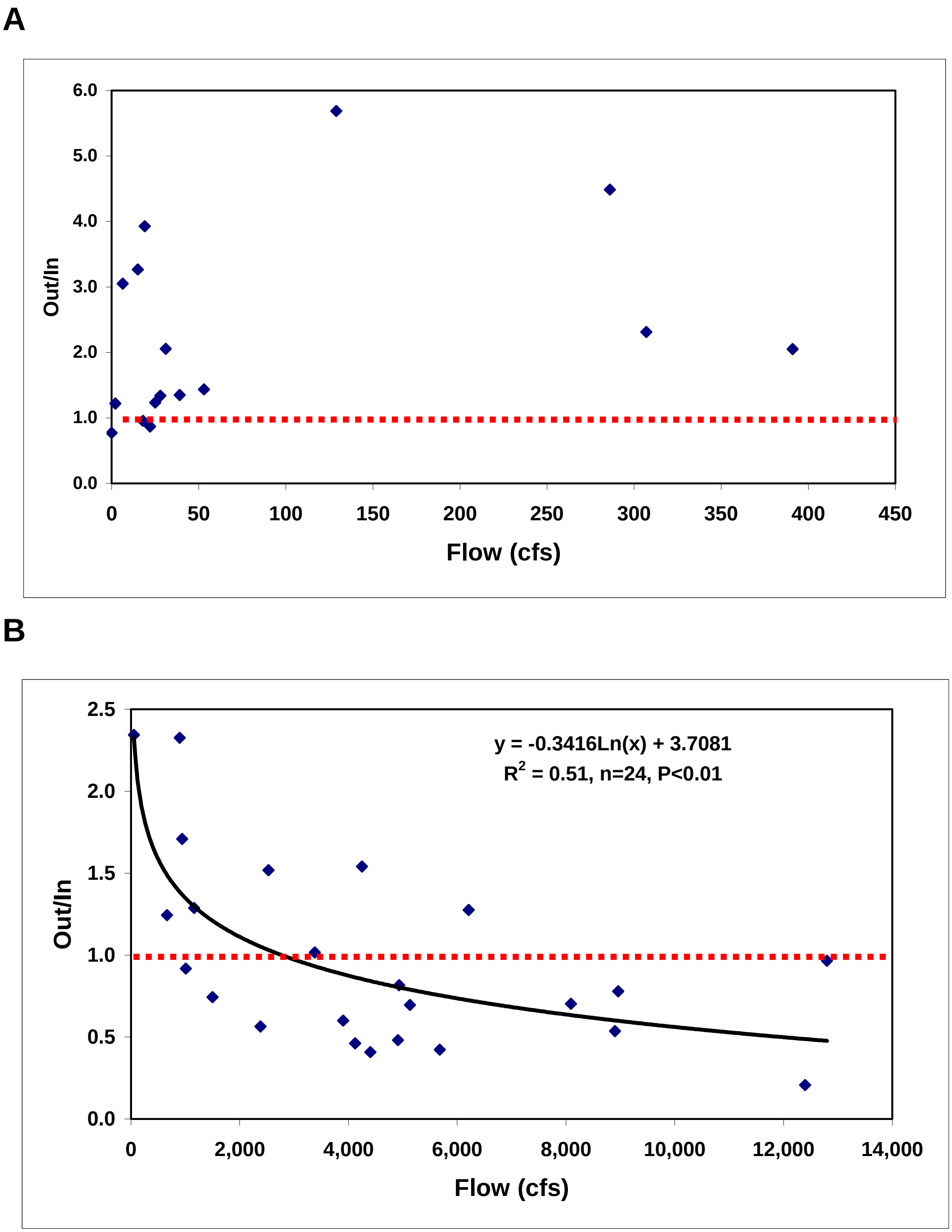

Figure 37. A. Ratio of unfiltered methyl mercury concentrations leaving to entering (Out/In) the Cache Creek Settling Basin as a function of discharge at the low flow weir. The ratio is positive indicating net production in the Basin and no apparent relationship with flow. B. The same ratio during discharge over the high flow weir. The concentration decreases as a function of increasing flow with an inflection point at about 2,800-cfs.

Table 1. Monthly water budget for the Delta (thousand acre-feet per month) for the first (March 2000-October 2001) and second (April 2003-June 2006) CALFED study periods.

Date	Water Sources						Water Exports				Inputs Minus Exports
	Sacramento River @ Freeport	San Joaquin River @ Vernalis	Prospect Slough	Cosumnes River @ I-5	Mokelumne River @ I-5	Total Inputs	Mallard Island	Delta Mendota Canal	State Water Project	Total Exports	
Mar-00	3,600.8	743.9	1,368.1	78.4	105.0	5,896.2	5400.3	207.8	341.5	5949.7	-53.5
Apr-00	1,585.2	298.3	32.9	39.3	22.8	1,978.4	1620.5	131.3	181.4	1933.2	45.3
May-00	1,257.3	296.0	28.4	32.4	28.4	1,642.5	1356.2	77.6	105.3	1539.2	103.3
Jun-00	957.2	165.0	39.6	8.7	27.1	1,197.6	525.0	181.2	260.7	966.9	230.6
Jul-00	1,281.9	116.7	38.8	3.3	17.9	1,458.6	561.0	265.5	359.8	1186.3	272.3
Aug-00	1,088.1	133.5	32.1	1.5	5.5	1,260.6	370.4	269.7	386.5	1026.6	234.0
Sep-00	902.3	138.6	19.3	2.0	8.9	1,071.2	275.0	252.9	387.0	914.9	156.3
Oct-00	718.4	173.8	8.2	3.3	12.2	915.9	352.0	258.7	310.5	921.2	-5.3
Dec-00	840.6	137.6	2.7	4.6	17.2	1,002.7	368.7	240.4	294.6	903.7	98.9
Jan-01	1,057.0	150.1	14.8	8.6	17.6	1,248.2	935.3	168.3	241.6	1345.2	-97.0
Feb-01	1,158.9	171.7	48.4	19.5	16.5	1,415.0	1086.7	195.5	262.9	1545.1	-130.1
Mar-01	1,518.5	210.9	118.1	28.2	15.8	1,891.6	1439.1	115.8	361.6	1916.4	-24.8
Apr-01	732.3	179.0	16.8	27.7	10.3	966.1	723.4	129.6	102.6	955.6	10.5
May-01	557.1	216.9	34.7	16.5	10.2	835.3	591.0	52.7	36.5	680.2	155.1
Jun-01	736.9	92.2	35.2	2.7	2.3	869.3	440.6	178.3	16.0	635.0	234.3
Jul-01	918.3	86.1	32.9	0.9	2.5	1,040.8	285.6	254.3	226.8	766.7	274.1
Aug-01	812.8	81.8	30.5	0.4	2.5	927.9	193.8	254.0	250.7	698.5	229.4
Oct-01	514.7	123.1	10.4	0.6	5.9	654.7	261.9	222.9	60.5	545.2	109.5
Apr-03	1,284.5	158.7	79.5	60.8	10.3	1,593.8	1310.8	113.0	153.4	1577.2	16.6
May-03	2,492.6	161.4	112.1	66.5	18.6	2,851.3	2574.9	90.1	60.5	2725.4	125.8
Jun-03	1,325.6	121.0	33.4	12.5	50.6	1,543.0	697.3	262.6	355.0	1314.8	228.2
Jul-03	1,379.1	81.2	37.3	2.3	37.7	1,537.6	592.2	258.2	412.3	1262.7	274.8
Sep-03	913.2	77.9	23.3	0.5	6.2	1,021.1	205.1	253.9	403.6	862.6	158.4
Jul-04	1,256.9	70.5	36.7	0.9	2.9	1,367.9	449.9	269.0	389.9	1108.8	259.1
Oct-04	775.1	107.8	7.1	2.8	8.1	900.9	523.1	267.5	174.8	965.4	-64.5
Nov-04	728.9	97.1	1.5	4.3	13.0	844.9	399.1	255.5	227.6	882.2	-37.3
Dec-04	1,091.1	97.0	16.6	17.2	12.8	1,234.7	765.5	233.3	259.8	1258.6	-23.8
Jan-05	2,070.9	302.4	214.4	71.9	14.8	2,674.4	2065.3	259.3	479.6	2804.3	-129.9
Feb-05	1,381.5	294.5	62.8	47.2	31.5	1,817.5	1384.1	216.0	274.2	1874.3	-56.8
Mar-05	1,867.2	495.9	122.4	121.3	71.1	2,677.9	2370.1	207.6	222.3	2800.1	-122.1
Apr-05	1,317.0	598.7	65.1	84.2	85.5	2,150.5	1777.7	126.2	230.1	2134.1	16.4
May-05	2,473.0	640.2	98.0	97.7	104.7	3,413.5	3131.5	65.9	117.7	3315.1	98.4
Jun-05	1,705.0	593.8	30.9	31.1	102.6	2,463.3	1656.5	247.9	333.2	2237.6	225.7
Jul-05	1,209.3	255.5	36.8	7.3	55.8	1,564.7	576.6	269.0	440.4	1286.0	278.7
Aug-05	1,060.4	160.8	32.0	2.5	40.9	1,296.6	343.5	271.0	439.4	1053.9	242.6
Sep-05	1,067.1	143.5	19.4	1.6	34.1	1,265.7	410.4	259.5	425.4	1095.4	170.4
Oct-05	865.4	161.0	10.0	1.8	15.2	1,053.5	292.9	267.0	387.6	947.5	106.0
Nov-05	796.6	121.3	3.8	2.4	16.4	940.5	312.3	255.1	314.0	881.4	59.1
Jan-06	4,067.5	809.9	4,663.9	109.0	180.2	9,830.5	9608.4	240.9	195.8	10045.0	-214.6
Feb-06	2,717.0	358.6	306.7	61.1	72.3	3,515.7	3070.0	240.0	272.2	3582.2	-66.5
Mar-06	4,145.1	719.7	2,655.4	158.4	51.1	7,729.7	7631.9	200.6	163.7	7996.1	-266.4
Apr-06	4,620.3	1,662.3	3,979.7	312.7	248.7	10,823.6	10891.1	48.6	161.4	11101.1	-277.4
May-06	3,206.3	1,602.0	209.4	96.2	237.9	5,351.7	5042.2	110.8	126.7	5279.8	72.0
Jun-06	1,619.1	933.6	63.6	24.3	132.8	2,773.3	2207.9	200.1	218.0	2626.0	147.4
Jul-06	1,142.9	341.1	70.5	7.3	61.7	1,623.4	740.5	270.9	421.9	1433.4	190.0
Sum	**68,817.0**	**14,682.6**	**14,903.6**	**1,684.3**	**2,046.1**	**102,133.5**	**77,817.4**	**9,215.8**	**11,847.3**	**98,880.6**	**3,253.0**

Table 2. Unfiltered monthly methyl mercury concentrations (ng/l) in the Delta for the first (March 2000-October 2001) and second (April 2003-November 2006) CALFED study periods.

	MMHg Inputs					MMHg Exports			Within Delta Monitoring Sites				
Date	Sac R Freeport	Prospect Slough	SJR. Vernalis	Cosumnes River	Mokelumne River	DMC	SWP	Mallard Is	Sac R. Rio Vista	Sac R. Collinsville	Port Chicago	Middle R Bullfrog	Old R Tracy
Mar-00	0.15	0.70	0.16		0.1710	0.15	0.14	0.20					
Apr-00	0.12	0.40	0.15		0.2800	0.01	0.05	0.08					
May-00	0.34	0.33	0.13		0.2500	0.17	0.14	0.24					
Jun-00	0.07	0.24	0.22		0.1140	0.07	0.01	0.11					
Jul-00	0.05		0.12		0.0110	0.01	0.01	0.01					
Aug-00	0.11	0.21	0.14		0.1540	0.01	0.01	0.01					
Sep-00	0.05	0.11	0.10		0.0110	0.01	0.06	0.02					
Oct-00	0.09	0.14	0.16		0.1300	0.01	0.01	0.01					
Nov-00													
Dec-00	0.09	0.27	0.10		0.0955	0.06	0.05	0.06					
Jan-01	0.24	0.41	0.24		0.2460	0.14	0.11	0.09					
Feb-01	0.18	0.41	0.18		0.3200		0.08	0.17					
Mar-01	0.08	0.33	0.18		0.1850	0.09	0.06	0.07					
Apr-01	0.11	0.14	0.09		0.2010	0.02	0.06	0.01					
May-01	0.10	0.23	0.12		0.1780	0.06	0.05	0.04					
Jun-01	0.09	0.21	0.26		0.2080	0.06		0.04					
Jul-01	0.11	0.27	0.15		0.1670	0.06	0.02	0.07					
Aug-01	0.07		0.19			0.03	0.01	0.05					
Sep-01		0.14			0.0650								
Oct-01	0.10	0.12	0.16		0.1840	0.01	0.03	0.01					
Jan-02				0.07									
Apr-03	0.13	0.20	0.11					0.09					
May-03	0.09	0.21	0.13	0.27	0.11	0.06		0.08					
Jun-03	0.04	0.21	0.15		0.07	0.08	0.03	0.09					
Jul-03	0.05	0.18	0.20		0.01	0.09	0.03	0.07					
Sep-03	0.07	0.17	0.16			0.09	0.06	0.10				0.05	0.07
Feb-04	0.18		0.17	0.53	0.11								
Mar-04	0.12		0.17										
Apr-04	0.10		0.14										
May-04	0.11		0.14										
Jun-04	0.12		0.18										
Jul-04	0.11	0.18	0.19			0.13	0.08	0.07				0.08	0.23
Aug-04	0.10		0.22										
Sep-04			0.15										
Oct-04	0.10	0.12	0.14			0.12	0.05	0.06	0.04			0.05	0.07
Nov-04	0.13	0.23	0.21	0.23	0.05	0.10	0.06	0.05	0.10			0.09	0.14
Dec-04	0.13	0.31	0.14	0.47		0.10	0.07	0.04	0.10			0.09	0.07

Table 2. (continued)

	MMHg Inputs					MMHg Exports			Within Delta Monitoring Sites				
Date	**Sac R Freeport**	**Prospect Slough**	**SJR. Vernalis**	**Cosumnes River**	**Mokelumne River**	**DMC**	**SWP**	**Mallard Is**	**Sac R. Rio Vista**	**Sac R. Collinsville**	**Port Chicago**	**Middle R Bullfrog**	**Old R Tracy**
Jan-05	0.13	0.34	0.25	0.31	0.01	0.16	0.12	0.05	0.17			0.14	0.19
Feb-05	0.14	0.39	0.19	0.22	0.08	0.19	0.16	0.11	0.13			0.19	0.10
Mar-05	0.10	0.34	0.19	0.32	0.05	0.13	0.10	0.13	0.13			0.14	0.15
Apr-05	0.09	0.30	0.16	0.30	0.05	0.06	0.02	0.10	0.08		0.10	0.06	0.11
May-05	0.16	0.23	0.20	0.39	0.03	0.07	0.06	0.15	0.12			0.12	0.12
Jun-05	0.09	0.46	0.57	0.48	0.07	0.26	0.14	0.16	0.13		0.16	0.09	0.36
Jul-05	0.08	0.12	0.18		0.08	0.10	0.06	0.10	0.09			0.08	0.15
Aug-05	0.07	0.12	0.15		0.05	0.09	0.08	0.05	0.09	0.06	0.09	0.04	0.12
Sep-05	0.10	0.15	0.10		0.06	0.06	0.07	0.04	0.07	0.07	0.03	0.06	0.13
Oct-05	0.08	0.10	0.12		0.08	0.05	0.03	0.03	0.07	0.04	0.03	0.05	0.09
Nov-05	0.10	0.08	0.10	0.09	0.10	0.05	0.04	0.02	0.08	0.04	0.02	0.03	0.06
Dec-05	0.14		0.10	0.86									
Jan-06	0.13	0.42	0.12	0.30	0.06	0.11	0.09	0.15	0.15	0.24	0.16	0.11	0.13
Feb-06	0.11	0.38	0.12	0.24	0.06	0.11	0.17	0.17	0.13	0.14	0.19	0.13	0.09
Mar-06	0.10	0.25	0.12	0.26	0.03	0.09	0.05	0.12	0.11	0.18	0.12	0.07	0.08
Apr-06	0.12	0.37	0.24	0.30	0.08	0.24	0.16	0.21	0.12	0.16	0.17	0.23	0.38
May-06	0.09	0.58	0.75	1.04	0.11	0.52	0.18	0.18	0.10	0.13	0.17	0.51	0.74
Jun-06	0.09	0.23	0.37	0.52	0.10	0.21	0.16	0.15	0.09	0.13	0.15	0.15	0.26
Aug-06	0.09		0.17					0.08					
Sep-06	0.12		0.12					0.07					
Oct-06	0.06		0.13					0.05					
Nov-06	0.16		0.17					0.05					
mean	**0.11**	**0.26**	**0.18**	**0.38**	**0.11**	**0.10**	**0.07**	**0.09**	**0.11**	**0.12**	**0.12**	**0.12**	**0.17**
95%CL	**0.01**	**0.04**	**0.03**	**0.12**	**0.01**			**0.02**	**0.01**	**0.05**	**0.04**	**0.05**	**0.07**
N	**55**	**43**	**56**	**19**	**22**	**42**	**41**	**48**	**20**	**10**	**12**	**22**	**22**

Table 3. Mean filter-passing methyl mercury concentrations (ng/l) in source and export water from the Delta.

		Filtered MMHg (ng/l)				
Nature of Site	**Location**	**Mean**	**95% CL[1/]**	**n**	**r[2,3/]**	**Average filtered to unfiltered MHg (%)**
Source	Freeport	0.04	0.01	28	0.46*	41.0
Source	Vernalis	0.07	0.04	33	0.94***	33.6
Source	Prospect Slough	0.07	0.02	26	0.75***	26.3
Export	Mallard Island	0.03	0.01	24	0.47*	45.4
Export	DMC	0.05	0.03	25	0.96***	57.1
Export	SWP	0.03	0.01	23	0.89***	59.4

[1/] 95 percent confidence limits for the mean.

[2/] Pierson correlation coefficient between filtered and unfiltered methyl mercury

[3/] *= P<0.05, **=P<0.01, ***P<0.001.

Table 4. Monthly methyl mercury budget (g/mo) for the Delta. Values for the Mokelumne between March 2000 and October 2001 include the Cosumnes. Values for Mallard Island before April 2003 were for X2.

Date	Methyl Mercury Inputs						Methyl Mercury Exports				Inputs Minus Exports
	Sacramento River	San Joaquin River	Prospect Slough	Cosumnes River	Mokelumne River	Total Inputs	Mallard Island	Delta Mendota Canal	State Water Project	Total Exports	
Mar-00	657.6	150.5	1,184.4		37.8	2,030.3	1,359.5	39.2	58.6	1,457.3	573.1
Apr-00	228.9	54.1	16.1		23.8	322.9	163.8	1.8	10.5	176.1	146.8
May-00	521.3	48.9	11.7		23.1	605.0	403.3	16.4	18.7	438.4	166.6
Jun-00	84.6	44.8	11.7		7.2	148.3	70.6	16.5	3.5	90.6	57.6
Jul-00	82.3	17.0	0.0		0.5	99.8	7.6	3.6	4.9	16.1	83.7
Aug-00	147.7	23.1	8.2		4.9	183.9	5.0	3.7	5.2	13.9	170.0
Sep-00	57.2	16.9	2.7		0.3	77.1	7.9	3.4	27.7	39.1	38.0
Oct-00	75.5	33.9	1.4		2.7	113.5	4.8	3.5	4.2	12.5	101.0
Dec-00	92.4	17.3	0.9		8.2	118.8	27.1	18.6	18.2	63.9	54.9
Jan-01	318.3	44.3	7.6		15.0	385.1	109.1	29.9	33.7	172.7	212.4
Feb-01	252.4	38.1	24.7		10.5	325.8	221.3	0.0	24.9	246.2	79.6
Mar-01	157.5	46.3	47.4		9.8	261.0	124.0	13.2	24.6	161.8	99.2
Apr-01	102.1	20.6	3.0		6.2	131.9	6.2	3.8	7.4	17.5	114.4
May-01	67.8	32.7	9.8		1.7	111.9	29.8	3.6	2.3	35.7	76.2
Jun-01	79.8	29.1	9.0		1.0	119.0	20.1	13.4	0.0	33.4	85.6
Jul-01	122.4	15.6	11.1		0.3	149.4	24.7	20.2	6.0	50.9	98.5
Aug-01	71.4	19.6	5.3		1.0	97.3	12.9	9.9	2.2	25.0	72.3
Oct-01	60.5	24.8	1.6			86.9	2.3	1.9	2.4	6.6	80.3
Apr-03	204.1	22.2	19.3			245.6	150.4	0.0	0.0	150.4	95.2
May-03	280.8	25.4	29.1	21.7	2.1	359.2	241.2	6.2	0.0	247.3	111.8
Jun-03	59.9	22.7	8.5		0.7	91.7	73.7	25.5	12.4	111.6	-19.8
Jul-03	87.3	19.9	8.1		3.5	118.7	50.9	29.7	14.4	95.1	23.6
Sep-03	76.0	15.3	4.9			96.1	24.8	27.7	28.9	81.4	14.7
Jul-04	169.1	16.8	8.3			194.2	38.2	42.8	36.5	117.5	76.7
Oct-04	93.1	18.2	1.0			112.2	37.1	38.3	9.9	85.3	27.0
Nov-04	114.0	25.3	0.4	1.2	0.9	141.9	24.8	31.8	17.0	73.6	68.3
Dec-04	175.4	16.7	6.3	10.0	0.0	208.3	40.0	28.8	22.6	91.4	116.9
Jan-05	330.9	92.9	90.0	27.1	0.2	541.2	137.4	51.8	69.8	259.0	282.1
Feb-05	230.1	68.0	30.2	12.9	3.0	344.2	179.3	51.2	54.5	285.0	59.2
Mar-05	240.0	114.6	51.9	47.6	4.7	458.8	389.0	33.4	28.0	450.4	8.4
Apr-05	141.5	118.7	24.0	31.1	5.4	320.7	214.5	9.9	6.8	231.2	89.5
May-05	489.4	155.9	27.6	46.8	4.3	724.1	562.9	6.0	8.5	577.4	146.7
Jun-05	180.5	420.3	17.4	18.3	8.3	644.8	326.1	80.4	56.1	462.7	182.2
Jul-05	122.5	57.3	5.3	0.0	5.7	190.7	71.6	33.3	33.5	138.4	52.4
Aug-05	91.3	29.3	4.7	0.0	2.6	127.9	21.8	29.6	43.2	94.6	33.2
Sep-05	125.5	18.2	3.7	0.0	2.4	149.8	21.2	20.3	37.9	79.4	70.4
Oct-05	83.3	23.6	1.3	0.0	1.5	109.7	9.8	17.8	15.6	43.1	66.6
Nov-05	95.2	15.3	0.4	0.3	2.0	113.1	9.6	14.2	17.1	40.8	72.3
Jan-06	653.8	122.0	2,402.6	40.2	13.7	3,232.3	1,743.6	32.4	21.3	1,797.3	1,435.0
Feb-06	358.0	51.8	143.2	17.9	5.2	576.1	625.1	31.9	58.5	715.4	-139.4
Mar-06	533.5	102.3	821.4	51.3	2.0	1,510.6	1,100.5	21.2	10.7	1,132.3	378.3
Apr-06	656.9	487.7	1,793.9	152.7	23.9	3,115.1	2,801.5	14.5	31.1	2,847.2	268.0
May-06	366.5	1,476.7	151.2	123.5	31.5	2,149.2	1,094.9	70.5	27.8	1,193.2	956.0
Jun-06	184.0	425.1	18.2	15.5	17.0	659.8	406.7	52.3	44.2	503.2	156.6
Sum	**9,322.1**	**4,639.8**	**7,029.4**	**618.1**	**294.8**	**21,904.1**	**12,996.4**	**1,004.3**	**961.2**	**14,961.9**	**6,942.3**

Table 5. Characteristics of primary watersheds draining to the Delta from the Central Valley. All values are expressed as a percent of the total for the Central Valley. Acreage is the percentage of land mass located below major reservoirs. Methyl mercury and water volume are for the period between March 2000 and June 2006 (Tables 1 and 2). Inorganic mercury and sediment are for the 20-year period between October 1983 and September 2003.

Watershed	**Acreage (%)**	**Water Volume (%)**	**Methyl mercury load (%)**	**Inorganic mercury load (%)**	**Sediment Load (%)**
Sacramento	57	67	43	38	40
San Joaquin	36	14	21	6	10
Yolo Bypass[1]	5	15	32	35	46
Mokelumne-Cosumnes	2	4	4	3	2

[1/] Includes the Cache and Putah Creek watersheds.

Table 6. Water balance (thousand acre-feet per month) for the upper Sacramento Basin. Tributary inputs “A” were Clear, Cow, Battle and Cottonwood Creeks while tributary inputs “B” were Elder, Thomes, Mill, and Deer Creeks, finally, tributary input “C” was Big Chico Creek.

Date	Sac R. @ Keswick	Ag Diversions	Sac R. @ Redding	Trib Inputs "A"	Sac R. @ Bend Br	Trib Inputs "B"	Ag Diversions	Sac R. @ Woodson	Ag Diversions	Sac R. @ Hamilton	Trib Inputs "C"	Ag Diversions	Sac R. @ Ord Ferry	Ag Diversions	Sac R. @ Butte City	Moulton & Colusa Weir Diversions	Ag Diversions	Sac R. @ Colusa	Predicted to Observed Colusa Flow
Mar-03	259	0	259	198	546	112	4	749	0	722	27	0	747	0	738	10	0	808	72%
Apr-03	454	6	448	234	747	119	12	917	43	793	66	0	853	6	845	6	0	833	96%
May-03	994	15	979	260	1,343	134	33	1,604	124	1,388	81	1	1,488	24	1,475	144	1	1,428	79%
Jun-03	769	19	749	84	871	61	62	877	134	765	25	1	798	23	731	0	2	700	100%
Jul-03	851	19	832	41	898	40	64	861	157	738	27	2	746	28	655	0	2	619	111%
Aug-03	634	18	616	31	676	16	42	644	119	552	26	1	588	15	521	0	1	519	98%
Sep-03	458	18	440	32	484	13	24	473	39	420	31	0	451	3	436	0	0	415	108%
Oct-03	418	12	405	37	450	13	14	461	58	383	21	2	366	16	371	0	1	329	117%
Nov-03	336	0	336	48	418	17	1	458	0	384	4	0	369	0	342	0	0	319	127%
Dec-03	505	0	505	310	965	66	0	1,217	0	1,227	102	0	1,279	0	1,284	95	0	1,153	77%
Jan-04	469	0	469	270	854	56	0	1,030	0	1,044	81	0	1,113	0	1,170	26	0	1,239	69%
Feb-04	1,230	0	1,230	589	2,045	218	2	2,435	0	2,377	234	0	2,459	0	2,678	903	0	1,658	82%
Mar-04	918	0	918	277	1,431	151	5	1,691	0	1,457	42	0	1,690	0	1,807	438	0	1,524	62%
Apr-04	500	11	489	124	634	81	18	790	93	481	34	0	653	15	586	0	1	639	94%
May-04	580	20	561	91	676	61	49	649	141	501	28	1	555	24	503	0	3	519	101%
Jun-04	829	18	811	52	893	45	66	817	159	687	22	2	666	26	600	0	3	624	108%
Jul-04	925	20	906	30	953	36	61	863	159	749	23	2	724	23	679	0	3	687	109%
Aug-04	680	17	663	24	685	32	37	627	119	523	21	1	539	14	518	0	2	517	110%
Sep-04	512	16	496	27	534	30	20	511	29	464	18	0	478	2	473	0	0	473	110%
Oct-04	441	1	440	44	490	35	8	495	65	414	9	2	424	16	433	0	3	407	107%
Nov-04	271	0	271	45	345	33	0	334	0	291	5	0	284	0	315	0	0	298	119%
Dec-04	252	0	252	210	580	81	0	620	0	397	64	0	738	0	717	93	0	646	80%
Jan-05	236	0	236	222	533	95	0	544	0	766	120	0	942	0	914	0	0	1,059	64%
Feb-05	207	0	207	151	411	92	1	505	0	546	95	0	763	0	594	0	0	693	78%
Mar-05	234	0	234	265	581	139	3	675	0	749	109	0	961	0	861	24	0	929	77%
Apr-05	241	6	235	164	440	93	13	550	39	557	67	0	540	10	572	0	0	622	80%
May-05	892	11	881	382	1,389	158	32	1,433	120	1,298	102	1	1,373	21	1,369	111	3	1,400	88%
Jun-05	713	17	696	99	842	58	59	793	134	633	32	1	682	21	664	0	2	726	92%
Jul-05	875	19	856	49	932	22	65	830	160	642	32	1	678	27	644	0	2	684	103%
Aug-05	651	19	633	32	690	14	47	610	129	479	33	0	502	17	504	0	2	484	107%
Sep-05	510	16	494	33	547	74	24	507	37	449	24	0	466	3	487	0	0	457	122%
Oct-05	472	0	472	39	518	56	12	504	47	434	14	2	446	1	460	0	2	413	125%
Nov-05	335	0	335	56	432	26	2	451	0	388	9	0	395	0	364	0	0	333	127%
Dec-05	466	0	466	665	1,295	272	1	1,361	0	1,482	156	0	1,515	0	1,503	275	0	1,145	112%
Jan-06	1,730	0	1,730	481	2,562	216	0	2,800	0	2,836	257	0	3,041	0	3,464	1,195	0	2,207	67%
Feb-06	750	0	750	307	1,219	124	7	1,324	0	1,296	61	0	1,372	0	1,354	94	0	1,302	88%
Mar-06	1,531	0	1,531	481	2,229	178	0	2,482	0	2,531	198	0	2,819	0	2,807	650	0	2,290	76%
Apr-06	1,715	0	1,715	672	2,586	261	2	3,048	3	3,103	290	0	3,402	0	3,381	1,142	0	2,341	76%
May-06	778	16	763	244	970	143	37	1,191	127	1,045	59	1	1,116	23	1,125	0	3	1,123	91%
Jun-06	841	17	825	100	898	66	60	947	140	799	31	1	820	21	797	0	3	770	104%
Sum	**26,464**	**332**	**26,132**	**7,502**	**36,594**	**3,537**	**887**	**39,680**	**2,375**	**36,791**	**2,681**	**22**	**39,843**	**379**	**39,744**	**5,207**	**42**	**35,332**	**Mean=95%**

[1/] Predicted to observed Colusa flow was calculated by summing all gauged upstream inputs and diversions and dividing by the gauged flow at Colusa.

Table 7. Water balance (thousand acre-feet per month) for the lower Sacramento Basin.

Date	Sac R. @ Colusa	Tisdale Weir Diversion	Colusa Basin Drain	Sac Slough	Fremont Weir Diversion	Yuba R. @ Marysville	Bear R. @ Wheatland	Feather R. @ Nicolaus	Sacramento Weir Diversion	American R. @ Discovery Pk	Sac R. @ Freeport	Predicted to Observed Freeport Flow
Mar-03	808	16	8	90	0	149	54	316	0	128	1,409	79%
Apr-03	833	13	6	52	0	158	63	314	0	127	1,284	99%
May-03	1,428	222	0	505	0	320	53	580	0	348	2,493	90%
Jun-03	700	0	21	62	0	194	4	451	0	251	1,326	102%
Jul-03	619	0	21	34	0	108	1	744	0	204	1,379	111%
Aug-03	519	0	54	71	0	112	1	509	0	167	1,204	98%
Sep-03	415	0	77	60	0	34	1	281	0	106	913	103%
Oct-03	329	0	8	31	0	36	1	198	0	122	677	107%
Nov-03	319	0	41	46	0	34	1	198	0	124	741	110%
Dec-03	1,153	77	36	287	0	108	6	295	0	131	1,709	91%
Jan-04	1,239	73	0	405	10	139	19	320	0	159	2,261	73%
Feb-04	1,658	366	22	1,653	1,292	200	74	634	0	220	2,555	87%
Mar-04	1,524	296	7	1,114	776	174	57	695	0	216	2,872	66%
Apr-04	639	0	17	43	0	96	19	537	0	259	1,416	99%
May-04	519	0	18	60	0	94	2	260	0	132	771	107%
Jun-04	624	0	14	42	0	56	2	336	0	135	900	114%
Jul-04	687	0	12	46	0	61	1	569	0	194	1,257	111%
Aug-04	517	0	49	77	0	56	1	492	0	114	1,102	107%
Sep-04	473	0	46	46	0	31	1	276	0	94	869	110%
Oct-04	407	0	18	31	0	37	1	213	0	94	775	99%
Nov-04	298	0	35	68	0	32	1	193	0	104	729	103%
Dec-04	646	75	24	146	0	55	1	207	0	113	1,091	85%
Jan-05	1,059	14	15	282	0	91	5	250	0	101	2,071	63%
Feb-05	693	0	12	97	0	61	41	238	0	216	1,381	80%
Mar-05	929	35	10	103	0	131	87	365	0	395	1,867	83%
Apr-05	622	0	17	59	0	134	58	287	0	250	1,317	83%
May-05	1,400	101	26	270	169	521	57	747	4	558	2,473	99%
Jun-05	726	0	21	86	0	165	16	392	0	436	1,705	86%
Jul-05	684	0	29	55	0	83	5	306	0	217	1,209	95%
Aug-05	484	0	51	93	0	45	2	295	0	197	1,060	96%
Sep-05	457	0	64	65	0	26	1	285	0	158	1,067	102%
Oct-05	413	0	8	23	0	30	1	242	0	141	974	93%
Nov-05	333	0	54	66	0	40	1	194	0	133	820	106%
Dec-05	1,145	170	35	625	746	462	59	1,478	16	570	2,082	147%
Jan-06	2,207	584	0	2,824	3,437	675	124	2,217	28	858	4,086	82%
Feb-06	1,302	223	6	490	186	238	88	873	4	456	2,789	92%
Mar-06	2,290	887	0	1,911	2,096	433	141	2,123	0	447	4,173	78%
Apr-06	2,341	851	0	2,668	3,359	777	155	2,701	1	1,140	4,453	92%
May-06	1,123	24	2	153	122	567	38	1,435	0	626	3,279	91%
Jun-06	770	0	33	85	0	143	11	446	0	333	1,665	93%
Sum	35,332	4,026	916	14,921	12,194	6,906	1,252	23,490	53	10,773	68,205	Mean=95%

[1/] Predicted to observed Freeport flow was calculated by summing all gauged upstream inputs and diversions and dividing by the gauged flow at Freeport.

Table 8. Methyl mercury concentrations (ng/l) in primary water sources in the Sacramento Basin

Date	Sac R. @ Redding	Sac R. @ Bend Bridge	Sac R. @ Woodson	Sac R @ Hamilton City	Sac R. @ Ord Ferry	Sac R @ Butte City	Sac R @ Colusa	CBD @ Rd 99E	Sac Sl @ Karnak	Feather R. @ Gridley	Yuba R. @ Marysville	Bear R @ Wheatland	Feather R. @ Nicolaus	American R. @ Nimbus	American R. @ Discovery Park	Sac R. @ Freeport
Mar-03	0.02	0.04	0.06	0.08		0.13	0.14	0.23	0.15	0.03	0.06	0.05	0.12		0.04	0.17
Apr-03	0.05	0.04	0.06	0.05		0.07	0.07	0.10	0.11	0.08	0.09	0.07	0.10	0.03	0.06	0.13
May-03	0.02	0.05	0.05	0.04		0.06	0.04	0.09	0.35	0.05	0.04	0.04	0.07	0.04	0.10	0.09
Jun-03	0.02	0.01	0.04	0.04		0.08	0.12	0.09	0.11	0.04	0.06	0.22	0.11	0.04	0.09	0.03
Sep-03	0.01	0.01	0.05	0.05		0.06	0.09	0.09	0.07	0.05	0.06	0.13	0.06	0.03	0.08	0.07
Feb-04	0.05	0.17	0.22	0.34			0.23	0.20		0.04	0.24	0.15	0.12	0.03	0.05	0.16
Mar-04	0.01	0.03	0.02	0.05	0.05	0.05	0.05	0.30	0.38	0.01	0.04	0.07	0.19	0.01	0.04	0.12
Apr-04	0.03	0.05	0.06	0.05	0.09	0.07	0.08	0.14	0.13	0.06	0.06	0.14	0.09	0.03	0.13	0.10
May-04	0.04	0.01	0.06	0.08	0.15	0.13	0.14	0.12	0.12	0.05	0.03	0.17	0.10	0.05	0.11	0.11
Jun-04	0.01	0.04	0.06	0.08	0.10	0.09		0.27	0.19	0.05	0.05	0.22	0.09	0.03	0.10	0.12
Jul-04	0.05	0.05	0.07	0.06	0.09	0.08	0.08	0.12	0.14	0.06	0.07	0.23	0.08	0.07	0.09	0.10
Aug-04	0.01	0.03	0.07	0.06	0.06	0.07	0.09	0.10	0.14	0.04	0.07	0.19	0.04	0.01	0.05	0.09
Nov-04	0.04	0.08	0.09	0.06	0.06	0.07	0.09	0.33	0.22	0.09	0.07	0.09	0.09	0.03	0.05	0.13
Dec-04	0.04	0.05	0.10	0.06	0.08	0.07	0.11	0.21	0.20	0.05	0.03	0.15	0.07	0.15	0.07	0.13
Jan-05	0.04		0.05	0.04		0.06	0.07	0.44	0.19	0.05	0.05	0.11	0.08	0.03	0.06	0.13
Feb-05	0.05	0.09	0.10	0.10	0.10	0.05	0.14	0.36	0.21	0.05	0.03	0.05	0.08	0.03	0.05	0.13
Mar-05	0.03	0.58	0.39	0.35	0.09	0.08	0.07	0.98		0.06	0.12	0.18	0.18	0.04	0.05	0.10
Apr-05	0.07	0.05	0.06	0.08		0.05	0.10	0.14	0.17	0.05	0.05	0.11	0.11	0.01	0.11	0.09
Jun-05	0.03	0.03	0.03	0.06	0.07	0.06	0.05	0.15	0.16	0.03	0.08		0.08	0.04	0.06	0.09
Jul-05	0.03	0.04	0.04	0.06	0.08	0.10	0.09	0.15	0.15	0.04	0.06	0.20	0.06	0.04	0.05	0.08
Aug-05	0.04	0.03	0.04	0.08		0.05	0.12	0.09	0.11	0.03	0.06	0.20	0.07	0.06	0.09	0.07
Sep-05	0.02	0.01	0.03	0.04	0.05	0.05	0.09	0.09	0.13	0.03	0.09	0.14	0.06	0.05	0.06	0.10
Oct-05	0.03	0.05	0.05	0.05	0.07	0.06	0.09	0.20	0.11	0.04	0.08	0.13	0.06	0.05	0.03	0.08
Nov-05	0.04	0.07	0.06	0.05	0.05	0.06	0.06	0.20	0.23	0.01	0.04	0.11	0.07	0.05	0.05	0.10
Dec-05	0.05	0.28	0.51	0.29	0.09	0.28	0.28	0.18		0.06	0.18	0.14	0.09	0.05	0.07	0.14
Jan-06	0.03	0.05	0.06	0.08	0.09	0.07	0.11	0.30	0.18	0.06	0.15	0.10	0.10	0.05	0.05	0.13
Feb-06	0.03	0.01	0.04	0.06	0.14	0.05	0.07	0.09	0.31	0.05	0.04	0.11	0.09	0.04	0.04	0.11
Mar-06	0.02	0.01	0.04	0.04	0.04	0.04	0.05	0.22	0.10	0.03	0.06	0.12	0.08	0.04	0.02	0.10
Apr-06	0.03	0.04	0.05	0.07	0.05	0.08	0.08	0.25	0.07	0.02	0.05	0.07	0.06	0.03	0.03	0.12
May-06	0.05	0.03	0.05	0.08	0.07	0.09	0.09	0.14	0.47	0.06	0.07	0.08	0.10	0.04	0.05	0.09
Jun-06	0.02	0.04	0.06	0.05	0.06	0.07	0.08	0.16	0.21	0.04	0.06	0.08	0.08	0.04	0.05	0.09
Mean	**0.03**	**0.07**	**0.09**	**0.09**	**0.08**	**0.08**	**0.10**	**0.21**	**0.18**	**0.05**	**0.08**	**0.13**	**0.09**	**0.04**	**0.06**	**0.11**
95%CL	**0.01**	**0.04**	**0.04**	**0.03**	**0.01**	**0.02**	**0.02**	**0.06**	**0.04**	**0.01**	**0.02**	**0.02**	**0.01**	**0.01**	**0.01**	**0.01**
Month n:	**31**	**30**	**31**	**31**	**22**	**30**	**30**	**31**	**29**	**31**	**32**	**31**	**31**	**30**	**31**	**35**

Table 9. Methyl mercury concentrations (ng/l) in creeks entering the Sacramento River between Redding and Colusa. These creeks were labeled tributary inputs “A”, “B” and “C” in Table 6 and 11. Samples collected in February 2004, March 2005, and December 2005 were taken during storm events.

Date	**Tributary Inputs “A”**				**Tributary Inputs “B”**				**Tributary Input “C”**
	Clear Ck	**Cow Ck**	**Battle Ck**	**Cottonwood Ck**	**Elder Ck**	**Thomes Ck**	**Mill Ck**	**Deer Ck**	**Big Chico Ck**
Mar-03	0.04			0.06		0.09			
Feb-04	0.08			0.31		0.72			
Mar-05				0.43					
Dec-05	0.31	0.10	0.22	0.24	0.28	0.87	0.59	0.16	0.08
Jan-06	0.06	0.05	0.03	0.04	0.04	0.04	0.05	0.03	0.04
Feb-06	0.04	0.02	0.04	0.03	0.03	0.03	0.11	0.03	0.04
Mar-06	0.06	0.17	0.04	0.05	0.06	0.13	0.05	0.11	0.04
Apr-06	0.07	0.02	0.05	0.06	0.04	0.08	0.05	0.02	0.03
May-06	0.05	0.08	0.06	0.07	0.17	0.12	0.08	0.05	0.08
Jun-06	0.06	0.06	0.05	0.05	0.05	0.04	0.11	0.04	0.07
Mean	**0.08**	**0.08**	**0.06**	**0.11**	**0.09**	**0.22**	**0.14**	**0.07**	**0.05**
N	**10**	**8**	**8**	**11**	**8**	**10**	**8**	**8**	**8**

Table 10. Methyl mercury loads entering the Sacramento River in small creeks located between Redding and Colusa.

Date	Clear Ck g/mo	Cow Ck g/mo	Battle Ck g/mo	Cottonwood Ck g/mo	Elder Ck g/mo	Thomes Ck g/mo	Mill Ck g/mo	Deer Ck g/mo	Big Chico Ck g/mo
Feb-04	3.4			116.3		66.30			
Mar-05				74.9					
Dec-05	11.4	33.5	19.8	87.2	9.9	109.3	49.5	14.5	3.8
Jan-06	1.8	12.2	2.2	10.5	1.1	4.4	2.8	2.1	2.2
Feb-06	1.0	3.1	2.7	5.3	0.5	1.2	4.6	1.4	1.2
Mar-06	2.1	40.6	3.7	10.0	1.5	3.2	3.7	11.4	2.9
Apr-06	3.2	5.2	6.2	25.0	1.9	6.0	4.0	2.7	2.4
May-06	0.9	6.9	5.1	7.4	2.4	5.1	4.4	2.8	0.6
Jun-06	0.6	1.7	2.5	1.8	0.2	0.7	4.2	0.9	0.3
Mean	**3.04**	**14.73**	**6.02**	**37.60**	**2.50**	**24.52**	**10.46**	**5.12**	**1.89**
N	**8**	**7**	**7**	**9**	**7**	**0**	**7**	**7**	**7**

Table 11. Methyl mercury loads (g/mo) in the Sacramento Basin.

Date	Sac R. @ Redding	Trib Inputs A	Sac R @ Bend Bridge	Trib Inputs B	Sac R @ Woodson	Sac R @ Hamilton City	Big Chico Ck	Sac R @ Ord Ferry	Sac R @ Butte City	Sac R @ Colusa	CBD @ Knights Landing	Feather R @ Gridley	Yuba R @ Marysville	Bear R @ Wheatland	Feather R @ Nicolaus	American R @ Nimbus	American R @ Discovery Park	Sac R @ Freeport
Mar-03	7.8		28.0		52.9	73.2			115.7	139.1	7.2	3.4	11.0	3.6	48.3		5.5	293.2
Apr-03	26.7		41.3		63.0	51.2			71.3	73.2	2.9	6.4	16.8	5.8	38.4	3.9	9.3	204.0
May-03	22.5		78.2		102.1	76.9			112.4	72.4	0.7	10.4	16.0	2.5	47.8	16.1	40.3	280.6
Jun-03	17.5		12.2		44.2	41.9			68.4	102.7	4.6	11.2	14.7	1.0	59.0	13.3	27.9	49.0
Sep-03	6.2		6.8		29.3	23.5			32.3	44.8	8.2	12.3	2.4	0.1	19.8	4.0	10.4	75.9
Feb-04	74.9		436.3		645.9	1008.6				465.4	5.4	13.6	58.1	13.5	97.3	8.5	12.8	519.0
Mar-04	13.2		49.2		49.0	96.2		102.4	100.5	86.3	2.8	5.8	8.3	4.8	163.8	3.1	10.0	432.2
Apr-04	15.3		36.4		62.8	31.2		71.0	50.3	63.6	2.9	27.8	7.6	3.3	60.2	10.9	40.1	167.0
May-04	29.1		9.8		52.0	47.1		99.3	81.3	87.0	2.6	9.0	3.9	0.4	30.8	7.7	17.1	108.4
Jun-04	11.7		46.4		62.6	65.8		83.9	66.4		4.8	14.1	3.5	0.5	36.8	4.4	16.4	129.9
Jul-04	60.3		53.6		75.2	54.4		76.0	66.3	68.0	1.7	34.2	5.1	0.3	55.2	16.8	21.1	162.7
Aug-04	9.6		29.5		50.3	39.5		38.4	44.4	59.4	5.9	17.3	4.8	0.2	25.5	1.7	7.3	128.8
Nov-04	13.1		32.7		37.2	20.8		21.5	25.4	34.7	14.3	15.4	2.6	0.1	20.8	3.6	6.1	114.0
Dec-04	12.0		37.1		76.4	30.9		70.8	59.2	89.3	6.6	8.4	2.2	0.2	17.3	19.0	8.1	175.3
Jan-05	11.1				31.7	40.0			66.0	92.5	8.1	8.7	5.6	0.7	23.1	4.0	6.2	330.8
Feb-05	11.6		44.7		61.5	67.1		91.3	35.8	122.3	5.9	6.5	2.5	2.7	24.3	8.2	11.9	213.4
Mar-05	9.1		411.8		321.2	321.6		102.5	87.1	83.9	13.4	7.9	19.4	19.7	78.8	20.8	26.2	239.9
Apr-05	19.9		28.9		40.7	54.9			36.8	73.5	3.1	4.2	8.4	8.2	37.8	3.0	34.4	141.4
Jun-05	21.7		35.2		25.4	43.4		55.0	47.0	42.4	4.0	7.5	15.4	0.0	39.3	21.5	34.2	180.5
Jul-05	27.0		44.7		43.6	44.6		65.1	81.9	77.9	4.9	9.1	5.9	1.2	21.0	12.0	12.9	122.5
Aug-05	29.4		29.5		29.5	45.2			31.5	69.9	5.3	9.4	3.3	0.4	26.5	15.2	20.6	91.3
Sep-05	12.7		6.5		19.6	20.9		28.8	27.9	49.5	7.0	8.2	3.0	0.2	20.4	9.8	11.8	125.4
Oct-05	16.2		31.2		33.0	27.1		37.2	31.4	47.0	4.4	10.5	2.9	0.1	17.4	8.4	5.4	93.8
Nov-05	15.5		38.7		31.5	22.3		24.8	27.8	23.2	8.6	1.6	1.7	0.1	17.3	7.5	7.7	97.9
Dec-05	30.3	151.9	449.9	183.1	856.4	529.5	3.8	165.2	517.3	394.1	5.6	65.2	101.8	10.0	170.0	31.1	48.8	369.8
Jan-06	56.6	26.7	157.5	10.4	222.0	262.4	2.2	320.2	314.9	304.6	5.7	87.6	127.3	14.6	278.9	54.0	54.4	656.6
Feb-06	28.1	12.0	14.4	7.7	62.2	97.9	1.2	240.0	79.1	114.5	1.4	26.3	11.0	11.9	98.6	21.4	22.5	367.3
Mar-06	43.4	56.3	26.5	19.8	127.7	114.8	2.9	140.7	138.4	148.3	3.0	55.4	29.9	21.4	213.1	22.5	10.8	537.0
Apr-06	65.4	39.6	121.9	14.6	201.4	258.7	2.4	208.1	314.0	227.3	5.5	44.5	49.0	13.0	212.5	40.6	38.7	632.9
May-06	45.2	20.3	40.4	14.8	66.2	99.8	0.6	98.2	131.1	127.0	4.4	48.3	49.1	3.8	174.5	32.9	36.7	374.6
Jun-06	23.9	6.6	49.2	6.0	71.4	46.5	0.3	57.0	73.7	71.4	4.3	13.7	10.5	1.1	44.1	16.2	21.3	189.1
sum	**787.2**	**313.4**	**2428.8**	**256.4**	**3647.8**	**3757.9**	**13.2**	**2197.2**	**2935.3**	**3454.8**	**165.3**	**604.0**	**603.8**	**145.5**	**2218.9**	**442.2**	**636.9**	**7604.1**

Table 12. Relationship between unfiltered methyl mercury (ng/l) and suspended sediment concentration (mg/l) in waterways draining to the lower Sacramento River. Data do not include samples collected during storm events.

Watershed	**Equation**	**N**	**r[1,2]**
American River	MHg=0.0052(SSC)+0.0027	16	0.65**
Bear River		6	ns
Colusa Basin Drain		7	ns
Feather River	MHg=0.0024(SSC)+0.0466	14	0..62*
Sacramento Slough	MHg=0.0077(SSC)-0.1279	7	0.79*
Yuba River		6	ns
Sacramento River	$MHg=0.022(SSC)^{0.344}$	63	0.69***

[1/] Pierson correlation coefficient.
[2/] *=P<0.05, **= P<0.01, ***=P<0.001, ns= no statistical relationship.

Table 13. Slope of the regression of filter-passing and unfiltered methyl mercury concentrations in waterways in the Sacramento Basin. Data do not include samples collected during storm events.

Watershed	**Ratio**	**N**	**r[1,2]**
Sacramento River	0.42	42	0.57***
Colusa Basin Drain		7	ns
Sacramento Slough	0.30	7	0.83**
Feather River	0.50	13	0.48*
Yuba River	0.48	7	0.79*
Bear River	0.73	7	0.95**
American River		15	ns

[1/] Pierson correlation coefficient.

[2/] *=P<0.05, **= P<0.01, ***=P<0.001, ns= no statistical relationship.

Table 14. San Joaquin water volumes in acre-feet per month. See Figure 2 for site locations.

Date	SJR @ Landers Ave	Salt Slough	Sum small Ag eastside inputs and diversions between Landers and Fremont Ford	Sum small ag westside inputs and diversions between Landers and Fremont Ford	SJR @ Fremont Ford	Mud Slough	Merced River	Sum small ag eastside inputs and diversions between Fremont Ford and Crows	Sum small ag westside inputs and diversions between Fremont Ford and Crows	SJR @ Crows Landing	Sum small ag eastside inputs and diversions between Crows and Patterson	Sum small ag westside inputs and diversions between Crows and Patterson	SJR @ Patterson	Tuolumne River	Stanislaus River	Sum small ag eastside inputs and diversions betweem Patterson and Vernalis	Sum small ag westside inputs and diversions between Patterson and Vernalis	SJR @ Vernalis
Apr-03	89	11,215	20	-335	10,990	4,857	27,267	6,372	937	50,424	6,440	11,736	68,601	42,989	46,555	4,106	-10,929	151,323
May-03	296	7,864	19	-434	7,745	4,279	41,751	3,977	298	58,050	6,443	2,613	67,106	40,216	54,759	3,810	-26,084	139,808
Jun-03	635	7,218	18	-770	7,100	4,941	10,355	6,238	-1,523	27,111	7,364	4,670	39,144	26,171	73,382	1,772	-25,687	114,782
Jul-03	667	8,596	18	-886	8,395	3,688	6,073	10,551	-612	28,095	8,102	6,378	42,575	29,270	39,229	724	-26,897	84,902
Sep-03	497	4,860	18	-443	4,932	3,281	5,485	1,694	1,968	17,360	8,929	1,134	27,423	24,074	24,249	1,778	-7,766	69,758
Feb-04	6,514	15,749	29	115	22,407	10,384	17,904	7,053	3,620	61,370	4,815	2,166	68,351	28,347	29,599	3,281	3,261	132,839
Mar-04	15,530	21,814	24	-266	37,101	17,404	17,900	10,710	2,498	85,614	5,486	1,317	92,417	82,561	20,394	3,743	-1,688	197,427
Apr-04	449	10,241	21	-400	10,310	3,881	23,062	10,964	3,200	51,418	6,304	13,826	71,548	86,101	41,745	4,161	-14,803	188,752
May-04	593	7,701	20	-588	7,727	3,850	42,917	7,579	-274	61,800	6,392	3,582	71,774	42,173	56,265	1,987	-27,556	144,643
Jun-04	992	8,880	19	-760	9,131	3,616	8,908	4,657	-1,403	24,909	7,435	4,359	36,703	17,441	42,918	1,484	-26,322	72,223
Jul-04	978	9,335	19	-847	9,485	4,784	5,556	8,388	-1,056	27,158	8,165	5,163	40,486	19,877	39,522	332	-26,763	73,454
Aug-04	803	8,479	18	-721	8,579	3,204	5,722	7,119	335	24,959	9,247	4,519	38,726	17,948	23,217	531	-16,147	64,275
Sep-04	230	5,496	19	-416	5,330	2,789	6,459	3,162	1,081	18,822	8,984	1,382	29,188	13,534	21,787	1,976	-6,463	60,021
Oct-04	481	5,957	26	-210	6,253	8,540	18,093	5,064	1,972	39,922	8,920	1,737	50,578	23,412	25,145	3,676	-1,472	101,340
Nov-04	1,759	10,510	20	91	12,380	9,770	15,464	1,385	4,130	43,129	3,766	1,551	48,446	17,339	23,504	669	2,015	91,974
Dec-04	7,906	8,307	27	66	16,305	9,843	16,882	1,000	2,449	46,480	2,465	1,499	50,444	19,271	23,440	2,442	2,318	97,916
Jan-05	127,322	19,027	48	409	146,806	19,578	50,132	11,686	10,897	239,099	4,055	5,091	248,245	61,523	35,957	7,684	9,792	363,202
Feb-05	63,586	21,691	62	247	85,586	16,873	29,742	10,665	15,502	158,367	4,526	5,560	168,453	131,878	28,590	5,832	11,610	346,363
Mar-05	66,790	30,304	587	103	97,785	19,715	48,294	15,545	14,570	195,909	5,649	5,034	206,592	281,976	29,231	5,281	7,654	530,735
Apr-05	29,723	16,139	72	-220	45,714	6,587	168,691	13,196	6,822	241,009	6,259	13,968	261,237	305,741	24,467	5,757	-6,761	590,441
May-05	81,994	14,272	54	-422	95,898	5,469	145,592	11,135	5,671	263,766	6,517	3,254	273,537	304,999	93,942	2,223	-21,973	652,728
Jun-05	109,683	9,062	27	-651	118,120	4,936	117,065	5,450	6	245,577	7,305	4,291	257,173	240,905	40,734	1,725	-21,096	519,440
Jul-05	8,868	12,150	21	-855	20,184	4,975	59,502	9,033	-217	93,478	8,025	5,461	106,964	143,507	26,661	1,306	-24,743	253,695
Aug-05	2,686	10,785	20	-743	12,749	4,136	43,111	10,273	2,948	73,217	9,381	6,254	88,852	72,663	22,832	1,279	-16,411	169,214
Sep-05	826	9,162	19	-431	9,576	3,645	44,010	6,342	3,556	67,129	8,882	2,287	78,298	35,258	26,966	1,954	-6,013	136,462
Oct-05	1,258	8,009			10,582	9,576	24,638			57,759			59,818	41,823	31,732			161,302
Nov-05	2,400	10,612			13,198	10,350	14,625			47,851			53,476	30,613	22,669			120,280
Dec-05	6,522	11,883			17,681	13,565	66,193			75,047			76,193	86,216	70,943			215,147
Jan-06	41,224	17,117			47,457	17,498	161,008			249,679			244,068	284,335	256,919			809,871
Feb-06	6,796	17,034			13,513	8,785	42,085			102,347			87,959	170,277	94,163			358,631
Mar-06	45,443	23,367			64,504	14,642	153,424			255,094			232,070	283,734	191,564			719,702
Apr-06	747,647	20,579			728,430	11,746	281,907			979,874			1,034,648	447,342	269,990			1,662,347
May-06	651,874	18,139			581,812	7,192	280,918			856,463			889,872	447,531	253,944			1,602,050
Jun-06	363,800	10,447			368,965	7,303	154,427			536,668			604,481	223,056	109,428			933,620
Sum	**2,396,862**	**431,998**	**1,245**	**-9,364**	**2,662,732**	**285,681**	**2,155,162**	**189,244**	**77,378**	**5,404,954**	**169,859**	**118,832**	**5,815,447**	**4,124,100**	**2,216,441**	**69,513**	**-278,924**	**11,930,667**
n months	**34**	**34**	**25**	**25**	**34**	**34**	**34**	**25**	**25**	**34**	**25**	**25**	**34**	**34**	**34**	**25**	**25**	**34**
% Vernalis	**20.09%**	**3.62%**	**0.02%**	**-0.18%**	**22.32%**	**2.39%**	**18.06%**	**3.54%**	**1.45%**	**45.30%**	**3.18%**	**2.22%**	**48.74%**	**34.57%**	**18.58%**	**1.30%**	**-5.22%**	

Table 15. Methyl mercury concentrations (ng/l) in the San Joaquin Basin.

Date	SJR @ Lander Ave	Salt Slough	SJR @ Fremont Ford	Mud Slough	Merced River	Orestimba Creek	SJR @ Crow's Landing	TID Lateral #5	SJR @ Patterson	Tuolumne River	Stanislaus River	SJR @ Vernalis
Apr-03		0.18	0.13	0.58	0.05	0.16	0.10	0.04	0.10	0.09	0.06	0.11
May-03		0.15	0.12	0.25	0.12	0.15	0.16	0.18	0.07	0.15	0.11	0.13
Jun-03		0.23	0.27	0.64	0.08	0.29	0.25	0.10	0.27	0.14	0.09	0.17
Jul-03		0.29	0.20	0.70	0.08	0.24	0.32	0.05	0.23	0.17	0.05	0.21
Sep-03		0.15	0.18	1.58	0.04	0.13	0.22	0.07	0.20	0.08	0.13	0.16
Feb-04		0.21	0.21	0.43	0.08	0.48	0.35	0.89	0.80	0.11	0.95	0.17
Mar-04		0.30	0.30	0.62	0.08	0.15	0.24	0.12	0.21	0.10	0.13	0.17
Apr-04		0.23	0.23	0.57	0.09	0.21	0.17	0.12	0.15			0.14
May-04		0.21	0.19	0.92	0.16	0.22	0.24	0.30	0.19	0.14	0.08	0.14
Jun-04		0.26	0.34	0.90	0.06	0.18	0.34	0.09	0.25	0.10	0.10	0.18
Jul-04		0.28	0.20	0.87	0.04	0.18	0.28		0.24	0.12	0.09	0.19
Aug-04		0.24	0.15	1.77	0.07	0.18	0.28	0.42	0.19	0.18	0.14	0.22
Sep-04		0.23	0.26	1.45	0.04	0.09	0.31	0.15	0.22	0.14	0.12	0.15
Oct-04		0.28	0.19	1.56	0.05	0.17	0.41	0.13	0.26	0.10	0.08	0.14
Nov-04		0.40	0.45	1.10	0.07	0.11	0.38	0.11	0.31	0.06	0.09	0.21
Dec-04		0.23	0.21	0.51	0.04	0.10	0.19	0.06	0.17	0.05	0.04	0.14
Jan-05		0.38	0.27		0.14	0.23	0.25	0.12	0.25	0.26	0.27	0.25
Feb-05		0.19	0.36	0.65	0.09	0.13		0.04	0.28	0.09	0.09	0.19
Mar-05		0.31	0.48	0.61	0.12	0.11	0.40	0.07	0.35	0.07	0.15	0.19
Apr-05		0.30	0.40	0.65	0.07	0.10	0.21	0.09	0.17	0.06	0.03	0.16
May-05		0.26	0.49	0.63	0.17	0.20	0.35	0.48	0.26	0.12	0.08	0.20
Jun-05	0.31	0.31	0.65	0.67	0.17	0.17	0.58	0.24	0.58	0.14	0.11	0.57
Jul-05		0.33	0.32	0.77	0.17	0.30	0.26	0.22	0.24	0.19	0.11	0.18
Aug-05		0.26	0.24	1.43	0.26	0.18	0.22	0.23	0.22	0.10	0.09	0.15
Sep-05		0.26	0.22	1.07	0.08	0.17	0.12	0.06	0.12	0.10	0.08	0.10
Oct-05		0.21	0.18	2.07	0.09	0.19	0.32	0.10	0.23	0.07	0.06	0.12
Nov-05	0.13	0.34	0.26	1.32	0.05	0.11	0.27	0.03	0.22	0.06	0.05	0.10
Dec-05	0.14	0.25	0.20	0.50	0.05	0.08	0.16	0.22	0.14	0.05	0.05	0.10
Jan-06	0.29	0.36	0.14	0.38	0.09	0.06	0.23	0.05	0.20	0.07	0.11	0.12
Feb-06	0.22	0.22	0.22	0.60	0.06	0.12	0.16	0.11	0.17	0.08	0.10	0.12
Mar-06	0.34	0.20	0.24	2.12	0.10	0.08	0.17	0.12	0.08	0.14	0.08	0.12
Apr-06	0.30	0.33	0.24	0.93	0.08	0.15	0.32	0.32	0.23	0.04	0.12	0.24
May-06	0.57	0.51	0.69	0.68	0.12	0.18	1.15	0.76	1.04	0.10	0.11	0.75
Jun-06	0.41	0.31	0.51	0.89	0.12	0.19	0.67	0.15	0.64	0.08	0.12	0.37
Jul-06			0.32				0.26					0.21
Average:	0.30	0.27	0.29	0.92	0.09	0.17	0.30	0.19	0.27	0.10	0.12	0.19
95% CL:	0.08	0.02	0.05	0.16	0.02	0.03	0.06	0.07	0.07	0.02	0.05	0.04
Month n:	10	35	35	34	35	34	35	33	35	34	34	36

Table 16. Mean filter-passing methyl mercury concentrations (ng/l) in major San Joaquin River sub watersheds.

		Filter-passing (ng/l)			Comparison to Mean Unfiltered Concentrations	
Watershed	**Location**	**Mean**	**95% CL[1]**	**n**	**$r^{2,3/}$**	**% filtered to unfiltered methyl mercury**
San Joaquin River	Vernalis	0.07	0.04	35	0.93***	35.4
San Joaquin River	Patterson	0.08	0.04	9	ns	41.8
San Joaquin River	Crows Landing	0.17	0.19	9	0.98***	42.3
San Joaquin River	Fremont Ford	0.14	0.14	8	0.97***	39.6
Salt Slough	Highway 165	0.12	0.07	9	0.83***	48.0
Mud Slough	Kesterson	0.36	0.36	9	0.94***	34.5
Merced River	Hatfield S.P.	0.05	0.03	9	0.88***	54.2
Tuolumne River	Shiloh Rd	0.06	0.02	9	0.84***	60.3
Stanislaus River	Caswell S.P.	0.06	0.02	9	0.66*	65.6
Orestimba Ck	River Rd	0.05	0.02	8	ns	31.4
Turlock Irrigation District Lateral #5	Carpenter Rd	0.05	0.03	8	ns	45.4

[1/] 95 percent confidence limits for the mean.
[2/] Pierson correlation coefficient between filtered and unfiltered methyl mercury
[3/] *P<0.05, **P<0.01, ***P<0.001

Table 17. Methyl mercury loads (g/mo) in the San Joaquin River watershed.

Date	SJR @ Landers Ave	Salt Slough	Sum small ag eastside inputs and diversions between Landers and Fremont Ford	Sum small ag westside inputs and diversions between Landers and Fremont Ford	SJR @ Fremont Ford	Mud Slough	Merced River	Sum small ag eastside inputs and diversions between Fremont Ford and Crows	Sum small ag westside inputs and diversions between Fremont Ford and Crows	SJR @ Crows Landing	Sum small ag eastside inputs and diversions between Crows and Patterson	Sum small ag westside inputs and diversions between Crows and Patterson	SJR @ Patterson	Tuolumne River	Stanislaus River	Sum small ag eastside inputs and diversions between Patterson and Vernalis	Sum small ag westside inputs and diversions Patterson and Vernalis	SJR @ Vernalis
Apr-03		2.6	0.0	0.0	1.7	3.4	1.8	0.313	0.19	6.2	0.3	2.3	8.3	4.9	3.3	0.2	-1.3	21.2
May-03		1.4	0.0	0.0	1.2	1.3	6.1	0.860	0.06	11.3	1.4	0.5	5.5	7.5	7.4	0.8	-2.1	22.0
Jun-03		2.0	0.0	0.0	2.4	3.9	1.0	0.801	-0.51	8.5	0.9	1.7	13.0	4.4	8.2	0.2	-8.5	23.4
Jul-03		3.0	0.0	0.0	2.1	3.2	0.6	0.682	-0.15	11.0	0.5	1.9	12.1	6.0	2.5	0.0	-7.6	21.5
Sep-03		0.9	0.0	0.0	1.1	6.4	0.3	0.149	0.32	4.7	0.8	0.2	6.9	2.4	3.9	0.2	-2.0	13.7
Feb-04		4.0	0.0	0.1	5.7	5.5	1.7	7.788	2.14	26.5	5.3	1.3	67.6	3.7	34.6	3.6	1.9	27.9
Mar-04		8.0	0.0	0.0	13.9	13.4	1.8	1.640	0.45	25.3	0.8	0.2	24.2	10.0	3.2	0.6	-0.4	40.2
Apr-04		3.0	0.0	0.0	2.9	2.8	2.5	1.611	0.82	10.9	0.9	3.5	13.3	0.0	0.0	0.6	-2.8	31.5
May-04		2.0	0.0	0.0	1.8	4.4	8.5	2.789	-0.06	18.2	2.4	1.0	16.8	7.3	5.5	0.7	-6.5	25.4
Jun-04		2.9	0.0	0.0	3.8	4.0	0.7	0.512	-0.59	10.5	0.8	0.9	11.4	2.1	5.3	0.2	-8.2	16.5
Jul-04		3.2	0.0	0.0	2.3	5.1	0.3	0.000	-0.26	9.5	0.0	1.1	12.0	2.9	4.5	0.0	-8.0	17.6
Aug-04		2.5	0.0	0.0	1.6	7.0	0.5	3.666	0.07	8.5	4.8	1.0	9.1	3.9	4.1	0.3	-3.8	17.3
Sep-04		1.6	0.0	0.0	1.7	5.0	0.3	0.574	0.12	7.3	1.6	0.2	8.0	2.3	3.1	0.4	-1.8	11.4
Oct-04		2.1	0.0	0.0	1.4	16.5	1.1	0.826	0.42	20.0	1.5	0.4	16.4	2.8	2.4	0.6	-0.5	17.1
Nov-04		5.2	0.0	0.0	6.9	13.3	1.3	0.192	0.56	20.1	0.5	0.2	18.8	1.4	2.7	0.1	0.3	24.0
Dec-04		2.3	0.0	0.0	4.3	6.1	0.7	0.077	0.31	11.1	0.2	0.2	10.4	1.1	1.3	0.2	0.3	16.8
Jan-05		8.8	0.0	0.1	48.2	0.0	8.4	1.746	3.05	72.3	0.6	1.4	76.0	19.9	11.8	1.1	2.7	111.6
Feb-05		5.1	0.0	0.0	37.9	13.6	3.2	0.512	2.53		0.2	0.9	57.8	14.8	3.3	0.3	1.9	80.0
Mar-05		11.7	0.1	0.0	57.4	14.9	7.0	1.361	2.02	97.7	0.5	0.7	88.3	23.4	5.3	0.5	1.1	122.8
Apr-05		6.0	0.0	0.0	22.5	5.3	13.6	1.507	0.88	63.0	0.7	1.8	53.3	22.0	1.0	0.7	-1.4	117.2
May-05		4.6	0.0	0.0	57.6	4.2	31.3	6.587	1.41	115.0	3.9	0.8	87.8	44.1	9.8	1.3	-7.1	159.1
Jun-05	42.2	3.4	0.0	-0.3	95.1	4.1	24.7	1.582	0.00	174.6	2.1	0.9	182.9	40.5	5.3	0.5	-15.0	368.0
Jul-05		5.0	0.0	0.0	8.0	4.7	12.3	2.432	-0.09	29.8	2.2	2.1	32.1	32.8	3.6	0.4	-7.4	56.9
Aug-05		3.4	0.0	0.0	3.7	7.3	13.6	2.867	0.65	19.6	2.6	1.4	24.1	9.2	2.5	0.4	-4.5	30.9
Sep-05		2.9	0.0	0.0	2.6	4.8	4.2	0.489	0.76	9.9	0.7	0.5	11.9	4.3	2.6	0.2	-0.9	17.4
Oct-05		2.1			2.4	24.5	2.8			22.6			16.8	3.4	2.4			23.6
Nov-05	0.4	4.4			4.2	16.9	0.9			15.8			14.7	2.3	1.3			15.2
Dec-05	1.1	3.6			4.3	8.4	3.7			14.8			13.6	5.2	4.5			25.7
Jan-06	14.9	7.7			8.1	8.2	17.7			69.7			61.5	23.6	34.6			122.2
Feb-06	1.8	4.7			3.7	6.5	3.3			19.6			18.7	17.2	11.6			51.9
Mar-06	18.9	5.6			19.3	38.3	18.1			54.7			23.1	49.4	19.8			102.7
Apr-06	275.2	8.5			213.2	13.6	28.3			390.3			290.1	24.8	39.0			488.1
May-06	458.1	11.4			495.8	6.0	41.6			1,216.4			1,138.0	52.6	33.6			1,477.9
Jun-06	184.5	4.0			232.2	8.1	23.1			445.4			474.8	21.6	16.6			425.4
Average	**110.8**	**4.4**	**0.0**	**0.0**	**40.3**	**8.6**	**8.4**	**1.7**	**0.6**	**89.4**	**1.4**	**1.1**	**85.9**	**13.9**	**8.8**	**0.6**	**-3.3**	**121.9**
95% CI	**125.0**	**0.9**	**0.0**	**0.0**	**33.9**	**2.6**	**3.7**	**0.8**	**0.4**	**77.7**	**0.6**	**0.3**	**72.6**	**5.2**	**3.8**	**0.3**	**1.8**	**93.1**
Month N	**9**	**34**	**25**	**25**	**34**	**34**	**34**	**25**	**25**	**34**	**25**	**25**	**34**	**34**	**34**	**25**	**25**	**34**

Table 18. Methyl mercury mass balance for the Yolo Bypass during low flow conditions. Twenty-seven to 64 percent of the load measured at Prospect Slough is estimated to have been produced in the Bypass.

	13 December 2004			**14 February 2005**			**14 March 2005**		
Station	**Flow (cfs)**	**MHg (ng/l)**	**MHg load (mg/d)**	**Flow (cfs)**	**MHg (ng/l)**	**MHg load (mg/d)**	**Flow (cfs)**	**MHg (ng/l)**	**MHg load (mg/d)**
Putah Ck	51	0.173	22	89	0.109	24	92	0.148	33
Cache Ck	80	0.203	40	110	0.40	108	235	0.271	156
Ridge Cut	569	0.213	295	666	0.370	651	723	0.197	348
Sum of Inputs			357			783			537
Lisbon	700	0.299	512	909	0.430	909	1050	0.410	1053
½ Lisbon	700	0.284	486	909	0.526	1112	1050	0.574	1474
Above Lisbon[1/]			155			126			516
Between Lisbon & ½ Lisbon[2/]			-26			203			421
Bypass/Total Production	**(155-26)/486=0.27**			**(126+203)/1112=0.30**			**(516+421)/1474=0.64**		

[1/] Net production from area located above Lisbon. Load calculated from the sum of upstream inputs minus the Lisbon load.

[2/] Net production from area between Lisbon and ½ Lisbon. Calculated from difference between loads at Lisbon and ½ Lisbon

Table 19. Methyl mercury mass balance for the Yolo Bypass during mini floods. Thirty six to 39 percent of the load measured at Prospect Slough is estimated to have been produced in the Bypass.

	12 January 2005			17 January 2005		
Station	**Flow (cfs)**	**MHg (ng/l)**	**MHg load (mg/d)**	**Flow (cfs)**	**MHg (ng/l)**	**MHg load (mg/d)**
Putah Ck	70	0.188	32	70	0.159	27
Cache Ck	2500	0.256	1568	430	0.147	155
Ridge Cut	530	0.199	258	2500	0.232	1418
Sum of Inputs			1858			1600
Lisbon	3100	0.320	2425	3000	0.305	2237
½ Lisbon	3100	0.385	2918	3000	0.356	2611
Above Lisbon[1/]			567			637
Between Lisbon & ½ Lisbon[2/]			493			374
Bypass/Total Production	**(567+493)/2918=0.36**			**(637+374)/2611=0.39**		

[1/] Net production from area located above Lisbon. Load calculated from the sum of upstream inputs minus the Lisbon load.

[2/] Net production from area between Lisbon and ½ Lisbon. Calculated from difference between loads at Lisbon and ½ Lisbon

Table 20. Methyl mercury concentrations (ng/l) in constructed drains discharging between Lisbon and ½ Lisbon in 2005. Concentrations in bold are greater than the value measured at Lisbon. Discharges from these sites increase methyl mercury concentrations in the Toe Drain.

		26-Apr-	9-May-	30-May	7-Jun
Location	Lat/Long	MHg	MHg	MHg	MHg
Lisbon		0.359	0.272	1.19	0.479
Drain # 1	38.47308/121.58926				**0.862**
Drain # 4	38.45389/121.59723				**5.18**
Drain # 5	38.44442/121.60209				**4.205**
Drain # 6	38.44442/121.60209				**0.798**
Drain # 9	38.43020/121.60828			**2.55**	**3.87**
Drain # 9.5				**2.92**	
Drain # 10	38.43020/121.60828	**1.69**	**1.74**	**1.9**	
Drain # 13	38.41323/121.61566			**2.43**	
Drain # 14	38.40203/121.62091				**3.34**
Drain # 15	38.40122/121.62123	0.309		0.225	
Drain # 18	38.39032/121.62632			**1.91**	**1.66**
Drain # 20				0.214	**0.538**
Drain # 21.5				**1.61**	
Drain # 22	38.37912/121.63150	**1**	**0.487**	**1.28**	**1.19**
Drain # 24	38.37658/121.63267		**0.703**	**2.67**	**1.1**
Drain # 25	38.37488/121.63340			**1.72**	
Drain # 29	38.35536/121.64333	**0.387**	0.234	1.18	
Levee Break				**1.9**	
Dredger Cut Drain			**0.429**		

Table 21. Estimate of flow (cfs) in Shag Slough at the Liberty Island Bridge and in the Toe Drain at ½ Lisbon from element specific mass balance calculations. The average flow in each channel and the flow split between Shag and the Toe Drain is also provided.

Date	Site	Flow Rate (cfs)				Average Flow	Ratio
		Mg	Na	Cl	B		
19 Apr 06	Shag	11,078	15,663	21,758	15,222	15,930	0.19
19 Apr 06	½ Lisbon	72,212	67,627	61,532	68,068	67,360	0.81
24 Apr 06	Shag	6,293	6,127		10,021	7,480	0.19
24 Apr 06	½ Lisbon	32,420	32,585		28,691	31,232	0.81
3 May 06	Shag	2,990	1,695	2,579	3,350	2,678	0.19
3 May 06	½ Lisbon	11,134	12,429	11,545	10,774	11,446	0.81