7 SOURCE ASSESSMENT – TOTAL MERCURY & SUSPENDED SEDIMENT

Sources and losses of total mercury and suspended sediment are described in this chapter. The Delta mercury TMDL program addresses total mercury in addition to methylmercury because:

- Methylmercury production has been found to be a function of the total mercury content of the sediment (Chapter 3), and decreasing total mercury loads may be an option for controlling methylmercury;
- The mercury control program for the Delta must maintain compliance with the USEPA's CTR criterion of 50 ng/l for total recoverable mercury for freshwater sources of drinking water developed for human protection; and
- The mercury TMDL for San Francisco Bay assigns a total mercury load reduction to the Central Valley watershed to protect human and wildlife health in the San Francisco Bay (Johnson & Looker, 2004). The draft San Francisco Bay Basin Plan amendment requires a reduction of 110 kg/yr of mercury from all sources entering the Delta or in water moving past Mallard Island. Meeting the San Francisco Bay goal will require a quantitative understanding of mercury and sediment loads entering and leaving the Delta.

Sections 7.1 and 7.2 describe mercury and suspended sediment concentrations (measured as total suspended solids, or TSS) for Delta sources and sinks and identify major data gaps and uncertainties. Input and loss loads were calculated for WY2000-2003, a relatively dry period corresponding to the available methylmercury data. In addition, the WY1984-2003 period was evaluated to determine mass balances for a more typical hydrologic period. This 20-year period includes a mix of wet and dry years that is statistically similar to what has occurred in the Sacramento Basin since accurate water records began to be collected (about 100 years). An assessment of mass balances during a typical distribution of wet and dry water years is critical because sediment and mercury transport is a function of water velocity and volume.

Section 7.3 presents the total mercury and suspended sediment mass budgets based on the input and export loads described in Sections 7.1 and 7.2. Section 7.4.1 reviews the mercury-to-TSS ratio (TotHg:TSS) for each input and export site to identify areas that may be the focus of future remediation efforts to reduce total mercury loading. Finally, Section 7.4.2 evaluates compliance with the CTR.

7.1 Total Mercury and Suspended Sediment Sources

The following were identified as sources of total mercury and suspended sediment to the Delta: tributary inflows from upstream watersheds, municipal wastewater, atmospheric deposition, and urban runoff. Table 7.1 lists the estimated loads associated with each source for WY2000-2003 and WY1984-2003.

7.1.1 Tributary Inputs

During WY2000-2003, tributaries to the Delta contributed approximately 97% of the mercury and 99% of the suspended sediment (Table 7.1). The Sacramento Basin alone (Sacramento River at Freeport + Yolo Bypass) contributed more than 80% of all mercury and TSS loads. The load estimates in Table 7.1 are based on the water volumes described in Section 6.1 and Appendix E and concentration data collected by several agencies provided in Appendix M.

Table 7.1: Average Annual Total Mercury and TSS Source Loads for WY2000-2003 and WY1984-2003.

	WY2000-2003				WY1984-2003			
	TotHg		TSS		TotHg		TSS	
	kg/yr ± 95% CI	% of All Inputs	Mkg/yr ± 95% CI	% of All Inputs	kg/yr ± 95% CI	% of All Inputs	Mkg/yr ± 95% CI	% of All Inputs
Tributary Inputs (a,b)								
Sacramento River	146 ±1	67	689 ±7	59	183 ±1	46	866 ±7	37
Prospect Slough	36 ± 2	16	273 ±14	23	162 ±9	41	1,190 ±87	51
San Joaquin River	19 ± 3	8	146 ±24	13	30 ±4	7.6	235 ±39	10
Calaveras River	4	1.6	14.	1.2	4	1.0	15.3	0.7
Mokelumne-Cosumnes River	3 ±1	1.5	9 ±2	0.7	4±1	1.1	11. ±3	0.5
Ulatis Creek	2	0.9	15	1.3	2	0.53	16	0.7
French Camp Slough	2	0.73	2	0.20	2	0.43	2	0.10
Morrison Creek	1	0.38	5	0.39	1	0.23	5	0.20
Marsh Creek	1 ± 0	0.25	1 ± 1	0.04	1 ±0	0.14	1 ±1	0.02
Bear/Mosher Creeks	0	0.13	2	0.19	0	0.07	2	0.10
Sum of Tributary Sources:	**214 ±3**		**1,156 ±28**		**389 ±10**		**2,342 ±91**	
Within-Delta Sources (c)								
Wastewater (Municipal & Industrial)	2	1.1			2	0.61		
Urban	3	1.1	8	0.69	3	0.66	8	0.4
Atmospheric (Indirect)	1	0.64			2	0.38		
Atmospheric (Direct)	1	0.41			1	0.22		
Sum of Within-Delta Sources:	**7**		**8**		**8**		**8**	
TOTAL INPUTS:	**221 ±3**		**1,164 ±28**		**397 ±10**		**2,350 ±91**	

(a) Confidence intervals (CI) were calculated for the average annual loads for inputs with daily flow data. See Appendix J for the calculation methods.
(b) Total mercury and TSS concentrations are not available for several small drainages to the Delta, including the following areas shown on Figure 6.1: Dixon, Upper Lindsay/Cache Slough, Manteca-Escalon, Bethany Reservoir, Antioch, and Montezuma Hills areas.
(c) Total mercury and sediment loading data for erosion of Delta soils are not available.

Central Valley Water Board staff began evaluating mercury loads from the Sacramento River watershed and Yolo Bypass in 1994 (Foe & Croyle, 1998). From March 2000 to September 2001, staff conducted monthly sampling at the Delta's four major tributary input sites (Foe, 2003): Sacramento River; San Joaquin River; Mokelumne River (downstream of the Mokelumne/Cosumnes Rivers confluence); and Prospect Slough at Toe Drain in the Yolo Bypass. In addition, other programs conducted periodic aqueous sampling between 1993 and 2003 on the Sacramento River (SRWP, 2004; CMP, 2004; Stephenson *et al.*, 2002). Central Valley Water Board staff resumed sampling in April 2003. Figure 6.2 shows the tributary monitoring locations. Table 7.2 and Figures J.1 through J.6 in Appendix J summarize the available mercury and TSS data.

Sections 7.1.1.1 through 7.1.1.3 describe the methods used to estimate the loads for the Delta's tributary watersheds and identify uncertainties. Because the Sacramento Basin is the primary source of mercury to the Delta, Section 7.1.1.3 provides an analysis of loading from major upstream Sacramento River tributaries. This information may be valuable for designing follow-up studies to determine where to implement mercury control programs.

Table 7.2: Total Mercury and TSS Concentrations for Tributary Inputs

Site (a)	**# of Samples**	**Sampling Begin Date**	**Sampling End Date**	**Min. Conc.** (ng/l)	**Ave. Conc.** (ng/l)	**Median Conc.** (ng/l)	**Max. Conc.** (ng/l)
TOTAL MERCURY CONCENTRATIONS							
Bear/Mosher Creeks (b)	4	3/15/03	2/26/04	3.55	8.15	8.84	11.36
Calaveras River @ RR u/s West Lane (b)	4	3/15/03	2/26/04	13.23	20.53	21.34	26.22
French Camp Slough near Airport Way	7 [4]	7/11/00	2/26/04	1.73 [3.32]	12.9 [20.5]	3.40 [11.63]	55.42 [55.42]
Marsh Creek @ Hwy 4	19 [3]	11/05/01	2/02/04	0.93	7.31	4.36	30.18
Mokelumne River @ I-5	21	3/28/00	9/30/03	0.26	5.34	5.19	12.28
Morrison Creek (c)	47 [15]	4/09/97	1/28/02	1.62 [3.9]	7.96 [10.46]	7.23 [9.12]	19.75 [19.75]
Prospect Slough (Yolo Bypass) (d)	28 [26]	1/10/95	9/30/03	7.18	73.10 (30.67)	26.70 (25.73)	695.6 (92.2)
Sacramento River @ Freeport	155	2/15/94	11/06/02	1.20	8.28	6.31	36.19
San Joaquin River @ Vernalis	35	10/29/93	2/26/04	3.12	8.18	7.22	23.54
Ulatis Creek near Main Prairie Rd	6 [4]	1/28/02	2/26/04	1.34 [24.21]	36.06 [53.24]	28.68 [52.51]	83.74 [83.74]
TSS CONCENTRATIONS							
Bear/Mosher Creeks (b)	4	3/15/03	2/26/04	15.8	65.8	24.1	199.1
Calaveras River @ RR u/s West Lane (b)	4	3/15/03	2/26/04	32.4	82.7	55.4	187.5
French Camp Slough near Airport Way	5 [4]	1/28/02	2/26/04	12.0 [16.7]	26.0 [29.5]	26.4 [27.5]	46.5 [46.5]
Marsh Creek @ Hwy 4	7 [2	3/15/03	2/02/04	17.9 [36.9]	69.1 [155.0]	36.9 [155.0]	273.2 [273.2]
Mokelumne River @ I-5	23	3/28/00	9/30/03	5.8	14.5	12.0	31.0
Morrison Creek (c)	44 [15]	4/09/97	1/28/02	6.0 [7.0]	39.9 [57.0]	27.0 [40.5]	140 [140]
Prospect Slough (Yolo Bypass) (d)	26 [24]	1/10/95	9/30/03	36.6	301.4 [170.0]	143.2 [139.9]	2300.7 [512.7]
Sacramento River @ Freeport	187	12/15/92	1/20/04	<0.5	38.0	26.0	368.0
San Joaquin River @ Vernalis	34	3/28/00	2/26/04	20.0	64.4	58.6	175.0
Ulatis Creek near Main Prairie Rd	6 [4]	1/28/02	2/26/04	2.5 [140.2]	276.5 [411.6]	217.8 [338.4]	829.6 [829.6]

(a) Flow gage data were not available for most of the small tributary outflows to the Delta. Therefore, wet weather concentration data (noted in brackets) and estimated wet weather runoff (Section E.2.3 in Appendix E) were used to develop load estimates.

(b) Only wet weather events were sampled on the Calaveras River and Bear and Mosher Creeks in Stockton. The one wet weather Mosher Creek sample result was combined with the Bear Creek data to estimate loads for both creeks (Appendix J).

(c) Concentration data collected at multiple sites on lower Morrison Creek were compiled to develop load estimates (Appendix J).

(d) Sampling took place at Prospect Slough (export location of the Yolo Bypass) both when there were net outflows from tributaries to the Yolo Bypass and when there was no net outflow (i.e., the slough's water was dominated by tidal waters from the south). The regression analysis focuses only on the conditions when there was net outflow from the Yolo Bypass. The above values do not include data collected when there was no net outflow. The values in parentheses are from calculations without the two very high values shown in Figure J.1. The regression is between total mercury concentrations observed at Prospect Slough (not including the two very high values shown in Figure J.1) and total export flows for the previous day estimated for Lisbon Weir, approximately 15 miles north of the Prospect Slough sampling station. The previous day's flow values were used to address the approximate residence time of the water as it travels through the Yolo Bypass to the export location where samples were collected.

7.1.1.1 Sacramento Basin Inputs to the Delta

Sacramento Basin mercury and TSS discharges to the Delta were determined for the Sacramento River at Freeport and the Yolo Bypass at Prospect Slough. Mercury and TSS concentrations for the Sacramento River at Freeport were regressed against Freeport flow to determine if a relationship might exist. Both regressions were statistically significant ($P < 0.01$) indicating that it is possible to predict Sacramento River mercury and TSS concentrations from flow. The mercury/flow and TSS/flow equations were used to predict average annual loads.[1,2] The methods used to calculate the 95% confidence intervals are described in Appendix J. The average annual load for the Sacramento River was 146 kg mercury and 689 Mkg TSS for WY2000-2003, and 183 kg mercury and 866 Mkg TSS for WY1984-2003 (Table 7.1).

Prospect Slough is a major channel draining the Yolo Bypass. Total mercury and TSS samples were collected in Prospect Slough during outgoing tides. Mercury and TSS concentrations observed on dates with net outflow were regressed against daily outflows at Lisbon Weir lagged by one day[3] to determine if statistically significant correlations might exist (Section E.2.2 in Appendix E and Figure J.1 in Appendix J). Extremely high mercury and TSS concentrations were measured on 10 and 11 January 1995 (Figure J.1). These values were not included in the regressions because, as described in Section E.2.2, the hydrologic conditions that caused them appear to have occurred only once during the WY1984-2003 study period. The TotHg/flow and TSS/flow regressions for Prospect Slough were significant ($P < 0.01$, Figure J.1), indicating that the concentrations of both constituents could be predicted from flow. The regressions were used to estimate annual average loads of 36 kg mercury and 273 Mkg TSS for WY2000-2003 and 162 kg mercury and 1190 Mkg TSS for WY1984-2003 (Table 7.1). The five-fold increase in loads during the wetter WY1984-2003 years illustrates the importance of basing load calculations on the long-term average hydrology of the basin.

All other studies that have evaluated mercury and sediment loads from the Sacramento Basin are summarized in Table 7.3. The Sacramento watershed is the major source of water, mercury, and sediment to the Delta. The results confirm that export from the watershed is strongly a function of water year type. The lowest mercury export rate occurred during the driest study period (94.8 kg/yr; Foe 2002), while the highest (801 kg/yr; Foe and Croyle, 1998) was during a very wet period. Most annual loading rates fall between 200 and 500 kg of mercury per year.

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[1] For all tributaries with statistically significant TotHg/flow or TSS/flow relationships, the predicted concentrations were multiplied by daily flow volumes to estimate daily loads. The estimated daily loads were summed and then divided by the number of years in the study period to estimate the average annual loads for WY2000-2003. If a flow record had dates with missing values, the data were normalized to estimate annual loads. For example, a 20-year record would be normalized by dividing 7305 (the number of days in the 20-year period) by the number of days with a recorded value in the flow record and then multiplying the resulting quotient by the calculated sum of loads; the result was then divided by 20 to obtain the average annual load.

[2] The Delta area that drains to the 13-mile reach of the Sacramento River between Freeport (near river mile 46) and the I Street Bridge (the northernmost legal Delta boundary, near river mile 59) is predominantly urban and is encompassed by the urban load estimate described in Section 5.2.5. No attempt was made to subtract this area from the Sacramento River watershed load estimate. Therefore, the Sacramento River load noted in Table 7.1 incorporates a small portion of the within-Delta urban runoff loading.

[3] The estimated daily flows from Lisbon Weir on Toe Drain were lagged one day to address the approximate residence time of water along the ~15 miles between Lisbon Weir and Prospect Slough. During drier years, there may be little-to-no net outflow from the Yolo Bypass's Toe Drain downstream of Lisbon Weir between April and November. (See Appendix E for a description of Yolo Bypass hydrology.) Therefore, although sampling of Prospect Slough took place during outgoing tides with the intent of sampling outflows from the Yolo Bypass, during the summer months this sampling most likely represents waters tidally-pumped northward from Cache Slough, rather than outflows from the Yolo Bypass north of Lisbon Weir.

Table 7.3: Comparison of Load Estimates for Sacramento Basin Discharges to the Delta

Study	Sampling Location	Period	Average Sacramento Valley Water Year Hydrologic Index (a)	Average Annual TotHg Load [± 95 CI] (kg)	Average Annual TSS Load [95% CI] (Mkg)
Sacramento River					
Delta TMDL (d)	Freeport	WY2000-2003	7.3	146 ± 1	689 ± 7
		WY1984-2003	7.8	183 ± 1	866 ± 7
Foe and Croyle (1998)	Greene's Landing	May 1994- April 1995	12.9	426	1,400
Foe (2002)	Greene's Landing	WY2001 (b)	5.8	91	526
LWA (2002)	Freeport	WY1980-1999	8.5	189 ± 2	na
Wright & Schoellhamer (2005)	Freeport	WY1999-2002	7.7	na	1,100 ± 170
Yolo Bypass					
Delta Mercury TMDL	Prospect Slough	WY2000-2003	7.3	36 ± 2	273 ± 14
		WY1984-2003	7.8	162 ± 9	1190 ± 87
Foe and Croyle (1998)	Prospect Slough	May 1994- April 1995	12.9	375	2,500
Foe (2002)	Prospect Slough	WY2001 (d)	5.8	3.8	42
LWA (2002)	Woodland	WY1980-1999	8.5	118 ± 17	na
Wright & Schoellhamer (2005)	Woodland	WY1999-2002	7.7	na	310 ± 130
Sacramento Basin Total (Sacramento River + Yolo Bypass)					
Delta Mercury TMDL		WY2000-2003	7.3	182 ± 2	962 ± 15
		WY1984-2003	7.8	345 ± 9	2056 ±83
Foe and Croyle (1998)		May 1994- April 1995	12.9	801	3,900
Foe (2002)		WY2001 (d)	5.8	94.8	568
LWA (2002)		WY1980-1999	8.5	306	Na
Wright & Schoellhamer (2005)		WY1999-2002	7.7	na	1,410 ± 300
Domagalski (2001) (c) 3 winter seasons, 20 December to 20 March		WY1997	10.8	487	na
		WY1998	13.3	506	na
		WY1999	9.8	169	na

(a) Source: DWR, http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST. DWR calculated a hydrologic index for the Sacramento Valley (Section E.2.1 in Appendix E). "Normal" hydrologic conditions for the Sacramento Valley are represented by an index value of 7.8, "wet" ≥9.2, "dry" 5.4 to 6.5, and "critical dry" ≤5.4. Figure E.1 in Appendix E illustrates the indices for each water year for the period of record.

(b) Foe's 2002 CALFED study estimated monthly total mercury and TSS loads for March 2000 through September 2001, but did not include load estimates for November 2000. November total mercury and TSS loads for WY2001 were estimated by averaging the loads for October and December 2000.

(c) Domagalski (2001) reported winter mercury loads from the Sacramento Basin for WY1997 through 1999 based on data collected at Sacramento River at Freeport and Yolo Bypass at Interstate 80 (upstream of Putah Creek inputs), but did not report individual loads for the Sacramento River and Yolo Bypass.

(d) See Appendix J for the methods used to estimate the 95% confidence intervals (CI) for the TMDL load estimates.

The WY1984-2003 mercury-loading rate of 345±9 kg/yr is midway between these values. The most comparable study is likely that of LWA (2002), which estimated an export rate of 306 kg/yr of mercury for another relatively similar 20-year hydrologic period. The difference between the two 20-year periods, while statistically significant, is only about 10%. Interestingly, the Sacramento River is the primary source of mercury to the Delta during dry years, but exports from the Yolo Bypass increase and become comparable to Sacramento River loads during wet periods.

Sediment transport is also strongly a function of water year type (Table 7.3). The smallest export rate occurred during the driest period studied (568 Mkg/yr, Foe 2002), while the highest rate happened during a wet year (3,900 Mkg/yr, Foe and Croyle, 1998). The WY1984-2003 sediment export rate of 2,056 ±87 Mkg/yr is among the higher reported. The importance of the Yolo Bypass, like for mercury, is strongly a function of flow. The Bypass only exports a small amount of sediment during dry periods, but loads increase and equal or exceed those of the Sacramento River during wet periods.

The sediment yield of the Sacramento Basin is reported to have declined by about 50% since 1957 (Wright and Schoellhamer, 2004). Primary causes are believed to be the reduced supply of erodible material since cessation of hydraulic mining and increased trapping of sediment in reservoirs. Therefore, future Sacramento Basin mercury and sediment export rates may be different than those computed with the present rating curves.

7.1.1.2 Other Tributary Inputs to the Delta

The TotHg/flow and TSS/flow regressions for the Mokelumne-Cosumnes and San Joaquin Rivers were not significant ($P > 0.05$). Therefore, average mercury and TSS concentrations (Table 7.2) were multiplied by average annual water volumes for WY2000-2003 and WY1984-2003 (Table 6.1) to estimate an average annual load. The Mokelumne River has an estimated average annual load of 3 kg mercury and 9 Mkg TSS for WY2000-2003 and 4 kg mercury and 11 Mkg TSS for WY1984-2003 (Table 7.1). Similarly, the San Joaquin River has an average annual load of 19 kg mercury and 146 Mkg TSS and 30 kg mercury and 235 Mkg TSS, for WY2000-2003 and WY1984-2003, respectively.

Several other studies have estimated mercury and sediment loads from the San Joaquin and Mokelumne-Cosumnes watersheds (Table 7.4). All studies confirm that mercury loads from both basins are much smaller than from the Sacramento Basin (Table 7.3). Reported annual mercury loads for the San Joaquin range from 16 to 30 kg/yr. The WY1984-2003 mercury load is 30 ±4 kg/yr. This value is statistically similar to the 20-year load calculated by LWA (2002) of 26 kg/yr. Mercury load estimates for the Mokelumne-Cosumnes watersheds are smaller and range from 2 to 4 kg/yr. The WY1984-2003 load estimate is 4 ±1 kg/yr while the WY1980-1999 LWA (2002) estimate is 3 kg/yr. Again, both 20-year loading rates are statistically similar.

Sediment export rates (Table 7.4) are also much smaller for both the San Joaquin and Mokelumne-Cosumnes systems than for the Sacramento Basin (Table 7.3). Export rates for the San Joaquin varied between 110 and 235 Mkg/yr. The 20-year TMDL rate is the highest calculated for the Basin at 235±39 Mkg/yr. The Mokelumne-Cosumnes sediment yield is lower. The 20-year TMDL value is 11±3 Mkg/yr.

Table 7.4: Comparison of Loading Estimates for Other Major Delta Tributaries

Study	Period	Average San Joaquin Valley Water Year Hydrologic Index (a)	Average Annual TotHg Load [± 95% CI] (kg)	Average Annual TSS Load [± 95% CI] (Mkg)
San Joaquin River @ Vernalis				
Delta TMDL (c)	WY2000-2003	2.7	19 ± 3	146 ± 24
	WY1984-2003	3.1	30 ± 4	235 ± 39
Foe (2002)	WY2001 (b)	2.2	16	110
LWA (2002)	WY1980-1999	3.5	26	na
Wright & Schoellhamer (2005)	WY1999-2002	2.9	na	210 ± 21
Mokelumne River downstream of Cosumnes River Confluence				
Delta TMDL	WY2000-2003	2.7	3 ± 1	9 ± 2
	WY1984-2003	3.1	4 ± 1	11 ± 3
Foe (2002)	WY2001 (b)	2.2	2	5
LWA (2002)	WY1980-1999	3.5	3	na
Eastside Tributaries (Cosumnes, Mokelumne & Calaveras Rivers & French Camp Slough)				
Delta TMDL	WY2000-2003	2.7	8 ± 1	25 ± 2
	WY1984-2003	3.1	10 ± 1	29 ± 3
Wright & Schoellhamer (2005)	WY1999-2002	2.9	na	36 ± 8

(a) Source: DWR, http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST. DWR calculated a hydrologic index for the San Joaquin Valley (Section E.1 in Appendix E). "Normal" hydrologic conditions for the San Joaquin Valley are represented by an index value of 3.1, "wet" is ≥3.8, "dry" is 2.1 to 2.5, and "critical dry" is ≤2.1.

(b) Foe's 2002 CALFED study estimated monthly total mercury and TSS loads for March 2000 through September 2001, but did not include load estimates for November 2000. November total mercury and TSS loads for WY2001 were estimated by averaging the loads for October and December 2000.

(c) See Appendix J for the methods used to estimate the 95% confidence intervals (CI) for the TMDL load estimates.

Mercury and TSS loads for Marsh Creek were estimated using flow at the Marsh Creek Brentwood gage. The Brentwood gage was not operational during WY2000. Therefore, the mercury and TSS loads in Table 7.1 were based on flow data for WY2001-2003. A statistically significant relationship was found for mercury/flow but not for TSS/flow. Mercury concentrations and loads were estimated using the regression, while TSS loads were computed by multiplying the 3-year average annual water volume by the average TSS concentration. The WY2001-2003 annual average mercury and TSS loads were 1 kg/yr and 1 Mkg/yr, respectively.

There are no flow gages on several small east and westside Delta tributaries: Morrison Creek, Bear Creek, Mosher Creek, French Camp Slough, and Ulatis Creek. Average wet season mercury and TSS concentrations (Table 7.2) were multiplied by estimated average annual rainfall runoff volumes (Table 6.1 and Section E.2.2 in Appendix E) to calculate an average annual load. The WY1984-2003 estimate of mercury and suspended sediment yield from the combination of all these small tributaries is 10 ±1 kg/yr and 29 ±3 Mkg/yr, respectively (Table 7.1).

7.1.1.3 Sacramento Basin Tributary Watersheds Loads

The Sacramento Basin accounts for about 80% of all mercury and TSS loading to the Delta (Table 7.1). Therefore, an evaluation was undertaken to determine the contribution of each of the major tributaries. The information may prove useful to help focus follow-up studies and implementation actions on key watersheds that contribute a disproportionate amount of mercury. During low flow, water in the Sacramento River at Freeport primarily originates from Shasta and Oroville Dams in the upper Sacramento and Feather River basins, respectively (Figure 7.1). In contrast, during large storms the Sacramento River at Freeport may be dominated by flows from the American and Feather Rivers. Storm overflow from the upper Sacramento River, Feather River, and Colusa Basin are routed down the Yolo Bypass. The Yolo Bypass also receives flows from Putah Creek and Cache Creek *via* the Cache Creek Settling Basin. The Cache Creek Settling Basin is located at the base of the Cache Creek watershed and currently captures about half of the sediment and mercury transported by Cache Creek (Foe and Croyle, 1998; CDM, 2004; Cooke *et al.*, 2004); untrapped sediment is flushed into the Yolo Bypass.

Four-year (WY2000-2003) and 20-year (WY1984-2003) average annual loading values were calculated for major tributaries to the Sacramento River. Table 7.5 summarizes the mercury and TSS concentration data. Table 7.6a, b, and c present watershed acreages, annual average export rates for water, mercury and TSS. The data were collected by the SRWP, DWR, USGS, CMP, and Central Valley Water Board staff (Appendix M). The water volume calculations are described in Appendix E. Appendix J provides graphs that illustrate time series of the available mercury and TSS data and TotHg/flow and TSS/flow regressions described in the following pages.

Total mercury and TSS concentrations for each tributary were regressed against flow to determine if correlations existed (Appendix J). The TotHg/flow and TSS/flow regressions for the American River, Cache Creek, Colusa Basin Drain, Feather River, and Sacramento River at Colusa were all significant ($P<0.01$) and were used to predict 4- and 20-year average annual loads (Table 7.6). The TSS/flow regression for Putah Creek was statistically significant, but the TotHg/flow regression was not. The TSS/flow regression was used to predict daily concentrations and loads, while mercury loads were calculated from the average mercury concentration (Table 7.5) and the average annual water volume.

No daily flow or concentration data were available for Natomas East Main Drain (NEMD). Concentration data collected by the SRWP, USGS, and City of Roseville were available for Arcade Creek near Norwood, Del Paso Heights, and Dry Creek, all within the NEMD watershed. Wet weather concentration data for Arcade and Dry Creeks (noted in parentheses in Table 7.5) and estimated wet weather runoff for the entire Natomas East Main Drain watershed (Appendix E) were used to develop preliminary load estimates. The Sutter Bypass watershed includes the areas that drain into Butte Creek south of Chico and areas that drain into the Sutter Bypass between the Sacramento and Feather Rivers and south of the Sutter Buttes (Figure 7.1). In addition, flood flows from the Sacramento River upstream of Colusa are diverted into Sutter Bypass through the Moulton and Colusa bypasses; flood flows from the Sacramento River downstream of Colusa are diverted into the Sutter Bypass through the Tisdale bypass.

Floodwaters from the Sacramento River also spill at several locations into the Butte Creek basin and Butte Sink, which drain to Sutter Bypass. During low flow conditions, the Sutter Bypass drains through Sacramento Slough near Karnak into the Sacramento River less than a mile upstream of the Feather River confluence. During high flow, the Sacramento Slough channel is submerged and the Sutter Bypass has unchannelized flow directly into the Sacramento River. Sutter Bypass average annual water volumes and

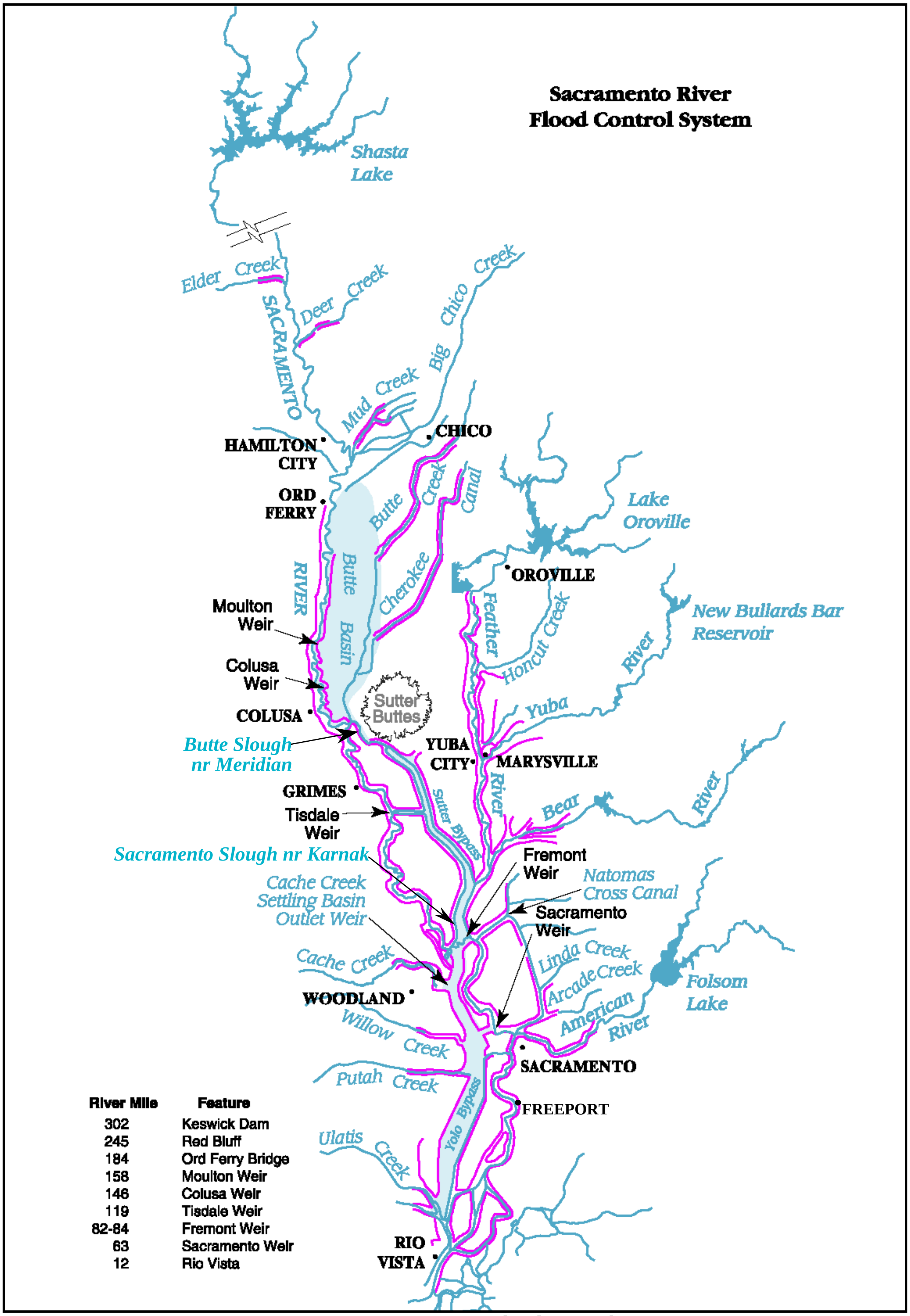

Figure 7.1: Sacramento River Flood Control System.
Pink lines represent levees. (Tetra Tech, 2005; DWR, 2003a)

Table 7.5: Total Mercury & TSS Concentrations for Sacramento Basin Tributaries.

Site	# of Samples	Sampling Begin Date	Sampling End Date	Min. Conc. (ng/l)	Average (ng/l)	Median Conc. (ng/l)	Max. Conc. (ng/l)
Total Mercury Concentrations							
American River @ Discovery Park	155	1/18/94	2/19/04	0.46	2.97	2.14	18.51
Cache Creek Settling Basin	26	12/23/96	2/17/04	4.07	185.73	63.04	984.60
Colusa Basin Drain	63	1/31/95	2/18/04	1.59	11.58	6.90	75.10
Feather River near Nicolaus	77	1/31/95	2/18/04	1.49	6.76	4.31	46.19
Natomas East Main Drain (a)	56 (12)	3/5/96	12/12/02	1.06 (9.52)	10.87 (27.78)	6.88 (20.84)	82.99 (82.99)
Putah Creek @ Mace Blvd.	36	1/31/95	3/09/04	1.25	33.10	9.29	485.00
Sacramento River above Colusa	68	3/10/95	2/17/04	0.60	12.18	4.08	105.16
Sacramento Slough near Karnak (b)	56	2/12/96	9/15/03	0.69	8.81	7.67	30.8
TSS Concentrations							
American River @ Discovery Park	191	12/15/92	2/19/04	0.5	6.23	3.0	116.0
Cache Creek d/s Settling Basin	24	12/23/96	2/17/04	41.0	452.7	187.5	1,900
Colusa Basin Drain	59	2/07/96	2/18/04	21.0	128.0	101.0	487.7
Feather River near Nicolaus	72	3/11/95	2/18/04	2.0	23.5	14.5	123.0
Natomas East Main Drain (a)	30 (8)	3/5/96	3/8/02	5.0 (16.6)	31.3 (43.0)	66.0 (34.5)	122.0 (96.0)
Putah Creek @ Mace Blvd.	27	3/28/00	2/29/04	1.6	53.4	30.0	417.8
Sacramento River above Colusa	51	3/10/95	2/17/04	10.0	101.6	36.0	662.2
Sacramento Slough near Karnak (b)	54	2/12/96	9/15/03	14.8	62.6	53.0	182.0

(a) No concentration or flow data gage data were available for Natomas East Main Drain outflows. The SRWP, USGS and City of Roseville collected total mercury and TSS concentration data on Arcade Creek near Norwood and Del Paso Heights and Dry Creek. Wet weather concentration data for Arcade Creek and Dry Creek (noted in parentheses), and estimated wet weather runoff for the entire Natomas East Main Drain watershed (Table 6.1 in Chapter 6 and Section E.2.2 in Appendix E), were used to develop preliminary load estimates. Note, Natomas East Main Drain was recently renamed “Steelhead Creek”.

(b) Sacramento Slough near Karnak is the low flow channel for Sutter Bypass.

Table 7.6a: Sacramento Basin Tributaries – Acreage & Water Volumes.

Tributary	Acreage	% All Acreage	Water Volume (M acre-feet/yr)		% All Water	
			WY2000-2003	WY1984-2003	WY2000-2003	WY1984-2003
Upstream Tributary Inputs						
American River	1,253,740	7.5	1.88	2.5	11	12
Cache Creek	724,526	4.3	0.22	0.38	1.3	1.9
Colusa Basin Drain	1,577,307	9.4	0.571	0.574	3.4	2.8
Coon Creek/Cross Canal	287,914	1.7	0.089	0.094	0.5	0.5
Feather River	3,793,179	23	3.7	5.5	22	27
Natomas East Main Drain	231,598	1.4	0.064	0.067	0.4	0.3
Putah Creek	652,762	3.9	0.24	0.32	1.5	1.6
Sacramento River @ Colusa	7,562,525	45	8.2	8.1	49	40
Sutter Bypass	682,071	4.1	1.8	2.8	11	14
Sum of Upstream Inputs:	**16,765,622**	**100%**	**16.8**	**20.3**	**100%**	**100%**
Exports to Delta						
Yolo Bypass (Prospect Slough)	- - -		1.0	2.7	6	14
Sacramento River (Freeport)	- - -		15.1	16	94	86
Sum of Exports to Delta:	- - -		**16.1**	**18.7**	**100%**	**100%**
Tributary Inputs – Exports to Delta:			**0.7**	**1.6**		
Exports to Delta / Tributary Inputs:			**96%**	**92%**		

Table 7.6b: Sacramento Basin Tributaries – Total Mercury Loads.

Tributary	Average Annual TotHg Load ± 95 CI (a) (Kg)		% of TotHg Inputs	
	WY2000-2003	WY1984-2003	WY2000-2003	WY1984-2003
Upstream Tributary Inputs				
American River	6 ±0	14 ±0	2.5	3.4
Cache Creek Settling Basin	27 ±3	119 ±5	11.2	28.5
Colusa Basin Drain	9 ±0	11 ±0	3.7	2.6
Feather River	29 ±1	76 ±2	12.0	18.2
Natomas East Main Drain	2	2	0.9	0.5
Putah Creek	10 ±9	13 ±11	4.1	3.1
Sacramento River @ Colusa	139 ±4	152 ±4	57.7	36.5
Sutter Bypass (a)	19	30	7.9	7.2
Sum of Upstream Inputs:	**241 ±10**	**417 ±13**	**100%**	**100%**
Exports to Delta				
Prospect Slough	36 ±2	162 ±9	20	47
Sacramento River @ Freeport	146 ±1	183 ±1	80	53
Sum of Exports to Delta:	**182 ±2**	**345 ±9**	**100%**	**100%**
Trib Inputs - Exports to Delta	**59**	**72**		
Exports to Delta / Trib Inputs	**76%**	**83%**		

(a) Confidence intervals (CI) were calculated for the average annual total mercury loads for the tributary stations with daily flow gages. See Appendix J for the methods used to estimate the confidence intervals.

Table 7.6c: Sacramento Basin Tributaries – TSS Loads.

Tributary	Average Annual TSS Load ± 95% CI (a) (MKg/yr)		% of TSS Inputs	
	WY2000-2003	WY1984-2003	WY2000-2003	WY1984-2003
Upstream Tributary Inputs				
American River	13 ±0	52 ±1	0.7	2.2
Cache Creek Settling Basin	72 ±6	269 ±10	4.2	11.6
Colusa Basin Drain	103 ±2	129 ±3	6.0	5.5
Feather River	100 ±3	254 ±7	5.9	10.9
Natomas East Main Drain	3	16	0.2	0.7
Putah Creek	8 ±2	21 ±2	0.5	0.9
Sacramento River above Colusa	1,266 ±35	1,371 ±35	74	58.9
Sutter Bypass	136	215	8.0	9.2
Sum of Upstream Inputs:	**1,701 ±35**	**2,327 ±37**	**100%**	**100%**
Exports to Delta				
Prospect Slough	273 ±14	1,190 ±87	28.3	57.9
Sacramento River @ Freeport	689 ±7	866 ±7	71.6	42.1
Sum of Exports to Delta:	**962 ±15**	**2,056 ±83**	**100%**	**100%**
Trib Inputs - Exports to Delta	**739**	**271**		
Exports to Delta / Trib Inputs	**43%**	**88%**		

(a) Confidence intervals (CI) were calculated for the average annual TSS loads for the tributary stations with daily flow gages. See Appendix J for the methods used to estimate the confidence intervals.

loads (Table 7.6) were estimated using flows from the DWR gage on Butte Slough near Meridian. The bypass at this location includes flows from Butte Creek and diversions from the Sacramento River made by Moulton and Colusa Weirs (which are upstream of the "Sacramento River above Colusa" sampling station), but not Tisdale Weir or other sources that discharge to the bypass downstream of Meridian. The WY1998-2003 flows were used to estimate long-term average mercury and TSS loads from Sutter Bypass, as only flows for these years are available for the Meridian gage. WY1998-2003 represent a relatively wetter period than the WY1984-2003, hence these load estimates may overestimate the Sutter Bypass contribution to the Delta.

Total mercury and TSS concentration data were available for the Sutter Bypass at Sacramento Slough near Karnak, about 30 miles downstream of the Meridian flow gage. The data were collected between February 1996 and September 2003 during a range of flow conditions, including when Sacramento Slough was submerged. There is a flow gage located nearby; however, it was operational only during the WY1996-1998 period. In addition, it was not rated for flows above 5,200 cfs (Figure 7.2); flows exceeded the 5,200 cfs rating curve happened for extended periods during each year. Therefore, the TotHg/flow and TSS/flow regressions for Sacramento Slough are based only on the samples collected when the Karnak gage recorded flows within its rating curve, most of which are low flow events. Not surprisingly, the TotHg/flow and TSS/flow regressions for Sacramento Slough were not statistically significant. Therefore, a preliminary estimate of Sutter Bypass loading was developed by multiplying water volumes recorded by the Meridian gage by the average total mercury and TSS concentrations observed at Karnak. This calculation does not address any uncertainty associated with using concentration data collected 30 miles downstream of the flow gage.

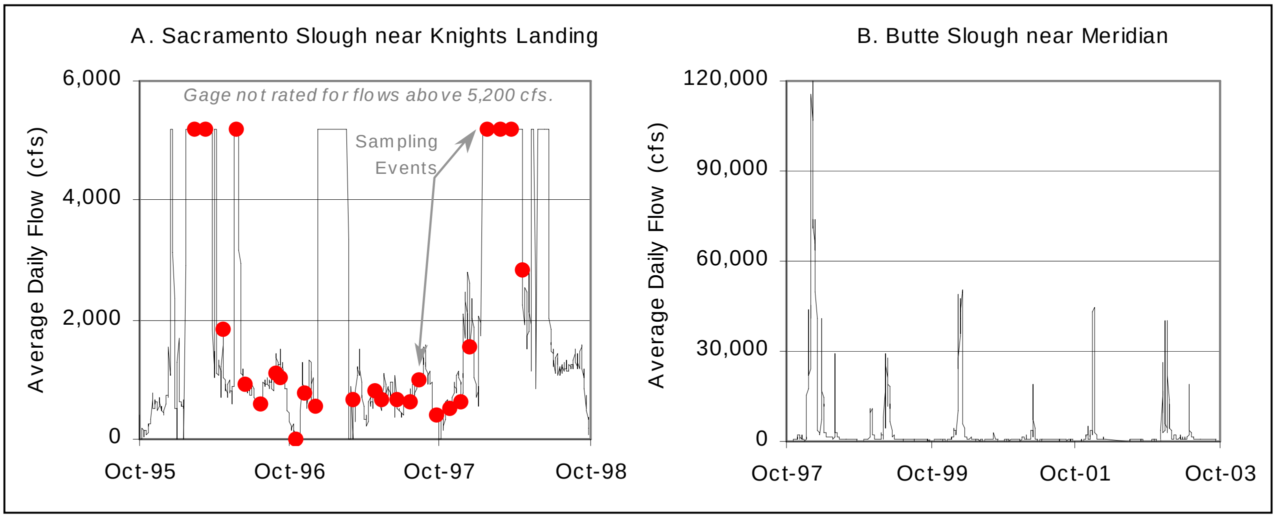

Figure 7.2: Flow Data Evaluated for Sutter Bypass.

Four watersheds provided more than 90% of the annual average water volume of the Sacramento Basin during WY2000-2003 and WY1984-2003 (Table 7.6a). The watersheds are the Sacramento River above Colusa, Feather River, Sutter Bypass and American River. The 4 and 20-year water budgets balance within 4 to 8% indicating that all the major water sources have been identified. A different four watersheds contributed about 90% of the annual mercury load (Table 7.6b). The watersheds are the Sacramento River above Colusa, Cache Creek Settling Basin, Feather River and Sutter Bypass. The sum of tributary mercury inputs for both the 4 and 20-year periods is greater than the load exported to the Delta (Table 7.6b). Mercury exports average 76 to 83% of inputs. This suggests that either tributary loads are overestimated or that deposition is occurring in the river channel upstream of Freeport and/or in the Yolo Bypass.

The same four watersheds that contribute the majority of the mercury also export more than 90% of the sediment (Table 7.6c). The sum of tributary inputs of sediment is greater than the exports to the Delta. Exports range from 43% of inputs during WY2000-2003 to 88% during WY1984-2003. The results suggest, like for mercury, that incoming loads are either being overestimated or that deposition is occurring in the Central Valley. Wright and Schoellhamer (2005) also found that the Sacramento Basin landward of Rio Vista was depositional. However, unlike this report, they concluded that deposition was greater in wet than in dry periods.

7.1.2 Municipal & Industrial Sources

There are 20 NPDES-permitted municipal and industrial discharges to surface water in the Delta[4] (Figure 6.5). Of the 20 facilities in the Delta, five are heating/cooling and power facilities; discharges from these facilities are not considered mercury inputs to the Delta because the available information indicates that the facilities do not add notable amounts of total mercury to the water that they withdraw from Delta waterways. Information on the facilities is from the State Water Resources Control Board's Surface Water Information (SWIM) database.

[4] It is assumed that facility discharges contain negligible amounts of suspended solids.

Information on average flows rates for each facility was obtained from the Central Valley Water Board's discharger project files and permits. Effluent total mercury concentration data were obtained from project files and dischargers' SIP monitoring efforts.[5] Table 6.5 in Chapter 6 and Table G.1 in Appendix G provide additional information about the facilities. Table G.1 lists the estimated annual mercury loads from each facility, which were obtained from the facility-specific average effluent concentration and average daily discharge volume multiplied by 365. Appendix M provides the effluent total mercury concentration data used to calculate the average effluent total mercury loads. It was assumed that total mercury loading from the facilities does not vary substantially between wet and dry years. This consideration will be re-evaluated as additional information becomes available. The sum of facility loads is approximately 2.4 kg/yr, about 1% of all Delta sources (Table 7.1).

7.1.3 Urban Runoff

Approximately 60,000 acres in the Delta are urban, most of which are regulated by NPDES waste discharge requirements. Table 6.10 in Chapter 6 lists the permits that regulate urban runoff and their corresponding acreage. Figure 6.7 shows their locations. Urban areas not encompassed by a MS4 service area were grouped into a "nonpoint source" category.

Total mercury and TSS concentration data were collected by Central Valley Water Board staff and the City and County of Sacramento from several urban waterways within or adjacent to the Delta. Figure 6.8 shows the urban areas and sampling locations, Figure I.1 in Appendix I illustrates the wet and dry weather concentrations by location, and Appendix M provides the concentration data used in Figure I.1. Data generation by analytical methods with detection limits less than 1 ng/l began in 1996. The total mercury concentrations ranged from a dry weather low of 1.06 ng/l (Arcade Creek) to a wet weather high of 1,138 ng/l (Strong Ranch Slough). The TSS concentrations ranged from a dry weather low of less than 3 mg/l (City of Sacramento Sump 111) to a wet weather high of 1,300 mg/l (Strong Ranch Slough). A visual inspection of the total mercury and TSS data suggests that the differences between the urban watersheds are not directly related to land use. Therefore, the data were averaged by wet and dry weather for each location (Table 7.7). The averages of these location-based wet and dry weather averages are assumed to represent runoff from all urban areas in or adjacent to the Delta.

To estimate wet weather mercury and TSS loads, the average wet weather concentrations were multiplied by the runoff volumes estimated for WY2000-2003 and WY1984-2003 for each MS4 area within the Delta. To estimate dry weather mercury and TSS loads, the dry weather concentrations were multiplied by the estimated dry weather urban runoff volume. Appendix E describes the methods used to estimate

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[5] In September 2002, the Central Valley Water Board issued a California Water Code Section 13267 order to all NPDES dischargers (except municipal stormwater dischargers) requiring the dischargers to collect effluent and receiving water samples and to have the samples analyzed for priority pollutants contained in the U.S Environmental Protection Agency's California Toxics Rule and portions of the USEPA's National Toxics Rule. This action was directed by Section 1.2 of the Policy for Implementation of Toxics Standards for Inland Surface Waters, Enclosed Bays, and Estuaries of California, also known as the State Implementation Policy (SIP), which was adopted by the State Water Resources Control Board on 2 March 2000. The SIP monitoring requires that the dischargers' mercury monitoring utilize "ultra-clean" sampling and analytical methods including Method 1669 (Sampling Ambient Water for Trace Metals at EPA Water Quality Criteria Levels, US EPA) and Method 1631 (Mercury in Water by Oxidation, Purge and Trap, and Cold Vapor Atomic Fluorescence, US EPA). The SIP monitoring requires major industrial and municipal NPDES dischargers to collect monthly samples for metals/mercury analysis, and minor industrial and municipal NPDES dischargers to collect quarterly samples. All dischargers were required to submit their effluent and receiving water data by 1 March 2003. Staff evaluated discharge data contributed prior to March 2003 to develop preliminary mercury load estimates. Staff will update this evaluation using the recently received data.

wet and dry weather urban runoff from urban areas within the Delta. Wet and dry weather mercury and TSS loads were summed to estimate the WY2000-2003 average annual loadings of 2.5 kg mercury and 8.0 Mkg/yr suspended sediment and WY1984-2003 average annual loadings of 2.6 kg mercury and 8.3 Mkg/yr TSS (Table 7.8). Urban land uses comprise a small portion of the Delta and contribute about 1% of the mercury load (Table 7.1). In contrast, approximately 320,000 acres of urban land – about 42% of all urban area within the Delta source region – are within 20 miles of the Delta boundary, about one day water travel time upstream. In addition, some of the urban watersheds outside the Delta discharge via sumps into Delta waterways. These discharges were not included in the Delta urban load estimate. As a result, the urban contribution to the Delta mercury load may be underestimated. To evaluate the potential contributions from upstream urban lands, the total mercury loadings from the two MS4 service areas with the greatest urban acreage immediately outside the Delta were estimated for the WY2000-2003 period. The sum of mercury loads from the Sacramento and Stockton MS4 areas may contribute more than 3% of loading to the Delta (Table 7.9). These loads are expected to increase as urbanization continues around the Delta.

7.1.4 Atmospheric Deposition

Atmospheric deposition of mercury has not been measured in the Delta. Figure 7.3 illustrates wet deposition sampling locations in northern and central California, Appendix M provides the available total mercury concentration data, and Table 7.10 summarizes the data. Volume-weighted average total mercury concentrations ranged from 4.1 ng/l at Covelo to 13 ng/l at Sequoia National Park. To estimate wet deposition, the volume-weighted average concentration observed at the North Bay/Martinez station (7.4 ng/l) was used because the station is closest to, and typically upwind of, the Delta. Total mercury loading from precipitation on surface water in the Delta (direct deposition) was estimated by multiplying the average mercury concentration in North Bay/Martinez rainwater (Table 7.10) by the average rainfall volume to fall on Delta water surfaces during WY2000-2003. Loading from runoff of mercury-contaminated rain falling on land (indirect deposition) was estimated by multiplying the average mercury concentration in rainwater by the estimated runoff volume for WY2000-2003. Runoff from urban areas was not included because it is inherently incorporated in the estimates for loading from urban runoff described in Section 7.1.3. Appendix E describes the method used to estimate rainfall runoff volumes for the Delta. Table 7.11 lists the estimated mercury loads from direct and indirect wet deposition. Wet deposition contributes approximately 1% of all mercury entering the Delta (Table 7.1).

There are several uncertainties inherent in the estimates of direct and indirect wet atmospheric deposition in the Delta These include the fact that the concentration of mercury in rain has not been measured and runoff coefficients have not been calculated to determine how much mercury falling on land is carried into surface water. However, these uncertainties are unlikely to have a substantial impact on the overall mercury budget for the Delta (Table 7.1), as atmospheric inputs account for only about 2% of the total mass balance.

Dry mercury deposition rates were not estimated for the Delta because there is no information on airborne particulate mercury concentrations. SFEI (2001b) estimated that about five times more mercury is deposited on an annual basis in dry than in wet deposition in San Francisco Bay. If so, direct dry deposition rates in the Delta may be about 5 kg/yr or 0.5% of the annual load. Dr. Gill (Texas A&M University) is currently measuring wet and dry mercury deposition rates in the Central Valley as part of CALFED project ERP-02-C06-B. The study will be completed and a report prepared by the fall of 2007.

Table 7.7: Summary of Urban Runoff Total Mercury and TSS Concentrations

Urban Watershed	# of Samples	Minimum Conc. (ng/l)	Average Conc. (ng/l)	Maximum Conc. (ng/l)
TOTAL MERCURY				
DRY WEATHER				
Arcade Creek	37	1.06	8.07	34.80
City of Sacramento Strong Ranch Slough	7	3.63	18.43	84.00
City of Sacramento Sump 104	7	1.61	7.78	24.30
City of Sacramento Sump 111	7	2.16	9.59	28.96
Tracy Lateral to Sugar Cut Slough	1	7.92	7.92	7.92
Average of Location Dry Weather TotHg Averages:			**10.36**	
WET WEATHER				
Arcade Creek	14	1.73	20.90	54.30
City of Sacramento Strong Ranch Slough	13	20.10	188.32	1137.90
City of Sacramento Sump 104	14	9.94	36.72	118.42
City of Sacramento Sump 111	13	10.68	28.56	65.23
Stockton Calaveras River Pump Station	5	14.18	26.07	49.71
Stockton Duck Creek Pump Station	1	13.57	13.57	13.57
Stockton Mosher Slough Pump Station	5	9.67	14.16	17.29
Stockton Smith Canal Pump Station	4	23.17	40.97	65.87
Tracy Drainage Basin 10 Outflow	3	8.78	12.13	16.12
Tracy Drainage Basin 5 Outflow	3	7.02	12.59	20.67
Tracy Lateral to Sugar Cut Slough	3	5.44	18.10	28.45
Average of Location Wet Weather TotHg Averages:			**37.46**	
TSS				
DRY WEATHER				
Arcade Creek	28	5.0	31.7	122.0
City of Sac'to Strong Ranch Slough	6	5.0	9.3	15.0
City of Sac'to Sump 104	7	4.0	7.6	12.0
City of Sac'to Sump 111	7	1.5	6.2	11.0
Tracy Lateral to Sugar Cut Slough	1	26.5	26.5	26.5
Average of Location Dry Weather TSS Averages:			**16.26**	
WET WEATHER				
Arcade Creek	12	7.0	99.5	320.0
City of Sac'to Strong Ranch Slough	13	23.0	208.7	1300.0
City of Sac'to Sump 104	14	31.0	104.3	270.0
City of Sac'to Sump 111	11	15.7	92.4	340.0
Stockton Calaveras River Pump Station	5	26.0	94.3	264.6
Stockton Duck Creek Pump Station	1	281.3	281.3	281.3
Stockton Mosher Slough Pump Station	5	6.0	19.6	34.0
Stockton Smith Canal Pump Station	4	76.0	125.8	184.6
Tracy Drainage Basin 10 Outflow	3	81.1	136.9	236.0
Tracy Drainage Basin 5 Outflow	3	26.1	77.5	148.1
Tracy Lateral to Sugar Cut Slough	3	6.3	153.7	342.9
Average of Location Wet Weather TSS Averages:			**126.7**	

Table 7.8: Average Annual Total Mercury and TSS Loadings from Urban Areas within the Delta

MS4 Permittee	WY2000-2003		WY1984-2003	
	TotHg Load (kg/yr)	**TSS Load** (Mkg/yr)	**TotHg Load** (kg/yr)	**TSS Load** (Mkg/yr)
City of Lathrop	0.03	0.10	0.03	0.11
City of Lodi	0.006	0.021	0.007	0.022
City of Rio Vista	0.002	0.005	0.002	0.006
City of Tracy	0.21	0.69	0.22	0.72
City of West Sacramento	0.21	0.69	0.21	0.70
County of Contra Costa	0.60	1.94	0.62	2.01
County of San Joaquin	0.41	1.33	0.42	1.38
County of Solano	0.02	0.06	0.02	0.07
County of Yolo	0.02	0.08	0.02	0.08
Port of Stockton MS4	0.05	0.15	0.05	0.16
Sacramento Area MS4	0.35	1.15	0.36	1.19
Stockton Area MS4	0.47	1.52	0.49	1.58
Urban Nonpoint Source (a)	0.31	0.99	0.10	0.33
Grand Total	**2.5**	**8.0**	**2.6**	**8.3**

(a) Urban areas not encompassed by a MS4 service area were grouped into a "nonpoint source" category within each Delta subarea.

Table 7.9: Comparison of WY2000-2003 Annual Delta Mercury and TSS Loads to Sacramento & Stockton Area MS4 Loads (a)

MS4 Service Area (Urban Acreage)	**Water Volume** (acre-feet) (b)	**TotHg Load** (kg/year)	**TSS Load** (Mkg/yr)
Sacramento MS4 Urban Total	174,593	6.85	22.31
Stockton MS4 Urban Total	25,304	0.97	2.05
Total Delta Inputs (c)	19,425,472	222	1,085
Stockton & Sacramento Urban Runoff as % of Total Delta Inputs	**1.0%**	**3.5%**	**2.2%**

(a) The Sacramento and Stockton Area MS4s are the two MS4 service areas with the greatest urban acreage immediately outside the Delta, with urban land use areas of 154,050 and 24,901acres, respectively.
(b) Refer to Appendix E for urban runoff volume estimates for wet and dry weather, which were summed to estimate the annual average water volumes shown above.
(c) These values represent the sum of all tributary and within-Delta total mercury and TSS sources shown in Table 7.1.

Table 7.10: Summary of Available Data Describing Mercury Concentrations in Wet Deposition in Northern and Central California.

Study (a)	**Station**	**Volume-Weighted Average TotHg Conc.** (ng/l)	**# of Samples**	**Collection Period**
San Francisco Bay Atmospheric Deposition Pilot Study (SFBADPS) (b)	North Bay	7.4	14	Aug. 1999 – Jul. 2000
	Central Bay	6.6	16	
	South Bay (c)	9.7	29	
National Atmospheric Deposition Program (NADP) Mercury Deposition Network (MDN)	San Jose (c)	10	86	Jan. 2000 – Dec. 2003
	Sequoia National Park (d)	13	5	Jul. 2003 – Dec. 2003
	Covelo (e)	4.1	60	Jan. 1998 – Sep. 2000

(a) Sources: NADP MDN – Sweet, 2000; NADP, 2004. SFBADPS – SFEI, 2001. Volume weighted average total mercury concentrations for the South Bay, Central Bay, and North Bay sites were calculated by the SFEI authors (SFEI, 2001). Volume weighted average total mercury concentrations for the San Jose, Sequoia National Park, and Covelo sites were calculated by Central Valley Water Board staff from the NADP data provided in Appendix M.

(b) The North Bay, Central Bay, and South Bay sites are located at Martinez, Treasure Island and Moffett Federal Airfield/NASA Ames Research Center near San Jose, respectively.

(c) In addition to being part of the SFBADPS, the South Bay site also became one of the NADP MDN stations. Co-location of mercury wet deposition sampling under the MDN/NADP with the Pilot Study at the South Bay site began in January 2000 and resulted in ten replicate field precipitation samples.

(d) Sequoia National Park is in the Sierra Nevada Mountains to the southeast of Fresno in the Tulare Basin, which is south of the San Joaquin Basin.

(e) Covelo is ~150 miles north of San Francisco Bay in the Coast Range.

Table 7.11: Average Annual Total Mercury Loads from Wet Deposition for WY2000-2003 (a)

Period/Deposition Type (b)	**Water Volume** (acre-feet) (c)	**TotHg** (kg/year)
Direct Deposition	93,498	0.85
Indirect Deposition	154,100	1.41
TOTAL	247,598	2.26

(a) The volume-weighted average concentration observed in the North Bay/Martinez (7.4 ng/l, Table 7.10) was used to estimate total mercury loading to the Delta.

(b) Direct deposition results from mercury-contaminated rain falling on Delta surface waters. Indirect deposition results from runoff of mercury-contaminated rain falling on land surfaces in the Delta. Runoff from urban areas was not included because it is inherently incorporated in the estimates for loading from urban runoff described in Section 7.1.3.

(c) Refer to Appendix E for a description of the methods used to estimate rainfall runoff volumes.

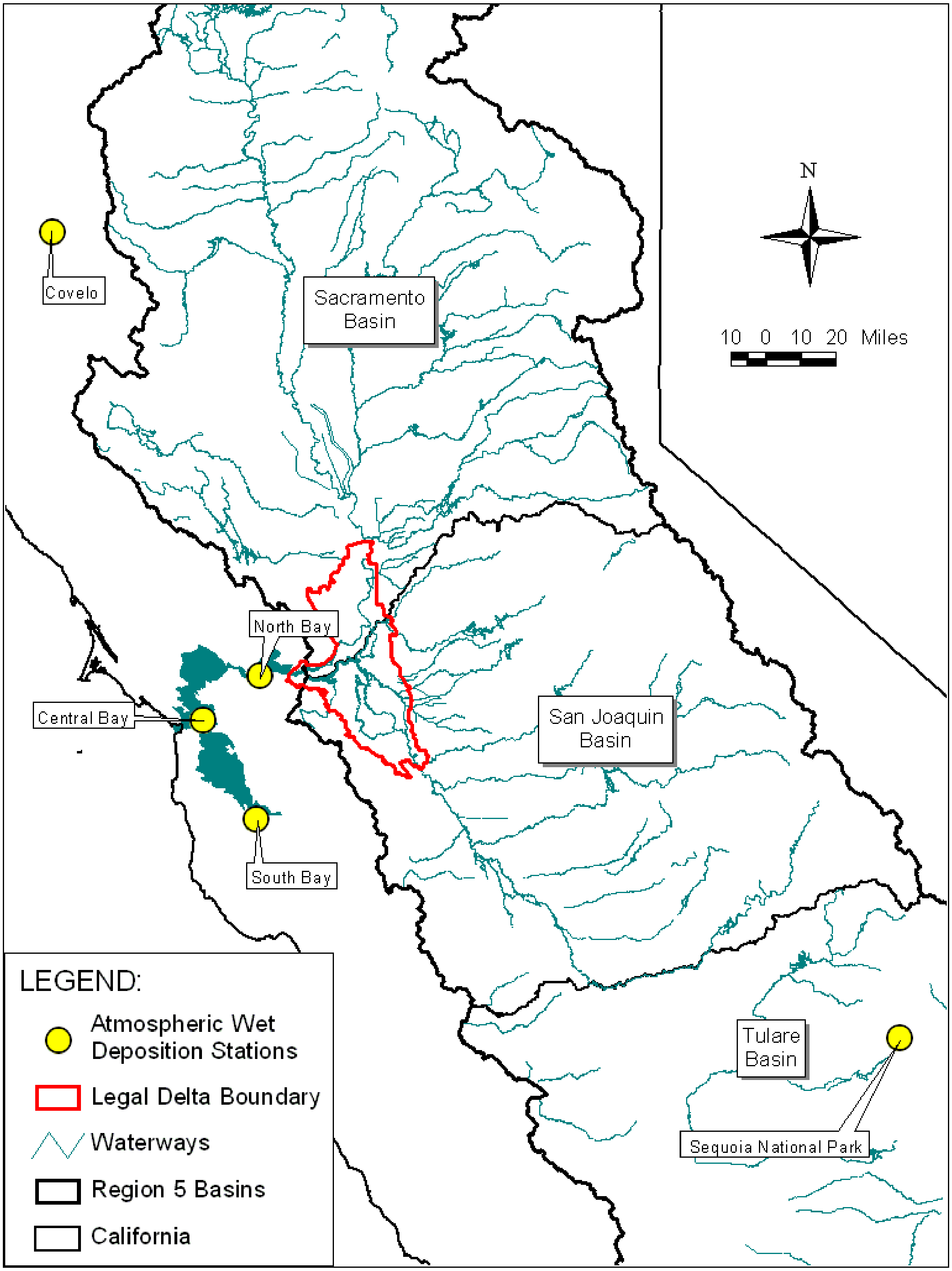

Figure 7.3: Wet Deposition Total Mercury Sampling Locations in Northern and Central California

In an attempt to identify local – and therefore potentially controllable – sources of mercury in atmospheric deposition in the Delta and its tributary watersheds, mercury loads emitted by facilities that report emissions to the California Air Resources Board (ARB) were reviewed. The ARB Emission Inventory Branch tracks mercury loading in air emissions in its California Emission Inventory Development and Reporting System database. ARB staff provided a database describing facilities that reported mercury emissions in 2002. Appendix K provides a summary of the types of facilities in each watershed and their estimated loads. The data indicate that almost 10 kg of mercury were released in the Delta by sugar beet facilities, electric services, paper mills, feed preparation, and rice milling. Cement and concrete manufacturing facilities and crematories in the Delta's tributary watersheds appear to have relatively high mercury emissions. These loads are not incorporated in the mass budgets because their deposition rates are not known. Local air emissions of mercury warrant additional research.

7.1.5 Other Potential Sources

Loading from Delta soils has not been evaluated. More than 70% of Delta lands have agricultural land uses and many of the urban areas in the Delta were once agricultural. Farming began in the Delta in 1849, about the same time that gold mining began in the Sierra Nevada Mountains (DWR, 1995). In 1861, the California legislature authorized the Reclamation District Act, which allowed drainage of Delta swampland and construction of levees; the extensive Delta levee system was mostly built between 1869 and 1880 (DWR, 1995). By 1852, hydraulic mining was the most common method for mining the placer gold deposits in the Sierra Nevada (Hunerlach *et al*., 1999) and continued until the Sawyer Decision outlawed the practice in 1884. Hydraulic gold mining resulted in the deposition of large amounts of silt and sand in Delta channels and upstream rivers (DWR, 1995). Much of these deposits may have been contaminated with mercury used to amalgamate gold. Therefore, some levees and Delta islands may have been constructed with mercury-contaminated sediment.

Barley and other grains have historically been common rotational crops in the Delta (Weir, 1952), and the seeds were treated with mercury-based fungicides before sowing (LWA, 2002). It is not known how much mercury was used in the Delta, but up to 38,000 kg of mercury may have been added in fungicides in the Sacramento Valley between 1921 and 1971 (LWA, 2002). Mercury is no longer used as an active ingredient in any pesticides (DPR, 2002).

Mercury has been measured in 6 soil samples in the Delta source region, mostly from agricultural fields (Bradford *et al.*, 1996). One sample was collected in the eastern Delta near White Slough north of Stockton (0.27 mg/kg) and five samples were collected within 10 miles of the Delta boundary (0.25, 0.34, and three results <0.2 mg/kg). The study authors concluded that there was no relationship between soil mercury levels and location and soil type. Some of the mercury concentrations are elevated above the proposed San Francisco Bay TMDL sediment objective of 0.2 mg/kg indicating that erosion in the Delta area may contribute to exceedances of the Bay area sediment objective.

7.2 Total Mercury and TSS Losses

The following were identified as processes contributing to mercury loss in the Delta: flow to San Francisco Bay, water diversions to areas south of the Delta, removal of dredged sediments, and evasion of elemental mercury. Table 7.12 summarizes mercury and TSS losses by type.

Table 7.12: Average Annual Total Mercury and TSS Losses for WY2000-2003 and WY1984-2003.

	WY2000-2003				WY1984-2003			
	TotHg		TSS		TotHg		TSS	
	Load ± 95% CI (kg/yr)	% of All Losses	Load ± 95% CI (Mkg/yr)	% of All Losses	Load ± 95% CI (kg/yr)	% of All Losses	Load ± 95% CI (Mkg/yr)	% of All Losses
Outflow to San Francisco Bay (a)	258 ±91	70	893 ±260	68	363 ±128	77	1,257 ±367	76
Dredging	57 ±71	16	304	23	57 ±71	12	304	18
Evasion	30	8	- -	--	30	6	--	--
State Water Project (b)	12 ±4	3	47 ±14	4	10 ±3	2	38 ±12	2
Delta Mendota Canal (b)	11 ±1	3	62 ±9	5	10 ±1	2	60 ±9	4
Sum of Losses	**368 ±111**	**100%**	**1306 ±250**	**100%**	**470 ±140**	**100%**	**1659 ±351**	**100%**

(a) Source: Leatherbarrow & others, 2005. The X2 TotHg and TSS loads listed for WY1984-2003 are based on the average annual load calculations for WY1995-2003.

(b) The 95% confidence intervals (CI) were calculated for the State Water Project and Delta Mendota Canal loads using the method described in Appendix J.

7.2.1 Outflow to San Francisco Bay

Estimates of mercury and sediment exports from the Delta to San Francisco Bay are critical components of the Delta mercury TMDL for two reasons. First, outflow to San Francisco Bay is the primary export from the Delta and must be accurately measured to determine whether the Delta is a net source or sink for mercury and sediment. Second, the San Francisco Bay mercury TMDL assigned the Central Valley a mercury load allocation of 330 kg/yr. The allocation must be met either at Mallard Island or by a 110 kg reduction in incoming mercury loads to the Delta (Section 2.4.2.3).

Central Valley Water Board staff evaluated TSS and mercury levels in Central Valley outflows to San Francisco Bay by collecting samples at X2. Figure 6.9 in Chapter 6 illustrates a typical location of X2. Board staff conducted monthly mercury and TSS sampling at X2 from March 2000 to September 2001 (Foe, 2003) and from April 2003 to September 2003 (Appendix M). Table 7.13 and Figures J.4a and J.4b in Appendix J summarize the available total mercury and TSS concentration data for X2. Total mercury concentrations at X2 averaged 17.3 ng/l and ranged from 3.9 ng/l to 49.2 ng/l. The TSS concentrations at X2 averaged 60 mg/l and ranged from 27 mg/l to 168 mg/l. Net daily Delta outflow was obtained from the Dayflow model (Appendix E). Total mercury and TSS concentrations at X2 were regressed against Delta outflow to determine whether either could be predicted from flow. Neither regression was significant. Therefore, average mercury and TSS concentrations were multiplied by average annual water volume for WY2000-2003, WY1984-2003 and WY1995-2005 to estimate annual loads (Table 7.13). These estimates only account for advective or riverine transport and do not incorporate dispersive or tidal flux. Annual average mercury loads to San Francisco Bay were 258, 363, and 660 kg/yr for WY2000-2003, WY1984-2003 and WY1995-2000, respectfully (Tables 7.12 and 7.14).

Table 7.13: Summary of Total Mercury and TSS Concentration Data for X2

	# of Samples (a)	**Min. Conc.**	**Ave. Conc.**	**Median Conc.**	**Max. Conc.**
TotHg (ng/l)	21	3.95	17.29	11.00	49.20
TSS (mg/l)	22	27.0	60.0	42.0	168.0

(a) Sampling at X2 took place between March 2000 and September 2003.

Table 7.14: Estimates of Delta Exports to San Francisco Bay

Study (a)	**Sampling Location**	**Period**	**Average Water Year Hydrologic Index** (b)	**Average Annual Water Volume** (M acre-feet) (c)	**Average Annual TotHg Load** ± 95% CI (kg)	**Average Annual TSS Load** ± 95% CI (kg)	**TotHg:TSS** (mg/kg)
Delta TMDL Program X2 Calculations	X2 (f)	WY2000-2003	7.3	12	258 ±91	893 ±260	0.29
		WY1984-2003	7.8	17	363 ±128	1,257 ±567	
		WY1995-2000	11.0	31	660 ±233	2,290 ±668	
Foe (2002)	X2 (d)	WY2001 (d)	5.8	7.2	122	473	0.25
S.F. Bay TotHg TMDL (2004)	Mallard Island	WY1995-2000	11.0	31	440 ±100	1,600 ±300	0.26 ±0.08
Leatherbarrow & others (2005) (e)	Mallard Island	WY1999-2003	7.8	18	97 ±33	524 ±166	0.11 / 0.29 (e)
		WY2000-2003	7.3	12	83 ±28	450 ±140	
		WY1995-2000	11.0	31	270 ±91	1,600 ±510	
		WY1995-2003	9.6	24	201 ±68	1,202 ±381	

(a) Sources: this report; Leatherbarrow & others, 2005; Johnson & Looker, 2004; Foe (CALFED), 2002.
(b) DWR calculated a hydrologic index for the Sacramento Valley (Appendix E). "Normal" hydrologic conditions for the Sacramento Valley are represented by an index value of 7.8, "wet" is ≥9.2, "dry" is between 5.4 and 6.5, and "critical dry" is ≤5.4.
(c) All average annual water volumes are from the Dayflow model results for Delta outflows to San Francisco Bay.
(d) Foe's 2002 CALFED study estimated monthly total mercury and TSS loads for March 2000 through September 2001, but did not include load estimates for November 2000. November total mercury and TSS loads for WY2001 were estimated by averaging the loads for October and December 2000.
(e) Leatherbarrow and others (2005) extrapolated total mercury loads from suspended sediment flux and suspended sediment mercury levels by adjusting for tidal dispersion and salinity, where for conductivity < 2 mS/cm, TotHg:TSS is 0.11 mg/kg, and conductivity > 2 mS/cm, TotHg:TSS is 0.29 mg/kg. Central Valley Water Board staff averaged the annual load estimates provided by Leatherbarrow and others (2005) for WY1995 through 2003 to estimate average annual loads for the periods that correspond to the San Francisco Bay mercury TMDL study period (WY1995-2000) and the Delta mercury TMDL WY2000-2003 study period.
(f) The 95% confidence intervals (CI) were calculated using the method described in Appendix J. Caution should be used in the comparison of the TMDL program WY1995-2000 and WY1984-2003 load estimates to other studies because the export rates used in the calculation are greater than those measured by others and may be biased high.

Four studies have measured mercury and sediment loads to San Francisco Bay from the Delta (Table 7.14). The results are surprisingly variable and range from 83 to 660 kg/yr. Some of the variation is undoubtedly due to the fact that different studies have measured export rates in different hydrologic years. However, three studies estimated annual average mercury export rates for WY1995-2000. The values range between 270 ±91 and 660 ±233 kg/yr (Table 7.14). The lower two rates (270 and 440 kg/yr) may be the more accurate for several reasons. First, both incorporate estimates of tidal dispersion in their load calculations. Tidal dispersion at Mallard Island reduces export rates as incoming tides have a greater sediment and mercury concentration than outgoing ones. This reduces the net export rate and likely provides a more accurate estimate. Second, both lower rates measured mercury at Mallard Island. In contrast, the TMDL measured sediment and mercury concentrations at X2. X2 is centered at Mallard Island but moves about 10 miles up and down the estuary depending on river outflow and tidal stage. X2 measurements are appropriate for predicting biotic exposure of water column organisms, such as pelagic fish, to methylmercury. This was the primary objective of the study. However, such measurements are undoubtedly less reliable than repeated water column measurements at Mallard Island for predicting mercury and sediment transport past the island. All present studies are deficient in that they did not measure export rates during high flow. High flow is when most of the mercury and sediment is in motion.

The Delta experienced high outflow during January and February of 2006. SFEI, Central Valley and San Francisco Bay Regional Board staff collaborated on a cooperative study of mercury and sediment transport at Mallard Island. A report should be available in the spring of 2007. It is recommended, until consensus is reached on 20-year export rates at Mallard Island, that compliance with the San Francisco mercury allocation to the Central Valley be determined by monitoring Delta inputs.

7.2.2 Exports South of Delta

Water diversions to the San Joaquin Valley and southern California account for 4 to 9% of mercury and TSS exports from the Delta (Table 7.12). Delta Mendota Canal (DMC) and State Water Project (SWP) exports were evaluated by collecting water samples from the DMC canal off Byron highway (County Road J4) and from the input canal to Bethany Reservoir, respectively. Bethany is the first lift station on the State Water Project canal system and is about one mile south of Clifton Court Forebay in the Delta (Figure 6.9).

Central Valley Water Board staff collected monthly total mercury and TSS samples from the DMC and SWP between March 2000 and September 2001 (Foe, 2003) and between April 2003 and 2004 (Appendix M). Table 7.15 and Figures J.4a and J.4b in Appendix J summarize the data. DMC and SWP exported water volumes were obtained from the Dayflow model (Appendix E). Total mercury and TSS concentrations were regressed against daily flow at both sites to determine whether concentrations could be predicted from flow. The regressions were not significant. Therefore, average mercury and TSS concentrations were multiplied by the WY2000-2003 and WY1984-2003 average annual water volume to estimate loads (Table 7.12).

Table 7.15: Summary of Total Mercury and TSS Concentration Data for Exports South of the Delta

Site	# of Samples (a)	Min. Conc.	Ave. Conc.	Median Conc.	Max. Conc.
Delta Mendota Canal					
TotHg (ng/l)	21	1.85	3.48	3.41	5.96
TSS (mg/l)	22	9.2	20.1	18.9	36.0
State Water Project					
TotHg (ng/l)	19	0.99	3.02	2.23	7.17
TSS (mg/l)	21	4.4	12.0	8.2	59.0

(a) Sampling of these exports took place between March 2000 and September 2003.

7.2.3 Dredging

Sediment is dredged from the Delta to maintain the design depth of ship channels and marinas. Dredge material is typically pumped to either disposal ponds on Delta islands or upland areas with monitored return-flow. Table 6.18 provides details on recent dredge projects in the Delta and Figure 6.9 shows their approximate location. The Sacramento and Stockton deep water channels have annual dredging programs; the locations dredged each year vary. Dredging occurs at other Delta locations when needed, when funds are available, or when special projects take place. Approximately 533,000 cubic yards of sediment are removed annually with about 200,000 cubic yards from the Sacramento Deep Water Ship

Channel and about 270,000 cubic yards from the Stockton Deep Water Channel. Other minor dredging projects, mostly at marinas, remove an additional 64,000 cubic yards per year.

The amount of mercury removed annually by dredging was estimated by multiplying dredge volume at each project site by its average mercury concentration. Average mercury concentrations in the sediment for the project sites range from 0.04 to 0.44 mg/kg (dry weight). Two critical assumptions were made to calculate the total mercury removed from the Delta by dredging projects:

- Water content of the dredged material is 100% (50% water and 50% sediment by weight) (USACE, 2002); and
- There are about 570 kilograms of dry sediment per cubic yard of wet dredged material based on relative densities of water and sediment (Weast, 1981; Elert, 2002).

The calculations indicate that annual dredging in the Delta removes about 57 kg of mercury and 304 Mkg of sediment. This accounts for approximately 12 to 16% of the mercury and 18-23% of all sediment exports (Table 7.12). Board staff will continue to collect dredging data and evaluate the annual variability of the measurements.

7.2.4 Evasion

The loss of elemental mercury from water surfaces can be estimated on the basis of measured dissolved gaseous elemental mercury concentrations, atmospheric mercury concentrations, and estimated wind speeds (Conaway *et al.*, 2003). Conaway and others (2003) estimated summer and winter evaporation rates for San Francisco Bay. The Bay has a surface area of approximately 1.24 x 10^9 square meters (~306,400 acres) and is estimated to lose about 190 kg/yr of mercury to the atmosphere (Johnson & Looker, 2004). Similar estimates are not available for the Delta. However, an ongoing CALFED project (ERP-02-C06-B) is attempting to measure evasion in the Delta. The results should become available in 2007. To obtain a preliminary estimate of evasion in the Delta, it was assumed that the loss rate would be proportional to that of San Francisco Bay. The mercury lost from the Bay's surface (190 kg/year) was multiplied by the ratio of the water surface area of the Delta to that of the Bay (0.16). The result is an evasion rate of about 30 kg/yr or 6 to 8 % of all mercury losses.

7.3 Total Mercury & Suspended Sediment Budgets

Delta mercury and suspended sediment assessments rely on a box model approach to approximate mass balances. Mass balances are useful because the difference between the sum of known inputs and exports is a measure of the uncertainty of the load estimates and can provide an indication of whether the Delta is depositional or erosional. The average annual water, mercury and TSS budget for WY2000-2003 is presented in Table 7.16.

The sum of water inputs and exports balance within 2%, indicating that all the major water sources and losses have been identified. In contrast, the mercury and TSS budgets do not balance. The best estimate of mercury and TSS loads indicate that exports are greater than imports. This would imply that the Delta is erosional, at least for dry years such as WY2000-2003. However, this conclusion should be viewed with caution because the export rates used in the calculation are greater than those measured by others (Table 7.13) and may be biased high. The results are also in conflict with the conclusions of Wright and

Schoellhamer (2005), who determined that about 65% of the sediment entering the Delta was deposited there. The mass balance calculations should be repeated once a better estimate of mercury and sediment exports at Mallard Island are determined.

Table 7.16: Water, Total Mercury & TSS Budgets for the Delta for WY2000-2003.

	Water Volume (M acre-feet/yr)	**Average Annual Load**	
		Total Mercury (kg/yr)	TSS (Mkg/yr)
Inputs	19.38	221 ±3	1,164 ±28
Exports	19.04	368 ±111	1,306 ±250
Inputs - Exports	**0.34**	**-147**	**-142**
Exports ÷ Inputs	**98%**	**167%**	**112%**

7.4 Evaluation of Suspended Sediment Mercury Concentrations & CTR Compliance

The evaluation of mercury contamination on suspended sediment particles for each Delta input and export site – in tandem with the source load analyses described in Sections 7.1 and 7.2 – is used to identify locations for possible remediation. The recommended total mercury control strategy described in Chapter 8 focuses on sources that have large mercury loadings and suspended sediment with high mercury concentrations, the premise being that it will be more cost effective to focus cleanup efforts on watersheds that export large amounts of highly contaminated sediment. In addition, the strategy incorporates source reductions needed to meet and maintain compliance with the CTR throughout the Delta.

7.4.1 Suspended Sediment Mercury Concentrations

Table 7.17 lists mercury to TSS ratios for Delta sources and export sites calculated using three different methods. The three approaches provide a range of particulate mercury contamination fluxing past a site. First, the ratios (in mg/kg) were estimated by dividing average annual mercury load (kg) by average annual TSS load (Mkg). This relationship is the preferred approach for Delta tributaries with statistically significant mercury and TSS relationships with flow because it provides a flow-weighted estimate. The ratio was also estimated from the slope of the regression between mercury and TSS using paired samples. This is the preferred approach for exports at Mallard Island as it is not biased by not having an accurate measure of the total export load. The least acceptable method is to take the median of the mercury to TSS ratios computed from individual paired samples. The median value tends to overemphasize low and moderate flows (the flows sampled most often) and not high flow events, which transport the majority of the suspended sediment and mercury. All three methods slightly overestimate particulate mercury (the focus of the San Francisco Bay sediment goal of 0.2 mg/kg) because none subtract the dissolved fraction from the total mercury concentration.

Table 7.17: Mercury to Suspended Sediment Ratios for Delta Inputs and Exports

	# of TotHg/TSS Paired Samples	**Method A** (a) TotHg Load ÷ TSS Load		**Method B** Linear Regression Slope for Paired TotHg/TSS (b)	**Method C** Median of TotHg/TSS Paired Sample Results
		WY2000-2003	WY1984-2003		
DELTA INPUTS					
Bear/Mosher Creeks	5	0.12		0.07	0.24
Calaveras River	4	0.25		0.17	0.41
French Camp Slough (c)	5	0.69		0.62 (0.32)	0.20
Marsh Creek	7	0.47		0.12	0.19
Mokelumne-Cosumnes Rivers	21	0.37		0.35	0.41
Morrison Creek (d)	44	0.24		0.16	0.24
Prospect Slough (Yolo Bypass)	24	0.18	0.16	0.16	0.19
Sacramento River (Freeport)	150	0.22	0.21	0.17	0.23
San Joaquin River	30	0.13		0.13	0.14
Ulatis Creek	6	0.13		0.11	0.19
Urban Runoff (e)	128 (123)	0.31		0.18 (0.22)	0.35
DELTA EXPORTS					
Outflows to San Francisco Bay (X2)	21	0.18		0.30	0.28
State Water Project	19	0.25		0.17	0.29
Delta Mendota Canal	21	0.15		0.16	0.18
Dredging (f)	*8 projects*	0.19		- - -	04 to 0.44
TRIBUTARIES TO THE SACRAMENTO BASIN [Sacramento River + Yolo Bypass]					
American River	117	0.46	0.27	0.20	0.41
Cache Creek Settling Basin	22	0.42	0.46	0.47	0.36
Colusa Basin Drain	56	0.09	0.09	0.09	0.07
Feather River	61	0.29	0.30	0.26	0.32
Natomas East Main Drain (Arcade Ck.)	30	0.65		0.22	0.32
Putah Creek	28	1.25	0.64	0.26	0.31
Sacramento River above Colusa	50	0.10	0.10	0.12	0.11
Sutter Bypass (Sacramento Slough)	52	0.14		0.13	0.13

(a) The preferred method for each monitoring location is highlighted in gray. If total mercury concentrations and TSS concentrations both correlated well with daily flow at a given monitoring location, Method A was the preferred method for estimating suspended sediment mercury concentrations. If the available concentration data for a location were too variable and/or sparse to reliably estimate annual average suspended sediment concentrations, none of the values were highlighted. The WY1984-2003 period was evaluated only for Sacramento Basin tributaries because the other tributary loads are based on average concentrations, resulting in the same TotHg:TSS ratios for both periods.

(b) Regressions between total mercury and TSS concentrations are illustrated in Appendix J.

(c) Alternate value noted in parentheses for French Camp Slough does not include one unusually high total mercury result.

(d) Appendix J provides the data for each Morrison Creek sampling location. The values noted in this table were generated from the compilation of data from all the sites.

(e) Urban runoff samples were collected at eleven locations. Methods B and C were performed between the urban runoff total mercury and TSS concentration data with and without five dramatically different sample TotHg:TSS ratios observed for Strong Ranch Slough.

(f) Sediment mercury concentrations in dredged material varied substantially across the Delta. The range of project-specific average concentrations was 0.02 to 0.77 mg/kg. The volume-weighted average mercury concentration of all the dredged material was approximately 0.19 mg/kg.

7.4.1.1 Mercury to TSS Ratios for Delta Outflows to San Francisco Bay

The San Francisco TMDL for mercury proposes a sediment objective of 0.2 mg/kg (Johnson & Looker, 2004). Mercury contamination on sediment in Delta outflow to San Francisco Bay averaged between 0.18 mg/kg and 0.30 mg/kg (Table 7.17). The low value is from estimates of mercury and suspended sediment loads at Mallard Island and should be viewed with caution. In contrast, the ratio of 0.28 to 0.30 mg/kg is from measurements taken in mid channel at X2 (Foe, 2003). These ratios may overestimate the degree of mercury contamination being exported from the Central Valley to San Francisco Bay. The major source of mercury and sediment to the Delta is from the Sacramento Basin. Suspended sediment ratios for the Sacramento River and Yolo Bypass range between 0.16 and 0.23 mg/kg of mercury (Table 7.17). These values are also consistent with bulk sediment concentrations in the Delta of 0.15 to 0.2 mg/kg determined by Slotton and others (2003) and Heim and others (2003). The results suggest that the contaminated sediment at X2 did not originate from the Central Valley during the study period.

The X2 ratios of 0.28 to 0.30 are similar to suspended sediment concentrations of 0.33 mg/kg in San Pablo Bay (Schoellhamer, 1996) and bulk surficial sediment concentrations in Suisun Bay of 0.3 to 0.35 ppm (Slotton *et al.*, 2003; Heim *et al.*, 2003). Hornberger and others (1999) report that the mercury concentration of sieved surficial sediment (<0.64 µm) in a core from Suisun Bay was 0.30 mg/kg; however, the concentration increased to 0.95 mg/kg at a depth of 30 cm. The mercury enriched zone persisted to a depth of about 80 cm before declining to a baseline concentration of 0.06 ±0.01 mg/kg. The increased mercury concentration at 30-cm was ascribed to deposition of mercury contaminated gold tailings. No current information is available on erosion rates in Suisun and Grizzly Bays but both embayments were eroding at the rate of 528 Mkg per year between 1942 and 1990 (Cappiella *et al.*, 2001). Therefore, a hypothesis is that the elevated mercury contamination on particles at X2 is the result of continuing erosion from Suisun Bay and possibly San Pablo Bay. Both embayments are within the legal jurisdiction of the San Francisco Bay Water Board and are part of its TMDL for mercury.

Urban runoff and almost all Delta inputs have mercury to TSS ratios greater than 0.2 mg/kg (Table 7.17). Exceptions are the San Joaquin River, Ulatis Creek, and Yolo Bypass. An evaluation of the tributary sources to the Sacramento River and Yolo Bypass indicates that all but the Sacramento River above Colusa, Sacramento Slough and Colusa Basin Drain have ratios greater than 0.2 mg/kg. A comparison of Table 7.5 and Table 7.17 indicates that several tributaries in the Sacramento Basin have high mercury to TSS ratios and large loads of mercury. Cache Creek and Feather River have high ratios and high average annual total mercury loads. This makes both attractive candidates for mercury control programs. The American River and Putah Creek also have high ratios but comparatively smaller mercury loads. In contrast, the Sacramento River above Colusa and Sacramento Slough (which receives most of its annual flows when upper Sacramento River flood waters are diverted to Sutter Bypass) have ratios comparable to background levels (0.10 and 0.14 mg/kg, respectively) but high mercury loads. This is because both are transporting large amounts of sediment. The 2002 LWA report noted a similar pattern in its evaluation of median mercury to TSS ratios for the Sacramento Basin. Suspended sediment mercury concentrations between 0.03 and 0.19 mg/kg may result from a combination of erosion of background soils and atmospheric deposition from regional and global mercury sources. Therefore, the low mercury to TSS ratios for the upper Sacramento River watershed may indicate, unless site-specific hot spots are found, that very little total mercury could be removed by means other than erosion control.

7.4.2 Compliance with the USEPA's CTR

The USEPA's California Toxic Rule mercury objective is 0.05 µg/L (50 ng/l) total recoverable mercury for freshwater sources of drinking water. The CTR criterion was developed to protect humans from exposure to mercury in drinking water and in contaminated fish. It is enforceable for all waters with a municipal and domestic water supply or aquatic beneficial use designation. This includes all subareas of the Delta. The CTR does not specify duration or frequency. As noted in Chapter 2, the Central Valley Water Board has previously employed a 30-day averaging interval with an allowable exceedance frequency of once every three years for protection of human health.

Mercury samples were not collected at a sufficiently high frequency to evaluate compliance with a 30-day average. Data therefore do not exist to show whether the CTR has actually been exceeded. To evaluate compliance with the CTR, regression analyses of flow and concentration were used to estimate 30-day running averages. As described in Sections 7.1.1.1 through 7.1.1.3, total mercury concentrations measured in instantaneous grab samples at Delta and Sacramento Basin tributary locations near flow gages were regressed against daily flow to determine if total mercury concentrations for days with no concentration data could be predicted. Figures 7.4 and 7.5 illustrate the regression-based 30-day running averages for locations with statistically significant ($P<0.01$) TotHg/flow correlations. Appendix J provides the TotHg/flow regressions upon which the 30-day averages are based. Table 7.18 provides a summary of the CTR compliance evaluation.

A waterway location was considered to be in compliance if its regression-based 30-day average total mercury exceeded 50 ng/l no more than once in any three-year period. Some locations had total mercury/flow regressions that were not statistically significant; also, some locations with concentration data were not near a flow gage. Such locations on larger waterways (e.g., Mokelumne River and San Joaquin River) were considered likely to be in compliance if none of the grab samples had mercury concentrations that exceeded 50 ng/l. Locations on small tributaries that typically experience short-duration, storm-related high flow events (e.g., French Camp Slough and Ulatis Creek) were considered likely to be in compliance if none of the water samples had mercury concentrations exceeding 50 ng/l, or if the exceedances occurred only during peak storm flows.

The evaluation of regression-based 30-day running average total mercury concentrations and available grab sample total mercury results indicates that all sampled locations within the Delta – except possibly Prospect Slough and Marsh Creek – are in compliance with the CTR criterion for total mercury. Although none of the grab samples collected from Marsh Creek near Highway 4 exceeded 50-ng/l total mercury, the regression-based 30-day running averages indicated that the CTR criterion might have been exceeded during one period. However, only about three years of flow data were available for the Marsh Creek location; therefore, compliance with the CTR criterion cannot be adequately determined with available data. Marsh Creek is already identified on the 303(d) List as impaired by mercury. The future mercury TMDL monitoring program for Marsh Creek will conduct another evaluation of CTR compliance as more data become available.

Evaluation of Yolo Bypass compliance with the CTR is complicated by the variety of watersheds that contribute water to it during varying hydrologic regimes. During low flow conditions, the Yolo Bypass receives flows from coastal mountain watersheds, particularly Cache Creek and Putah Creek, and other agricultural and native areas that drain directly to the bypass (Figure 7.1). During high flow conditions on the Sacramento River, excess flows from the upper Sacramento River, Sutter Bypass, Feather River,

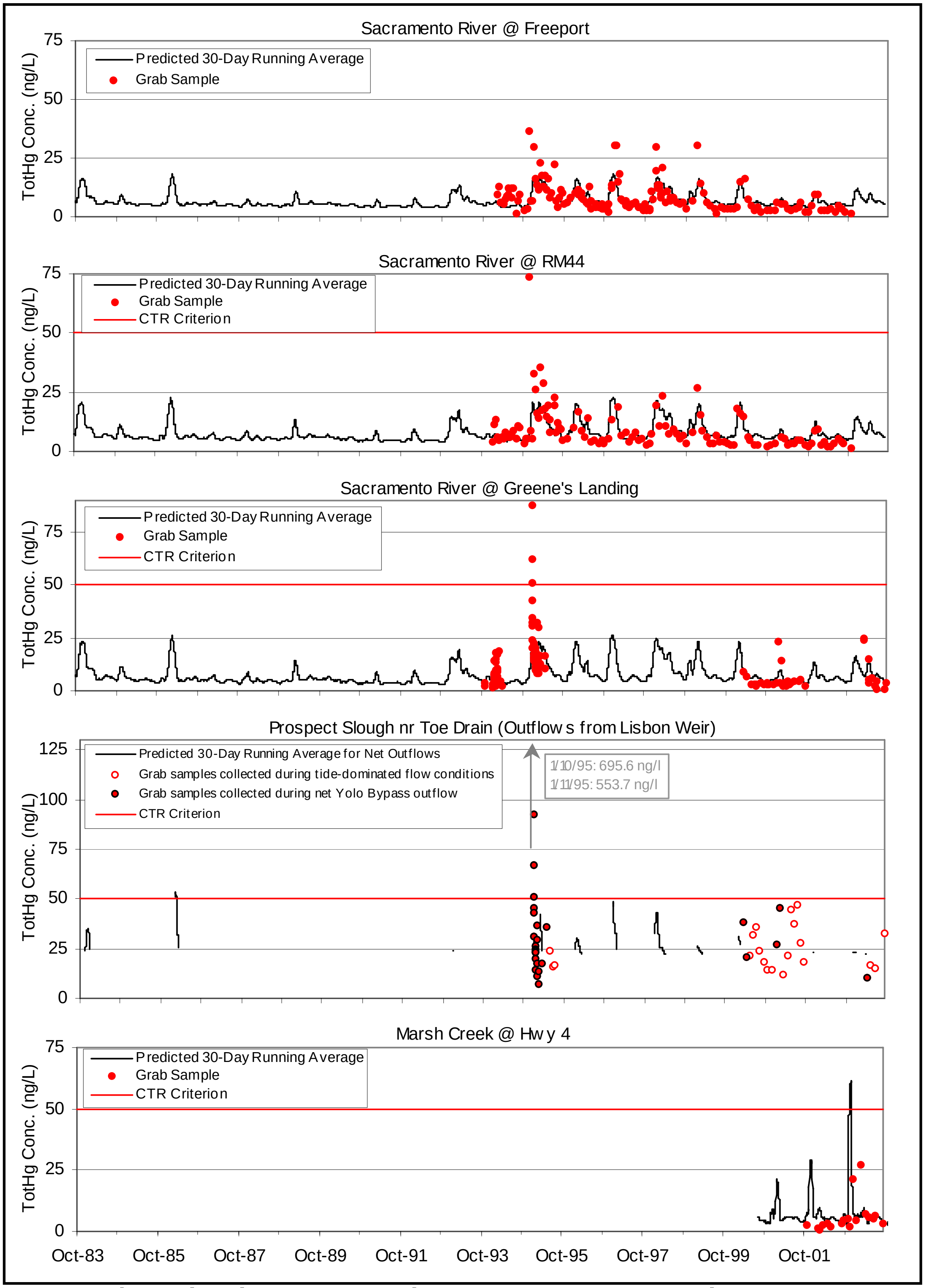

Figure 7.4: Grab Sample and Regression-Based 30-Day Running Average Total Mercury Concentrations for Delta Locations with Statistically Significant (P<0.05) Aqueous TotHg/Flow Correlations

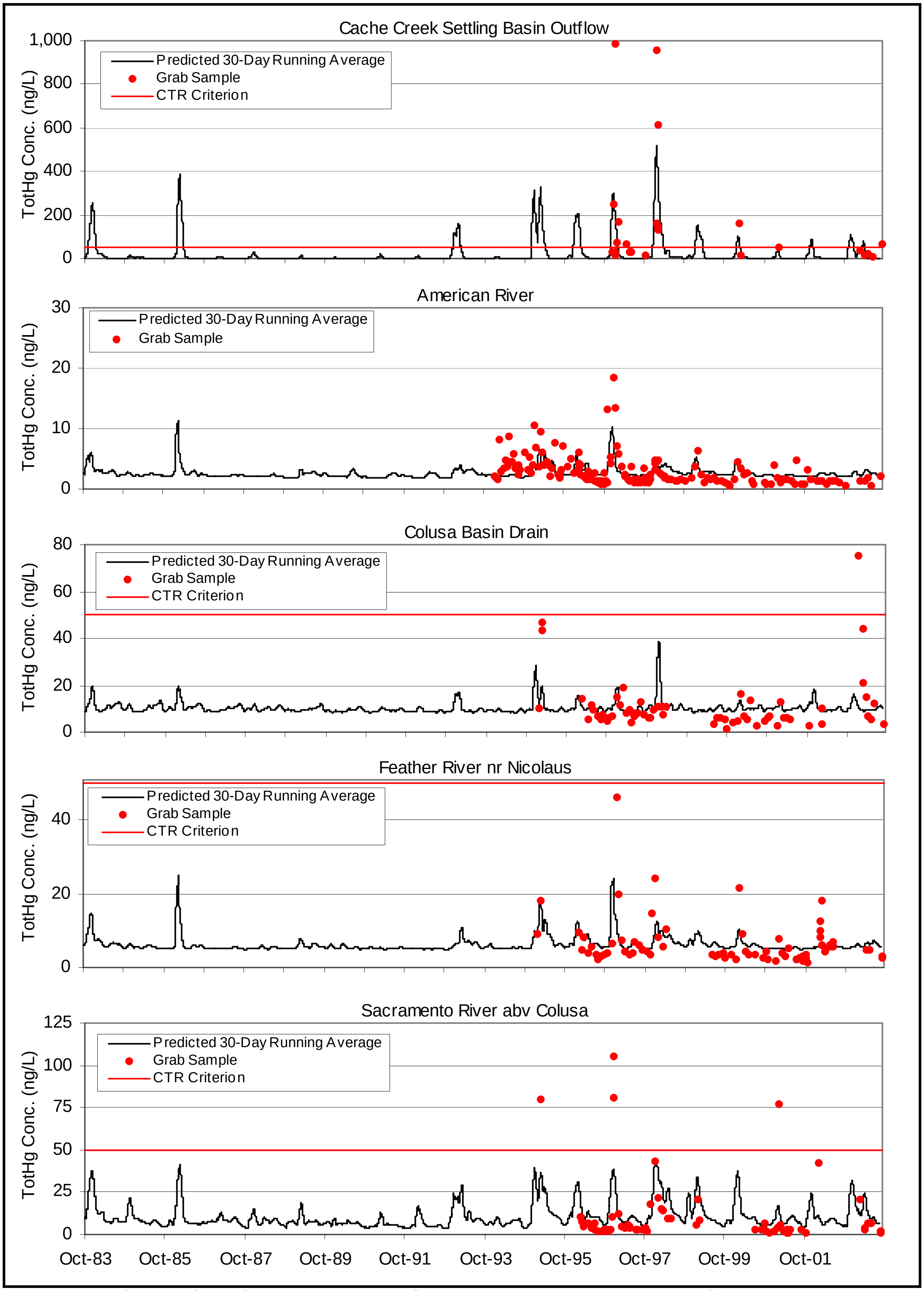

Figure 7.5: Grab Sample and Regression-Based 30-Day Running Average Total Mercury Concentrations for Sacramento Basin Tributary Locations with Statistically Significant (P<0.05) Aqueous TotHg/Flow Correlations

Table 7.18: Evaluation of CTR Compliance at Delta and Sacramento Basin Tributary Locations

Site	Is TotHg/Flow Regression Significant? (a)	Does Predicted 30-Day Average TotHg Ever Exceed CTR's 50 ng/l? (a)	# of Grab Samples > 50 ng/l	Is the Site in Compliance with CTR?
DELTA LOCATIONS				
Bear/Mosher Creeks (b)	- - -	- - -	0	Likely Yes
Calaveras River @ RR u/s West Lane (b)	- - -	- - -	0	Likely Yes
Delta Mendota Canal	No	- - -	0	Likely Yes
French Camp Slough near Airport Way	- - -	- - -	1	Likely Yes
Marsh Creek @ Hwy 4	Yes	Once in 3 year record.	0	***Possibly Not***
Mokelumne River @ I-5	No	- - -	0	Likely Yes
Morrison Creek (c)	- - -	- - -	0	Likely Yes
Outflow to San Francisco Bay	No	- - -	0	Likely Yes
Prospect Slough (Yolo Bypass) (d)	Yes	Once (d).	5	***Possibly Not***
Sacramento River @ Freeport (e)	Yes	No.	0	Yes
Sacramento River @ Greene's Landing (e)	Yes	No.	4	Yes
Sacramento River @ RM44 (e)	Yes	No.	1	Yes
San Joaquin River @ Vernalis	No	- - -	0	Likely Yes
State Water Project	No	- - -	0	Likely Yes
Ulatis Creek near Main Prairie Rd	- - -	- - -	2	Likely Yes
SACRAMENTO BASIN TRIBUTARIES (f)				
American River @ Discovery Park	Yes	No.	0	Yes
Cache Creek d/s Settling Basin	Yes	In 11 of 20 years.	15	***No***
Colusa Basin Drain	Yes	No.	2	Yes
Feather River near Nicolaus	Yes	No.	0	Yes
Natomas East Main Drain (g)	- - -	- - -	1	Unknown
Putah Creek @ Mace Blvd.	No	- - -	4	***Possibly Not***
Sacramento River above Colusa	Yes	No.	4	Yes
Sacramento Slough near Karnak (h)	No	- - -	0	Likely Yes

(a) Flow gage data were not available for most of the small tributary outflows to the Delta. All of the regressions for sampling locations near a flow gage were based on 20-year flow datasets except for Marsh Creek, for which only a 3-year dataset was available. Regressions were considered statistically significant for R^2 values with $P < 0.05$. Appendix J provides the regression plots.

(b) Only wet weather events were sampled on the Calaveras River and Bear and Mosher Creeks in Stockton. The one wet weather Mosher Creek sample result was combined with the Bear Creek dataset to evaluate compliance for both creeks.

(c) Concentration data collected at multiple sites on lower Morrison Creek were compiled to evaluate compliance.

(d) Sampling took place at Prospect Slough (export location of the Yolo Bypass) both when there were net outflows from tributaries to the Yolo Bypass and when there was no net outflow (i.e., the slough's water was dominated by tidal waters from the south). The regression analysis focuses only on the conditions when there was net outflow from the Yolo Bypass. Available flow information (Appendix E) indicates that during many years, the Yolo Bypass does not have a net outflow that lasts for 30 days or more.

(e) The Sacramento River sampling locations at Freeport and River Mile 44 (RM44) are upstream and downstream, respectively, of the outfall for the Sacramento Regional County Sanitation District's Sacramento River Wastewater Treatment Plant. Greene's Landing is about nine miles downstream of the RM44 sampling location. Concentration data collected at all three sites were regressed against the flow data recorded at the Freeport gage, as no other gages are operational in this river reach. Appendix M provides the total mercury concentration data available for all three Sacramento River locations.

(f) Flows from the listed tributary watersheds may be diverted to the Yolo Bypass during high flow conditions via Knights Landing Ridge Cut, Fremont Weir and Sacramento Weir. The Coon Creek/Cross Canal watershed also contributes to the Sacramento River downstream of the Feather River but no aqueous total mercury data are available for its discharges.

(g) No concentration or flow data gage data were available for Natomas East Main Drain outflows. The SRWP, USGS and City of Roseville collected total mercury concentration data on Arcade Creek near Norwood and Del Paso Heights and Dry Creek. It was assumed that this dataset characterizes NEMD outflows.

(h) Sacramento Slough near Karnak is the low flow channel for Sutter Bypass.

Colusa Basin, and American River watersheds may be routed down the Yolo Bypass at Fremont Weir, Sacramento Bypass and Knights Landing Ridge Cut. In a typical storm event, flows from the Cache Creek Settling Basin (northwest and outside of the legal Delta boundary) and other local sources reach the Yolo Bypass first, to be followed by lower concentration inputs from the Colusa Basin, Sacramento River and Feather River.

As indicated in Figure 7.4 and described in detail in Appendix E (Section E.2.2 and Figure E.2), the Yolo Bypass may not experience 30 days of continuous net outflow from Lisbon Weir upstream of Prospect Slough during dry years. In addition, storm data collected in 1995 indicate that total mercury concentrations in Prospect Slough (the primary outflow from the Bypass to the Delta) peak for a very short time. To evaluate conditions within the Bypass, the total mercury levels in tributary inputs to the Bypass were evaluated (Figure 7.5). The regression-based 30-day averages of predicted total mercury concentrations in the Sacramento River upstream of Colusa and the Feather River indicate that their flows are in compliance with the CTR criterion. However, the regression-based 30-day running average total mercury concentrations in Cache Creek Settling Basin outflows indicate that Cache Creek flows into the Yolo Bypass are not in compliance with the CTR criterion. The TotHg/flow regression for Putah Creek was not statistically significant; therefore, compliance with the CTR criterion cannot be adequately determined with available data. However, four grab samples collected from two separate storm events (one in March 1995, the other in March 2004) on Putah Creek had mercury levels between 52 and 485 ng/l, indicating that inputs from Putah Creek to the Yolo Bypass also may not be in compliance with the CTR criterion. This implies that when the Bypass is dominated by flows from Cache and Putah Creeks, it may not be in compliance with the CTR criterion. Therefore, Yolo Bypass areas downstream of the Cache Creek Settling Basin and Putah Creek outflows probably do not meet the CTR criterion.

The Basin Plan Amendment for control of mercury in Cache Creek was adopted by the Central Valley Water Board in October 2005. As outlined in the Basin Plan Amendment report (Cooke & Morris, 2005), implementation actions would enable CTR compliance in outflows from Cache Creek. Continued monitoring of Putah Creek outflows to the Yolo Bypass as part of implementation activities for the Delta mercury TMDL could enable better evaluation of CTR compliance. In order to meet the mercury loading allocation proposed for the Central Valley by San Francisco Water Board staff, the total mercury reduction strategy described in Chapter 8 assigns a 37% load reduction to mercury exports from the Feather River, American River and Putah Creek. In addition, Putah Creek is already identified on the 303(d) List as impaired by mercury. If future monitoring indicates that Putah Creek and Cache Creek Settling Basin outflows to the Yolo Bypass do not comply with the CTR even after proposed total mercury reductions described are achieved, and other reductions designed to accomplish safe fish tissue methylmercury levels in Cache Creek and Putah Creek are achieved, additional reductions will be required.

Key Points

- The primary sources of total mercury in the Delta include tributary inflows from upstream watersheds, atmospheric deposition, urban runoff, and municipal and industrial wastewater. Losses include flow to San Francisco Bay, water exports to southern California, removal of dredged sediments and evasion.
- The Sacramento Basin (Sacramento River + Yolo Bypass) contributed 83 to 87% of the mercury load to the Delta. Most of the material was transported during high flow.
- Present mercury exports rates to San Francisco Bay are unreliable. This precludes accurate calculations of erosion/deposition rates in the Delta and assessment of compliance with the proposed San Francisco Bay mercury allocation to the Central Valley at Mallard Island.
- The Cache Creek, Feather River, American River, and Putah Creek watersheds in the Sacramento Basin had both relatively large mercury loadings and high mercury to TSS ratios, making them attractive candidates for remediation.

This addendum replaces Chapter 7 in the June 2006 Delta methylmercury TMDL draft report.
Chapter 8 of the June 2006 report begins on page 140.