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 and Looker, 2004; SFBRWQCB, 2006). The San Francisco Bay mercury control program approved by the State Water Board 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 transport of sediment and mercury 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.

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	66%	689 ±7	64%	183 ±1	45%	865 ±7	40%
Prospect Slough	37 ±1	17%	197 ±5	18%	169 ±5	42%	1,014 ±31	47%
San Joaquin River	18 ±2	8.2%	138 ±23	13%	29 ±4	7.2%	223 ±37	10%
Calaveras River	3.8 ±2	1.7%	15 ±21	1.4%	4.1 ±2	1.0%	16 ±23	0.7%
Mokelumne-Cosumnes Rivers	2.8 ±0.6	1.3%	7.7 ±2	0.7%	4.6 ±1	1.1%	12 ±3	0.6%
Ulatis Creek	2.1 ±2	1.0%	16 ±19	1.5%	2.2 ±2	0.5%	17 ±19	0.8%
French Camp Slough	1.6 ±3	0.7%	2.3 ±2	0.2%	1.7 ±3	0.4%	2.4 ±2	0.1%
Morrison Creek	0.79 ±0.2	0.4%	4.3 ±2	0.4%	0.83 ±0.2	0.2%	4.5 ±2	0.2%
Marsh Creek	0.54 ±0.01	0.3%	1.1 ±11	0.1%	0.54 ±0.01	0.1%	1.1 ±11	0.1%
Bear/Mosher Creeks	0.29 ±0.2	0.1%	2.4 ±5	0.2%	0.30 ±0.2	0.1%	2.4 ±5	0.1%
Sum of Tributary Sources:	**213 ±4**	**97%**	**1,073 ±28**	**99%**	**395 ±7**	**98%**	**2,157 ±51**	**>99%**
Inputs within the Delta/Yolo Bypass								
Wastewater	2.5	1.1%			2.5	0.6%		
Urban	2.3	1.1%	7.5	0.7%	2.4	0.6%	7.8	0.4%
Atmospheric (Indirect)	1.5	0.7%			1.5	0.4%		
Atmospheric (Direct)	0.81	0.4%			0.84	0.2%		
Sum of Within-Delta Sources:	**7.1**	**3%**	**7.5**	**1%**	**7.2**	**2%**	**7.8**	**<1%**
TOTAL INPUTS:	**220 ±4**		**1,080 ±28**		**402 ±7**		**2,165 ±51**	

(a) Confidence intervals (CI) were calculated for the average annual loads for inputs with daily flow data. See Appendix I 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.

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 L.

Central Valley Water Board staff began evaluating mercury loads from the Sacramento River watershed and Yolo Bypass in 1994 (Foe and 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 I.1 through I.6 in Appendix I summarize the mercury and TSS data available at the time the TMDL was developed.

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.

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. [38,39] The methods used to calculate the 95% confidence intervals are described in Appendix I. The average annual load for the Sacramento River was 146 kg mercury and 689 Mkg TSS for WY2000-2003, and 183 kg mercury and 865 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[40] to determine if statistically significant correlations might exist (Section E.2.2 in Appendix E and Figure I.1 in Appendix I). Extremely high mercury and TSS concentrations were measured on 10 and 11 January 1995 (Figure I.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 I.7a and I.7b), indicating that the concentrations of both constituents could be predicted from flow. The

[38] 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.

[39] 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.

[40] 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.

regressions were used to estimate annual average loads of 37 kg mercury and 197 Mkg TSS for WY2000-2003 and 169 kg mercury and 1,014 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.

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 2003), 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.

The WY1984-2003 mercury-loading rate of 349±7 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, 2003), while the highest rate happened during a wet year (3,900 Mkg/yr, Foe and Croyle, 1998). The WY1984-2003 sediment export rate of 1,894 ±32 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.

Table 7.2: Total Mercury and TSS Concentrations for Tributary Inputs

Site [a]	# of Samples	Sampling Begin Date	Sampling End Date	Min. Conc.	Ave. Conc.	Median Conc.	Max. Conc.
TOTAL MERCURY CONCENTRATIONS (ng/l)							
Bear/Mosher Creeks [b]	4	3/15/03	2/26/04	3.55	8.08	8.70	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	5 [4]	7/11/00	2/26/04	1.73 [3.32]	16.75 [20.5]	4.71 [11.63]	55.42 [55.42]
Marsh Creek @ Hwy 4	19 [3]	11/05/01	2/02/04	0.93	7.34	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	10.58	73.22 [30.80]	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	34	10/29/93	2/26/04	3.12	7.99	7.33	21.73
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 (mg/l)							
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	298.4 [166.8]	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	29	3/28/00	2/26/04	20.0	61.1	56.0	170.8
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 I).

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

(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 I.1. The regression is between total mercury concentrations observed at Prospect Slough (not including the two very high values shown in Figure I.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.

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 Mercury TMDL [b]	Freeport	WY2000-2003	7.3	146 ± 1	689 ± 7
		WY1984-2003	7.8	183 ± 1	865 ± 7
Foe and Croyle (1998)	Greene's Landing	May 1994- April 1995	12.9	426	1,400
Foe (2003)	Greene's Landing	WY2001 [c]	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
Louie and others (2008)	Freeport	WY1984-2003	7.8	183 ± 2	959 ± 6
Yolo Bypass					
Delta Mercury TMDL	Prospect Slough	WY2000-2003	7.3	37 ± 1	197 ± 5
		WY1984-2003	7.8	169 ± 5	1,014 ± 31
Foe and Croyle (1998)	Prospect Slough	May 1994- April 1995	12.9	375	2,500
Foe (2003)	Prospect Slough	WY2001 [c]	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
Louie and others (2008)	Prospect Slough	WY1984-2003	7.8	168 ± 4	1,107 ± 25
Sacramento Basin Total (Sacramento River + Yolo Bypass)					
Delta Mercury TMDL		WY2000-2003	7.3	183 ± 1	886 ± 9
		WY1984-2003	7.8	352 ± 5	1879 ±31
Foe and Croyle (1998)		May 1994- April 1995	12.9	801	3,900
Foe (2003)		WY2001 [c]	5.8	94.8	568
LWA (2002)		WY1980-1999	8.5	306	na
Wright & Schoellhamer (2005)		WY1999-2002	7.7	na	1,410 ± 300
Louie and others (2008)		WY1984-2003	7.8	351	2,066
Domagalski (2001) [d] 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, 2006 (http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST). DWR calculated a hydrologic index for the Sacramento Valley (Section E.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) See Appendix I for the methods used to estimate the 95% confidence intervals (CI) for the TMDL load estimates.

(c) Foe's 2003 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.

(d) 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.

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 8 Mkg TSS for WY2000-2003 and 5 kg mercury and 12 Mkg TSS for WY1984-2003 (Table 7.1). Similarly, the San Joaquin River has an average annual load of 18 kg mercury and 138 Mkg TSS and 29 kg mercury and 223 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). The studies confirm that mercury loads from both basins are much smaller than from the Sacramento Basin (Table 7.3). Annual mercury loads for the San Joaquin reported at the time the TMDL was developed ranged from 16 to 29 kg/yr. The WY1984-2003 mercury load is 29 ±4 kg/yr. This value is statistically similar to 20-year loads calculated by LWA (2002) and Louie and others (2008) of 26 kg/yr and 28.3 ±3.0 kg/yr, respectively. Louie and others 2008 CalFed study completed since the TMDL was developed incorporated additional data collected during wet periods; inclusion of more data did not substantially change the load estimate for the San Joaquin River.

The TMDL's WY1984-2003 load estimate for the Mokelumne River downstream of its confluence with the Cosumnes River is based on data available at the time the TMDL was developed and is 5 ±1 kg/yr. The WY1980-1999 LWA (2002) estimate is 3 kg/yr for the Mokelumne River downstream of the Cosumnes River confluence. The recent CalFed study that incorporated additional data collected during wet periods (Louie *et al*., 2008) estimated 20-year average annual loads of 1.8 ±0.08 kg/yr for the Mokelumne River and 12.4 ±0.8 kg/yr for the Cosumnes River, upstream of their confluence.

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). The TMDL's export rates for the San Joaquin varied between 110 and 240 Mkg/yr. The Mokelumne-Cosumnes sediment yield is lower. The 20-year TMDL value is 12±3 Mkg/yr. The recent CalFed study that incorporated additional data collected during wet periods (Foe *et al*., 2008) estimated 20-year average annual loads of 8.4 ±0.2 kg/yr for the Mokelumne River and 48.0 ±3.2 kg/yr for the Cosumnes River, upstream of their confluence.

Louie and others (2008) noted that, although the Cosumnes and Mokelumne Rivers have adjacent watersheds with similar average annual water budgets and both watersheds have histories of hydraulic gold mining, there are several watershed characteristics that could explain why the Cosumnes River discharges six times more mercury and sediment to the Delta than does the Mokelumne River. Louie and others (2008) identified the following:

- The Mokelumne River has two major upstream impoundments (Camanche and Pardee Reservoirs), whereas the Cosumnes River has none. It is likely that some of the material being transported by the Mokelumne is deposited in upstream reservoirs and does not

make it downstream to the Delta. Louie and others' study did not include sampling for the reservoirs on the Mokelumne River.

- The Cosumnes River is the largest river on the west-slope Sierra Nevada mountains without a major dam (Booth *et al*., 2006), allowing unimpaired downstream movement of storm runoff. For example, the maximum daily average flow for the Cosumnes River at Michigan Bar was 61,600 cfs during WY1984-2003, while the maximum daily average flow for the Mokelumne River at Woodbridge (below Camanche and Pardee Reservoirs) was only 5,240 cfs. Additionally, the return frequency of greater than 5,000 cfs for this 20-year period is 1 in 4 years for the Mokelumne River and 1 in 86 days for the Cosumnes River.
- The higher mercury and sediment yields from the Cosumnes are likely, at least in part, because the transport of both constituents is a function of water velocity (Foe and Croyle, 1998; Foe, 2003). Higher periodic flows on the Cosumnes may result in more mercury and suspended sediment transport.

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 5 ±2 kg/yr and 26 ±13 Mkg/yr, respectively (Table 7.1).

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 [b]	WY2000-2003	2.7	18 ± 2	138 ± 23
	WY1984-2003	3.1	29 ± 4	223 ± 37
Foe (2003)	WY2001 [c]	2.2	16	110
LWA (2002)	WY1980-1999	3.5	26	na
Wright & Schoellhamer (2005)	WY1999-2002	2.9	na	210 ± 21
Louie and others (2008)	WY1984-2003	3.1	28.3 ±3	236.9 ±29
Mokelumne River downstream of Cosumnes River Confluence				
Delta TMDL	WY2000-2003	2.7	3 ± 1	8 ± 2
	WY1984-2003	3.1	5 ± 1	12 ± 3
Foe (2003)	WY2001 [c]	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 ± 2	25 ± 13
	WY1984-2003	3.1	10 ± 2	30 ± 14
Wright & Schoellhamer (2005)	WY1999-2002	2.9	na	36 ± 8

(a) Source: DWR, 2006 (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) See Appendix I for the methods used to estimate the 95% confidence intervals (CI) for the TMDL load estimates.

(c) Foe's 2003 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.

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 L). The water volume calculations are described in Appendix E. Appendix I provides time series plots 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 I). The TotHg/flow and TSS/flow regressions for the American River, Cache Creek, Colusa Basin Drain, Feather River, Putah Creek and Sacramento River at Colusa were all significant ($P<0.05$) and were used to predict 4- and 20-year average annual loads (Table 7.6).

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; and flood flows from the Feather River flow into the Sutter 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 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 represents 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, this report's preliminary estimates of Sutter Bypass loading (25 ±4 kg/yr for the WY1984-2003; 19 ±3 kg/yr for the WY2000-2003 period) were 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. The recent CalFed study that incorporated additional data collected during wet periods (Louie *et al*., 2008) estimated a 20-year average annual load of 31.0 ±4.2 kg/yr for the Sutter Bypass, which is statistically similar to the 20-year average load calculated for this report.

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 5% indicating that all the major water sources have been identified. A different grouping of 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 79 to 87% 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 55% of inputs during WY2000-2003 to 89% 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) and Louie and other (2008) also found that the Sacramento Basin landward of Rio Vista was depositional. However, unlike this report, Wright and Schoellhamer (2005) concluded that deposition was greater in wet than in dry periods.

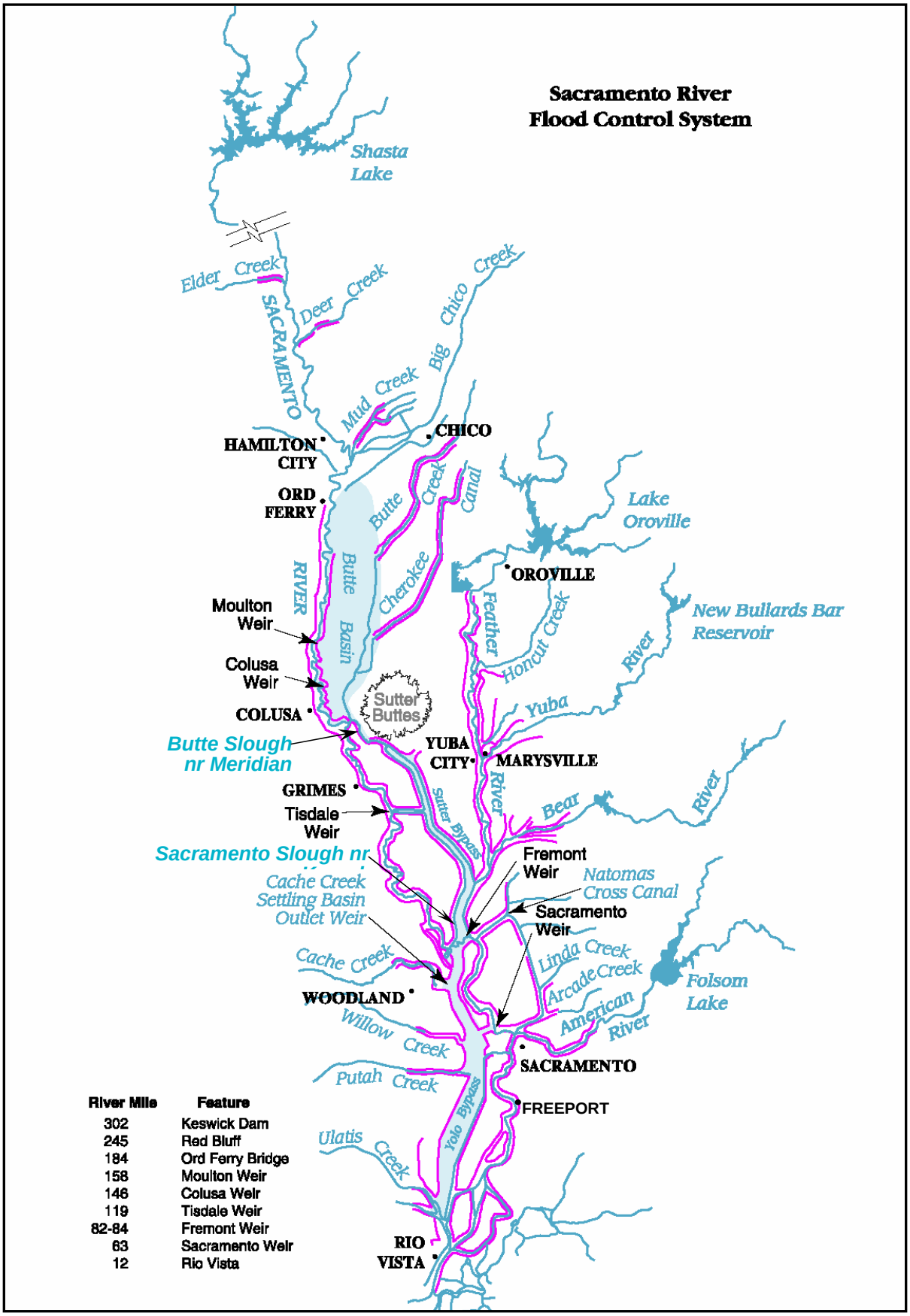

Figure 7.1: Sacramento River Flood Control System.
Pink lines represent levees. (Tetra Tech, Inc., 2005b; DWR, 2003)

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

Site	# of Samples	Sampling Begin Date	Sampling End Date	Min. Conc.	Average	Median Conc.	Max. Conc.
Total Mercury Concentrations (ng/l)							
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	171.89	58.24	984.60
Colusa Basin Drain	63	1/31/95	2/18/04	1.59	11.58	6.90	75.10
Feather River near Nicolaus	67	1/31/95	2/18/04	1.49	6.90	4.43	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	33.02	9.14	485.00
Sacramento River above Colusa	64	3/10/95	2/17/04	0.60	12.30	4.27	105.16
Sacramento Slough near Karnak [(b)]	55	2/12/96	9/15/03	0.69	8.77	7.57	30.8
TSS Concentrations (mg/l)							
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	23	12/23/96	2/17/04	41.0	425.1	140.0	1,900
Colusa Basin Drain	59	2/07/96	2/18/04	21.0	128.1	101.0	487.7
Feather River near Nicolaus	70	3/11/95	2/18/04	2.0	23.1	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)	26.0 (34.5)	122.0 (96.0)
Putah Creek @ Mace Blvd.	29	3/28/00	2/29/04	1.6	59.01	30.0	417.8
Sacramento River above Colusa	48	3/10/95	2/17/04	10.0	98.6	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. 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 and 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%	1.9	2.5	11%	13%
Cache Creek	724,526	4.3%	0.22	0.38	1.3%	1.9%
Colusa Basin Drain	1,577,307	9.4%	0.67	0.66	4.0%	3.4%
Coon Creek/Cross Canal	287,914	1.7%	0.089	0.094	0.5%	0.5%
Feather River	3,793,179	23%	3.9	5.3	23%	27%
Natomas East Main Drain	231,598	1.4%	0.084	0.088	0.5%	0.5%
Putah Creek	652,762	3.9%	0.041	0.11	0.2%	0.6%
Sacramento River @ Colusa	7,562,525	45%	8.2	8.1	49%	41%
Sutter Bypass	682,071	4.1%	1.8	2.3	11%	12%
Sum of Upstream Inputs:	**16,765,622**	**100%**	**16.9**	**19.5**	**100%**	**100%**
Exports to Delta						
Yolo Bypass (Prospect Slough)	- - -		1.0	2.7	6%	14%
Sacramento River (Freeport)	- - -		15.1	16.1	94%	86%
Sum of Exports to Delta:	- - -		**16.1**	**18.8**	**100%**	**100%**
Tributary Inputs – Exports to Delta:			**0.8**	**0.7**		
Exports to Delta / Tributary Inputs:			**95%**	**96%**		

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

Tributary	Average Annual TotHg Load ± 95 CI [(a)] (kg/yr)		% of TotHg Inputs	
	WY2000-2003	WY1984-2003	WY2000-2003	WY1984-2003
Upstream Tributary Inputs				
American River	6.4 ±0.1	14 ±0.1	2.8%	3.4%
Cache Creek Settling Basin	26 ±3	118 ±5	11%	30%
Colusa Basin Drain	10	13	4.3%	3.3%
Feather River	28 ±1	67 ±2	12%	17%
Natomas East Main Drain	2.9 ±1	3.0 ±1	1.2%	0.8%
Putah Creek	1.0 ±0	8.8 ±1	0.4%	2.2%
Sacramento River @ Colusa	139 ±4	151 ±4	60%	38%
Sutter Bypass	19 ±3	25 ±4	8.2%	6.3%
Sum of Upstream Inputs:	**232 ±6**	**400 ±8**	**100%**	**100%**
Exports to Delta				
Prospect Slough	37 ±1	169 ±5	20%	48%
Sacramento River @ Freeport	146 ±1	183 ±1	80%	52%
Sum of Exports to Delta:	**183 ±1**	**352 ±5**	**100%**	**100%**
Trib Inputs - Exports to Delta	**49**	**48**		
Exports to Delta / Trib Inputs	**79%**	**88%**		

(a) Confidence intervals (CI) were calculated for the average annual total mercury loads for the tributary stations with daily flow gages. See Appendix I 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 ±0.2	52 ±0.5	0.8%	2.4%
Cache Creek Settling Basin	68 ±6	259 ±10	4.2%	12%
Colusa Basin Drain	117	148	7.2%	7.0%
Feather River	98 ±3	216 ±6	6.0%	10%
Natomas East Main Drain	4.5 ±2	4.7 ±2	0.3%	0.2%
Putah Creek	2.2 ±0.2	16 ±1	0.1%	0.8%
Sacramento River above Colusa	1,180 ±41	1,256 ±41	73%	59%
Sutter Bypass	138 ±21	177 ±27	8.5%	8.3%
Sum of Upstream Inputs:	**1,621 ±48**	**2,129 ±49**	**100%**	**100%**
Exports to Delta				
Prospect Slough	197 ±5	1,014 ±31	22%	54%
Sacramento River @ Freeport	689 ±7	865 ±7	78%	46%
Sum of Exports to Delta:	**886 ±9**	**1,879 ±31**	**100%**	**100%**
Trib Inputs - Exports to Delta	**735**	**250**		
Exports to Delta / Trib Inputs	**55%**	**88%**		

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

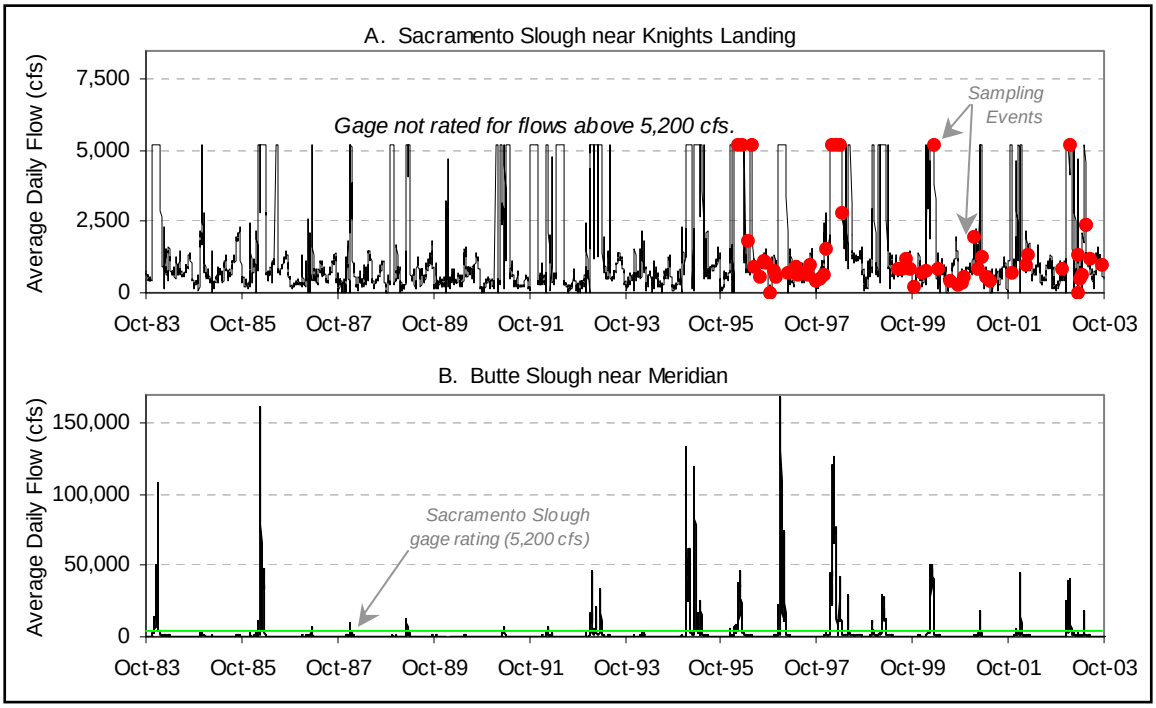

Figure 7.2: Flow Data Evaluated for Sutter Bypass.
(Note the 20-fold difference in the Y-axis flow values for these two graphs.)

7.1.2 Municipal & Industrial Sources

During the TMDL period, WY2000-2003, there were 23 NPDES-permitted municipal and industrial discharges to surface water in the Delta/Yolo Bypass[41] (Figure 6.5). The sum of total mercury loads from the discharges is approximately 2.4 kg/yr, about 1% of all Delta sources (Table 7.1).

Information on average flow rates for each facility was obtained from the Central Valley Water Board's discharger project files, permits and the State Water Resources Control Board's Surface Water Information (SWIM) database. Effluent total mercury concentration data were obtained from project files and dischargers' SIP monitoring efforts.[42] 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 L 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.

Of the 23 facilities in the Delta, two are power and heating/cooling facilities that use ambient water for cooling water: Mirant Delta LLC Contra Costa Power Plant (CA0004863) and the State of California Central Heating/Cooling Plant (CA0078581). Based on the comparison of the available intake and outfall mercury data for the Mirant Delta facility and other similar facilities that discharged to the Delta in years past (Table G.5 in Appendix G), such facilities may not act as measurable sources of mercury to the Delta. According to its NPDES permit, the Central Heating/Cooling Plant adds no chemicals to its supply water; however, the permits for Mirant Delta and other similar facilities in the tributary watersheds indicate that mercury-containing chemicals may be added to their cooling water and other low-volume waste streams may be included in their discharges (see Tables G.6 and G.7 in Appendix G). Staff recommends that the assumption that power and heating/cooling plants do not contribute mercury to Delta and upstream surface waters be re-evaluated as additional information becomes available.

---

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

[42] 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.

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 H.1 in Appendix H illustrates the wet and dry weather concentrations by location, and Appendix L provides the concentration data used in Figure H.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 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 2.3 kg mercury and 7.5 Mkg/yr suspended sediment and WY1984-2003 average annual loadings of 2.4 kg mercury and 7.7 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 WY1984-2003 period. The sum of mercury loads from the Sacramento and Stockton MS4 areas may contribute more than 2% of loading to the Delta (Table 7.9). These loads are expected to increase as urbanization continues around the Delta.

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

Urban Watershed	# of Samples	Minimum Conc.	Average Conc.	Maximum Conc.
TOTAL MERCURY (ng/l)				
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 (mg/l)				
DRY WEATHER				
Arcade Creek	28	5.0	31.7	122.0
City of Sacramento Strong Ranch Slough	6	5.0	9.3	15.0
City of Sacramento Sump 104	7	4.0	7.6	12.0
City of Sacramento 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 Sacramento Strong Ranch Slough	13	23.0	208.7	1300.0
City of Sacramento Sump 104	14	31.0	104.3	270.0
City of Sacramento 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/Yolo Bypass

MS4 Permittee	WY2000-2003		WY1984-2003	
	TotHg Load (kg/yr)	**TSS Load** (Mkg/yr)	**TotHg Load** (kg/yr)	**TSS Load** (Mkg/yr)
Contra Costa County	0.60	1.9	0.62	2.0
Lathrop	0.032	0.10	0.033	0.11
Lodi	0.006	0.021	0.007	0.022
Port of Stockton	0.047	0.15	0.049	0.16
Rio Vista	0.002	0.005	0.002	0.005
Sacramento MS4 Permit Area	0.21	0.68	0.22	0.71
San Joaquin Co MS4 Permit Area	0.35	1.2	0.37	1.2
Solano County	0.019	0.062	0.020	0.065
Stockton MS4 Permit Area	0.47	1.5	0.49	1.6
Tracy	0.21	0.69	0.22	0.72
West Sacramento	0.21	0.68	0.21	0.71
Yolo County	0.050	0.16	0.051	0.17
Urban Nonpoint Source [(a)]	0.10	0.33	0.10	0.33
Grand Total	2.3	7.5	2.4	7.8

(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 WY1984-2003 Annual Delta Mercury and TSS Loads to Sacramento and Stockton Area MS4 Loads.

MS4 Service Area [(a)]	**Water Volume** (M acre-feet) [(b)]	**TotHg Load** (kg/year)	**TSS Load** (Mkg/yr)
Sacramento MS4 Urban Total	0.19	7.4	24
Stockton MS4 Urban Total	0.026	1.0	4.0
Total Delta Inputs [(c)]	23	400	1,080
Stockton & Sacramento Urban Runoff as % of Total Delta Inputs	**1.0%**	**2.1%**	**1.3%**

(a) The Sacramento and Stockton Area MS4s are the two MS4 service areas with the greatest urban acreage immediately upstream of the Delta, with urban land use areas of 160,000 and 25,000 acres, 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.

7.1.4 Atmospheric Deposition

Atmospheric deposition of mercury has not been measured in the Delta until very recently. Figure 7.3 illustrates wet deposition sampling locations in northern and central California available at the time the TMDL was developed, Appendix L 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 from non-urbanized land surfaces 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 (2.3 kg/yr) 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. For example, the concentration of mercury in rain in the Delta had not been measured at the time this source analysis was developed 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) because atmospheric inputs account for only about 1% of the total mass balance. A recently completed CalFed study (Gill, 2008b) observed volume-weighted mercury concentrations in rain of 4.2 and 3.7 ng/l at Twitchell Island (western Delta) and Woodland (near the Yolo Bypass), respectively, which indicate that the estimate of wet deposition included in Table 7.1 may be over-estimated.

Dry mercury deposition rates were not estimated for the Delta because there was no information on airborne particulate mercury concentrations at the time this source analysis was developed. SFEI (2001) 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 12 kg/yr or about 1 to 2% of the annual load. Dr. Gill (Texas A&M University) recently completed measuring dry mercury deposition rates in the Central Valley as part of CALFED project ERP-02-C06-B. At his Woodland monitoring location, Dr. Gill estimated dry deposition flux rates of 1.1 and 3.4 $\mu g/m^2/yr$ in the winter and summer, respectively, compared to his wet deposition flux rates of 2.0 and 0.10 $\mu g/m^2/yr$ in the winter and summer, respectively, which indicates that, on an annual basis, mercury loading to the Delta from dry deposition may be about equal to loading from wet deposition.

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 J provides a summary of the types of facilities in each watershed and their estimated emission loads. The available 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. About 113 kg of mercury were released in the tributary watersheds. Some facility categories appear to have relatively high mercury emissions compared to other types of facilities in the tributary watersheds: cement, concrete and paving mixture/block manufacturing facilities (51 kg); electrical services (19 kg); crematories (15 kg); and national security (13 kg). Emission loads in Appendix J are not incorporated in the mass budgets because their deposition rates are not known. Local air emissions of mercury warrant additional research.

Potentially uncontrollable sources of mercury (i.e., sources outside of the United States) in atmospheric deposition in the Delta and its tributary watersheds are discussed in Chapter 8, Section 8.4.3.5.

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 L.

(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 [a]

Period/Deposition Type [b]	WY2000-2003		WY1984-2003	
	Water Volume (acre-feet) [c]	**TotHg** (kg/year)	**Water Volume** (acre-feet) [c]	**TotHg** (kg/year)
Direct Deposition	88,669	0.81	91,960	0.84
Indirect Deposition	159,394	1.5	165,325	1.5
TOTAL	248,063	2.3	257,284	2.3

(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/Yolo Bypass 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.

Space intentionally left blank.

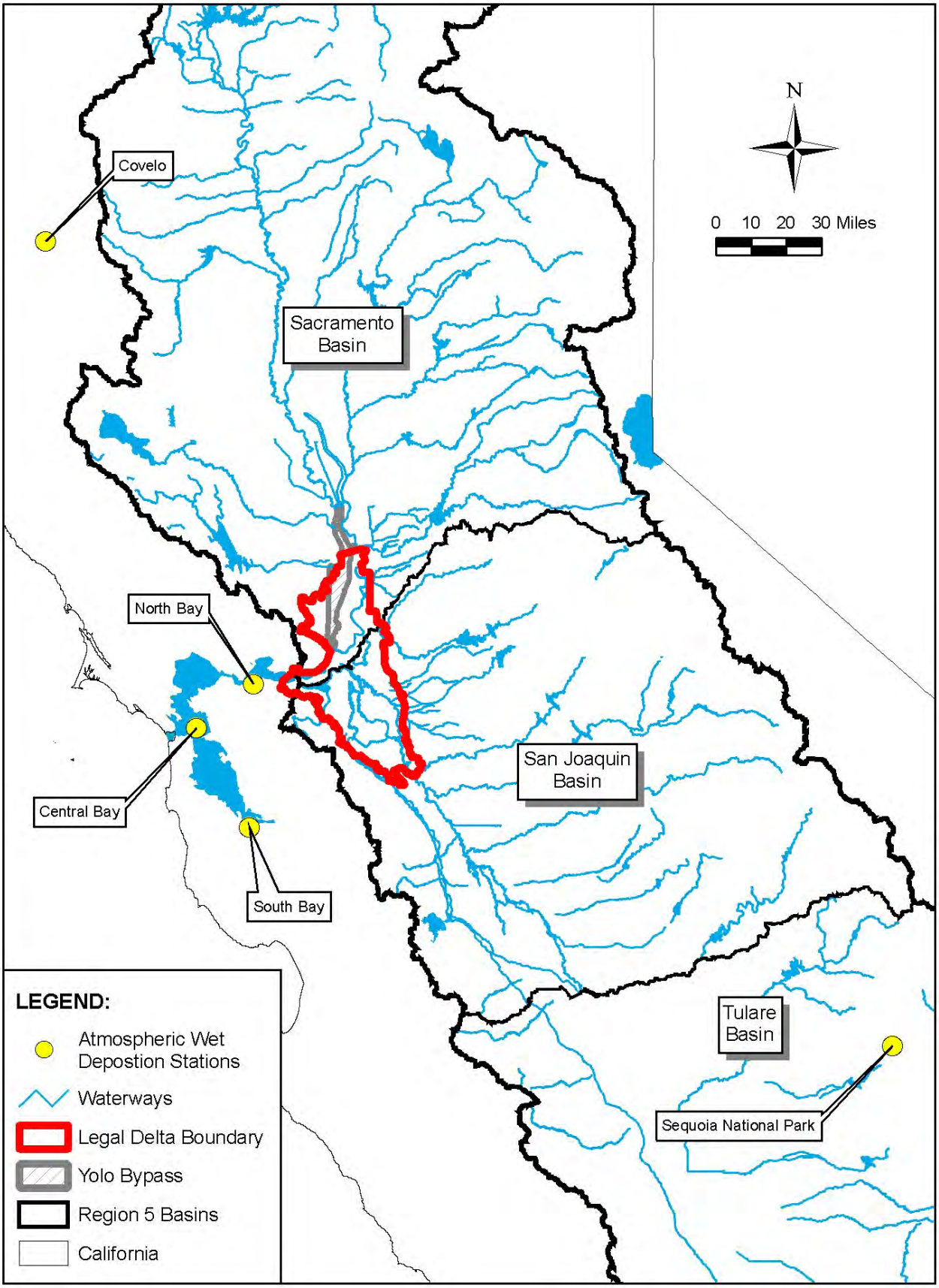

Figure 7.3: Wet Deposition Total Mercury Sampling Locations in Northern and Central California.

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 six 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.

Space intentionally left blank.

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	270 ±93	71%	930 ±283	67%	379 ±132	78%	1,309 ±398	75%
Dredging	57 ±71	15%	349	25%	57 ±71	12%	349	19%
Evasion	30	8%	- -	--	30	6%	--	--
State Water Project [(a)]	11 ±3	3%	46 ±22	3%	9 ±3	2%	38 ±18	2%
Delta Mendota Canal [(a)]	11 ±1	3%	62 ±9	5%	10 ±1	2%	60 ±9	4%
Sum of Losses	**379 ±112**	**100%**	**1,387 ±271**	**100%**	**485 ±143**	**100%**	**1,756 ±381**	**100%**

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

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 L). Table 7.13 and Figures I.4a and I.4b in Appendix I summarize the available total mercury and TSS concentration data for X2. Total mercury concentrations at X2 averaged 18.1 ng/l and ranged from 3.9 ng/l to 49.2 ng/l. The TSS concentrations at X2 averaged 62 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 7.14). 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

270, 379, and 691 kg/yr for WY2000-2003, WY1984-2003 and WY1995-2000, respectfully (Tables 7.12 and 7.14).

Six studies (including this source analysis) have measured mercury and sediment loads to San Francisco Bay from the Delta (Table 7.14). The results are quite variable. Some of the variation is undoubtedly due to the fact that different studies have measured export rates in different hydrologic years. However, four studies estimated annual average mercury export rates for WY1995-2000. The values range between 270 ±91 and 691 ±240 kg/yr (Table 7.14). The rate developed by David and others (2009) may be the most accurate for several reasons. First, it incorporates 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, it measured mercury at Mallard Island. Third, it includes data collected during high flows. In contrast, the TMDL's source analysis uses sediment and mercury concentration data collected 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 used to develop the TMDL's estimate. However, such measurements are undoubtedly less reliable than repeated water column measurements at Mallard Island for predicting mercury and sediment transport past the island.

To further complicate estimates of mercury loads to San Francisco Bay, all of the Mallard Island load estimates are based on the assumption that the channel at Mallard Island is well mixed. However, the results of a recent cross-section study suggest that mercury and suspended sediment concentrations are not homogenous across the Mallard channel and that caution should be used in estimating export loads from data collected at a single point (Louie *et al*., 2006). The error estimation method used by David and others (David *et al*., 2009) accounts for heterogeneity in the cross section at Mallard Island. None-the-less, 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.

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)	20	3.95	18.10	11.59	49.20
TSS (mg/l)	20	27.0	62.41	44.50	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 [d]	WY2000-2003	7.3	12	270 ±93	930 ±283	0.29
		WY1984-2003	7.8	17	379 ±132	1,309 ±398	
		WY1995-2000	11.0	31	691 ±240	2,384 ±726	
Foe (2003)	X2	WY2001 [e]	5.8	7.2	122	473	0.26
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), McKee & others (2006) [f]	Mallard Island	WY1999-2003	7.8	18	97 ±33	524 ±166	0.19
		WY2000-2003	7.3	12	83 ±28	450 ±140	0.18
		WY1995-2000	11.0	31	270 ±91	1,600 ±510	0.17
		WY1995-2003	9.6	24	201 ±68	1,202 ±381	0.17
Louie & others (2008)	Mallard Island	WY1984-2003	7.8	17	198 ±33	801 ±160	0.25
David & others (2009)	Mallard Island	WY2001	5.8	7.2	53 ±19	300 ±100	-
		WY2000-2003	7.3	12	89 ±32	450 ±150	-
		WY1995-2000	11.0	31	372 ±134	1,600 ±500	-
		WY1995-2006	9.6	24	260 ±94	1,200 ±400	0.20 [g]

(a) Sources: this report; Leatherbarrow and others, 2005; Johnson and Looker, 2004; Foe (CALFED), 2003.
(b) DWR calculated a hydrologic index for the Sacramento Valley (DWR, 2006; see 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) The 95% confidence intervals (CI) were calculated using the method described in Appendix I.
(e) Foe's 2003 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.
(f) 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 mercury and sediment load estimates provided by Leatherbarrow and others (2005) and McKee and others (2006) 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. Volume-weighted TotHg:TSS ratios for each period were calculated by dividing the average annual mercury load (kg) by average annual TSS load (Mkg).
(g) Flow-weighted average particulate concentration for WY2002-2006, the period during which the concentration data were collected.

7.2.2 Exports South of Delta

Water diversions to the San Joaquin Valley and southern California account for 4 to 6% of mercury exports from the Delta and 6 to 8% of TSS exports (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 L). Table 7.15 and Figures I.4a and I.4b in Appendix I 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): 11 and 10 kg/yr for WY2000-2003 and WY1984-2003, respectively, for the DMC; and 11 and 9 kg/yr for WY2000-2003 and WY1984-2003, respectively, for the SWP. For comparison, the 20-year average annual loads estimated by Louie and others (2008), which incorporate data for a variety of wet and dry years, are 11.4 ±1.7 kg/yr for the DMC and 6.6 ±2.0 kg/yr for the SWP; including data for wet years did not substantially change the load estimates for these exports.

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)	23	1.85	3.41	3.28	5.96
TSS (mg/l)	22	9.2	20.1	18.9	36.0
State Water Project					
TotHg (ng/l)	20	1.16	2.91	2.20	7.17
TSS (mg/l)	20	4.4	11.9	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 6.17 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 199,000 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 0.41 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 349 Mkg of sediment. This accounts for approximately 12 to 15% of all mercury exports and 19 to 25% 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 (DGM) concentrations, atmospheric mercury concentrations, and estimated wind speeds (Conaway *et al.*, 2003). Conaway and others (2003) estimated summer and winter loss 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 and Looker, 2004). To obtain an 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.

After this source analysis was developed, a recent CalFed study conducted measurements of DGM concentrations in surface waters just west of the legal Delta boundary (Mandeville Bay, Suisun Bay, and Honker Bay) and within the Delta (Little Break and Georgiana Slough) and used this information to model the air-water exchange flux of DGM, resulting in an estimated loss rate of 0.99 µg/m^2/yr (Gill, 2008c). There are approximately 235,778,006 m^2 of open water area in the Delta/Yolo Bypass (Table 6.4 in Chapter 6); when this area is multiplied by 0.99 µg/m^2/yr, the resulting loss load is 0.23 kg/yr, a substantially lower estimate than that calculated in the previous paragraph.

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 budgets for WY2000-2003 and WY1984-2003 are presented in Table 7.16.

The sum of water inputs and exports balance within 5%, indicating that all the major water sources and losses have been identified. In contrast, the mercury and TSS budgets do not balance and vary substantially depending on which estimates are used to characterize Delta outflows to San Francisco Bay. Table 7.16 incorporates the Delta TMDL Program's X2 and evasion calculations, which results in mercury and TSS budgets that indicate that exports are greater than imports. This would imply that the Delta is erosional. However, this conclusion should be viewed with caution because the export rates used in the calculation are greater than

those measured by others and may be biased high.[43] The Table 7.16 budget results are also in conflict with the conclusions of two other studies. Wright and Schoellhamer (2005) determined that about 65% of the sediment entering the Delta was deposited there. Louie and others (2008) determined that 48% and 62% of the incoming mercury and suspended sediment loads, respectively, were deposited in the Delta. When the X2 and evasion load estimates shown in Table 7.16 are replaced with David and others (2009) Mallard Island load estimates (89 kg/yr and 450 Mkg/yr for WY2000-2003 mercury and sediment loads, respectively; 260 kg/yr and 1,200 Mkg/yr for WY1995-2006 mercury and sediment loads, respectively) and the updated evasion estimate provided in the previous section (0.23 kg/yr), the budget results are more comparable to the results of the Wright and Schoellhamer (2005) and Louie and others (2008) studies.

Table 7.16: Water, Total Mercury and TSS Budgets for the Delta for WY2000-2003 and WY1984-2003.

	Water Volume (M acre-feet/yr)		**Average Annual Load**			
			WY2000-2003		WY1984-2003	
	WY2000-2003	WY1984-2003	TotHg (kg/yr)	TSS (Mkg/yr)	TotHg (kg/yr)	TSS (Mkg/yr)
Inputs	20.07	23.64	221 ±4	1,081 ±28	403 ±7	2,164 ±51
Exports	18.99	23.29	377 ±112	1,387 ±271	484 ±143	1,756 ±381
Inputs - Exports	**1.08**	**0.35**	**-156**	**-306**	**-81**	**408**
Exports ÷ Inputs	**95%**	**99%**	**170%**	**128%**	**120%**	**81%**

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

[43] For example, if Leatherbarrow and others' 2005 load estimates of 83 kg/yr mercury and 450 Mkg/yr TSS are incorporated in the WY2000-2003 budget in Table 7.16, inputs would exceed exports, implying that the Delta is depositional.

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. 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.

The San Francisco TMDL for mercury includes a sediment objective of 0.2 mg/kg (Johnson and Looker, 2004; SFBRWQCB, 2006). Mercury contamination on sediment (TotHg:TSS) in Delta outflow to San Francisco Bay averaged between 0.17 mg/kg and 0.30 mg/kg (Tables 7.14 and 7.17). The lower values are from estimates of mercury and suspended sediment loads at Mallard Island that attempt to better address tidal dispersion from the Bay area. The higher values are based on measurements taken in mid channel at X2. The higher values 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 0.24 mg/kg of mercury (Table 7.17), which are more similar to the flow-weighted average particulate concentration of 0.20 for WY2002-2006 calculated by David and others (2009) (see Table 7.14). 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 entirely originate from the Central Valley during the study period.

The X2 TotHg:TSS ratios of 0.28 to 0.30 mg/kg are similar to suspended sediment mercury concentrations of 0.33 mg/kg in San Pablo Bay (Schoellhamer, 1996) and bulk surficial sediment mercury 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 suspended sediment 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 San Francisco Bay 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. The American River and Putah Creek also have high ratios but comparatively smaller mercury loads. The Feather, American, Putah and Cache watersheds have waterways that are already identified on the 303(d) List as mercury-impaired. Having 303(d) Listed waterways and exports with elevated mercury to TSS ratios makes these watersheds attractive candidates for remediation efforts during the initial implementation phases of the Delta and upstream mercury control programs.

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 mercury to TSS ratios (0.12 and 0.13 mg/kg, respectively) comparable to background levels 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.

A recent CalFed study evaluated particulate mercury by subtracting the dissolved (filter passing) fraction from the total mercury concentration and developed ratios with suspended sediment concentration (particulate Hg:SSC) for different Central Valley watersheds to determine the basins exporting the most contaminated sediment and likely responsible for a disproportionate amount of the downstream methylmercury production (Louie *et al*., 2008). Although using an alternative method (analysis for SSC rather than TSS), the CalFed study also determined that the American River, Feather River, Cache Creek Settling Basin outflow, and Putah Creek have elevated particulate Hg:SSC ratios, and that the Cosumnes and Mokelumne Rivers upstream of their confluence had elevated Hg:SSC ratios, 0.28 mg/kg and 0.18 mg/kg, respectively. (For comparison, the total Hg:SSC values for the Cosumnes and Mokelumne Rivers calculated by Louie and others were 0.41 and 0.22 mg/kg, respectively.) Several watershed characteristics, including its high Hg:TSS ratio make the Cosumnes River, in addition to the before-mentioned watersheds, an attractive candidate for remediation efforts during the initial implementation phases of the Delta and upstream mercury control programs; these characteristics are discussed in Section 8.2 in Chapter 8.

The Louie and others 2008 CalFed study also developed Hg:SSC ratios for numerous sites in the upper Sacramento and San Joaquin watersheds; these will be useful for evaluating potential sources of mercury-contaminated sediment when TMDL control programs are developed for the upstream watersheds during the first phase of the Delta mercury control program's implementation.

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	4	0.12		0.07	0.24
Calaveras River	4	0.25		0.17	0.41
French Camp Slough	4	0.70		0.63	0.30
Marsh Creek	7	0.49		0.12	0.19
Mokelumne River downstream of the Cosumnes River	20	0.37		0.37	0.42
Morrison Creek [c]	15	0.18		0.15	0.22
Prospect Slough (Yolo Bypass)	44	0.19	0.17	0.18	0.20
Sacramento River (Freeport)	134	0.21	0.21	0.17	0.24
San Joaquin River	29	0.13	0.13	0.13	0.14
Ulatis Creek	4	0.13		0.11	0.14
Urban Runoff [d]	128 (123)	0.31		0.18 (0.22)	0.35
DELTA EXPORTS					
Outflows to San Francisco Bay (X2)	20	0.29		0.30	0.28
State Water Project	19	0.24		0.18	0.29
Delta Mendota Canal	22	0.18		0.16	0.18
Dredging [e]	*8 projects*	0.19		- - -	0.03 to 0.41
TRIBUTARIES TO THE SACRAMENTO BASIN [Sacramento River + Yolo Bypass]					
American River	109	0.50	0.27	0.20	0.41
Cache Creek Settling Basin	21	0.39	0.45	0.48	0.36
Colusa Basin Drain	56	0.09		0.09	0.07
Feather River	60	0.29	0.31	0.26	0.33
Natomas East Main Drain (Arcade Ck.)	8	0.64		0.38	0.45
Putah Creek	29	0.45	0.55	0.26	0.30
Sacramento River above Colusa	47	0.12	0.12	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 I.

(c) Appendix I provides the data for each Morrison Creek sampling location.

(d) 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.

(e) 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.

7.4.2 Compliance with the USEPA's CTR

The USEPA's California Toxic Rule mercury criterion 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 consumption of aquatic organisms 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 interval. 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 I 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 and the TMDL can incorporate total mercury load reduction requirements as needed to comply with the CTR.

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, 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 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.3), 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, Putah Creek and 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. This implies that when the Bypass is dominated by flows from Cache Creek, it may not be in compliance with the CTR criterion. Therefore, the Yolo Bypass area downstream of the Cache Creek Settling Basin probably does 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 Cache Creek TMDL Basin Plan Amendment report (Cooke and Morris, 2005), implementation actions would enable CTR compliance in outflows from Cache Creek. In order to meet the mercury loading allocation assigned to the Central Valley by the San Francisco Bay mercury TMDL control program, the total mercury reduction strategy described in Chapter 8 (Section 8.2) assigns a 110 kg/yr load reduction to tributary inputs to the Delta, a 28% load reduction compared to the current 20-year average input of 395 kg/yr (see Table 7.1). Initial reduction efforts should focus on watersheds that contribute the most mercury-contaminated sediment to the Delta and Yolo Bypass, such as the Cache Creek, American River, Putah Creek, Cosumnes River, and Feather River watersheds. These waterways, except the Cosumnes River, are already identified on the 303(d) List as impaired by mercury. If future monitoring indicates that Cache Creek Settling Basin outflows to the Yolo Bypass do not comply with the CTR even after proposed total mercury reductions are achieved, and other reductions designed to accomplish safe fish tissue methylmercury levels in Cache Creek are achieved, additional reductions will be required.

Key points for the total mercury source analysis are listed after Figures 7.4 and 7.5 and Table 7.18.

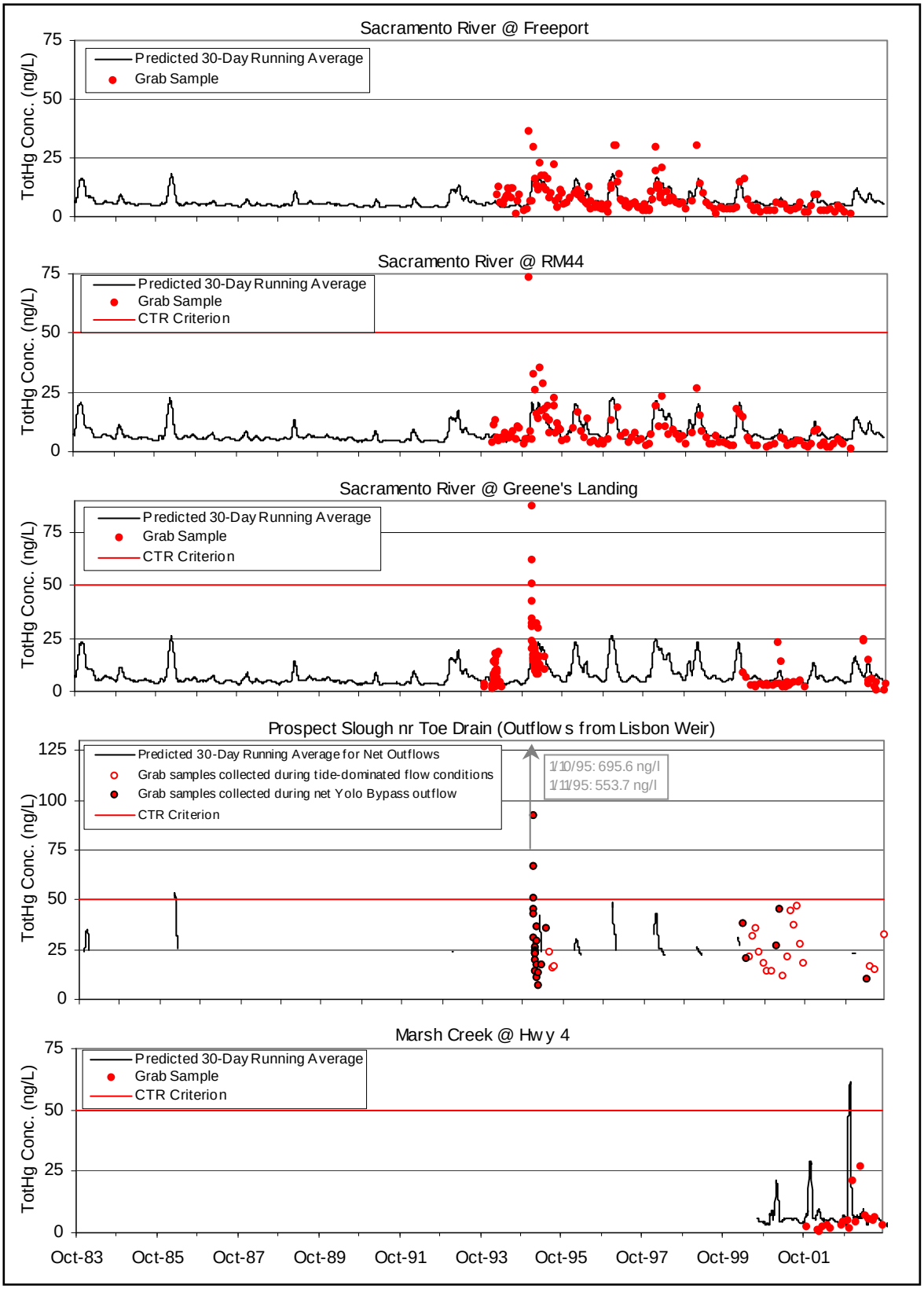

Figure 7.4: Grab Sample and Regression-Based 30-Day Running Average Total Mercury Concentrations for Delta Locations with Statistically Significant (P<0.05) Aqueous TotHg/Flow Correlations

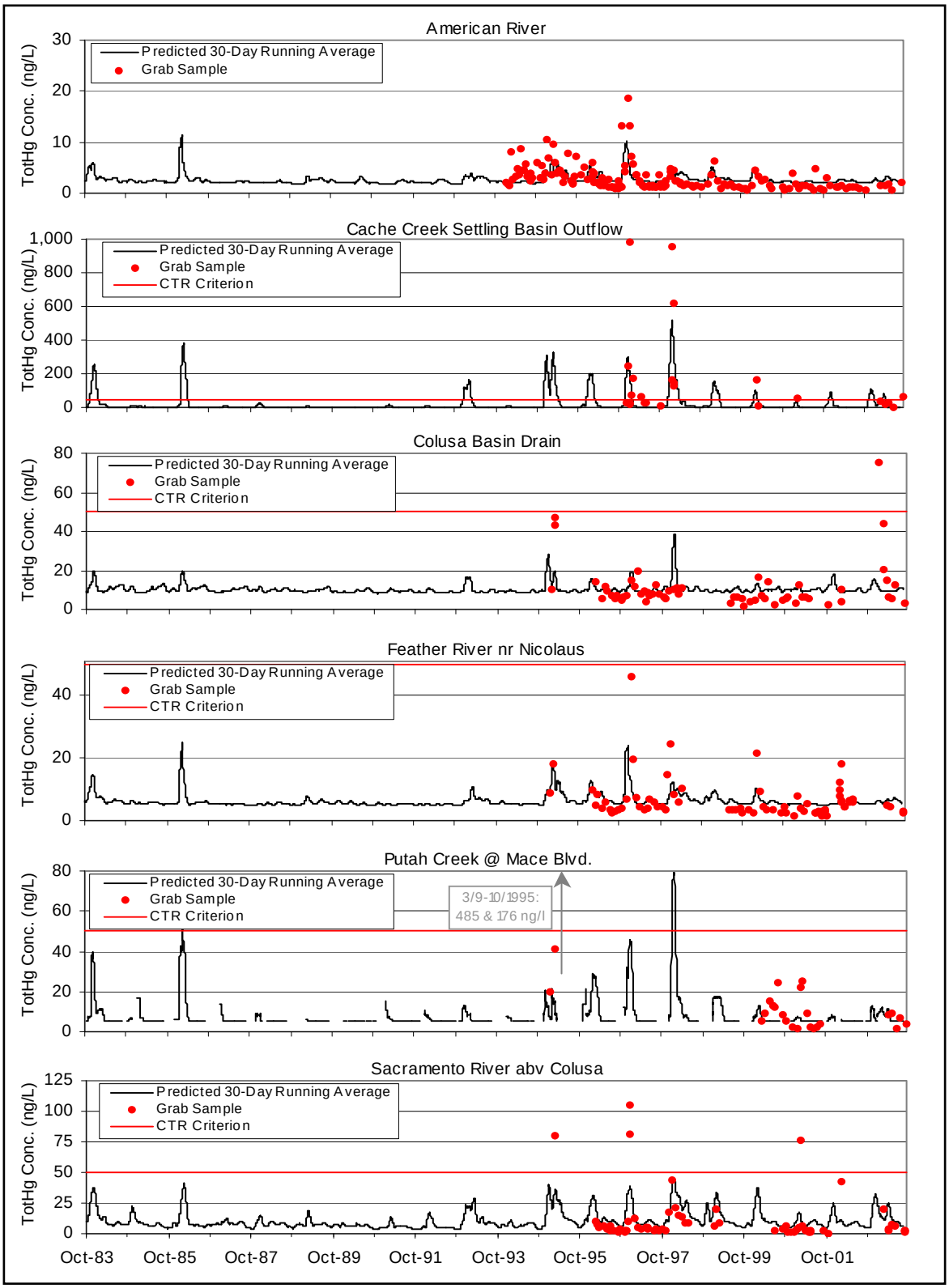

Figure 7.5: Grab Sample and Regression-Based 30-Day Running Average Total Mercury Concentrations for Sacramento Basin Tributary Locations with Statistically Significant (P<0.05) Aqueous TotHg/Flow Correlations

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 Concentration Ever Exceed the CTR (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. [h]	Yes	Twice, not within 3 years.	4	Likely Yes
Sacramento River above Colusa	Yes	No.	4	Yes
Sacramento Slough near Karnak [i]	No	- - -	0	Likely Yes

Table 7.18 Footnotes:

(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 I 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 SRCSD WWTP. 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 L provides the TotHg concentration data available for all three 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 TotHg 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 TotHg concentration data on Arcade Creek near Norwood and Del Paso Heights and Dry Creek. It was assumed that this dataset characterizes NEMD outflows.

(h) The predicted 30-day concentrations for Putah Creek are based on modeled flows (see Appendix E) estimated since the June 2006 draft TMDL Report. Although the regression between modeled flow and concentration is statistically significant ($P < 0.05$), there is greater uncertainty in the predicted 30-day concentrations. Two grab samples collected from a storm event in March 1995 and two grab samples from a storm event in February 2004 had TotHg concentrations greater than 50 ng/l: March 9 and 10, 1995: 485 and 176 ng/l; and February 18 and 25, 2004: 126 and 53 ng/l. Figure 7.5 does not illustrate grab samples collected after WY2003.

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

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 flows.
- Estimated mercury exports rates to San Francisco Bay are quite variable. 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, Cosumnes 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 efforts during the initial implementation phases of the Delta and upstream mercury control program.

Page intentionally left blank.

8 METHYLMERCURY ALLOCATIONS, TOTAL MERCURY LIMITS & MARGIN OF SAFETY

This chapter presents recommended point and nonpoint methylmercury allocations and watershed total mercury limits for methyl and total mercury sources to the Delta. Reductions in ambient water methylmercury concentrations are required to reduce methylmercury concentrations in fish. Reductions in total mercury loads are needed to enable water and fish methylmercury reductions and to comply with the USEPA's CTR criterion for human protection and the San Francisco Bay mercury TMDL control program's total mercury allocation for the Central Valley. Section 8.1 describes the proposed methylmercury load and waste load allocations for within-Delta and tributary inputs. Section 8.2 describes the proposed watershed total mercury limit. Sections 8.3 and 8.4 describe the associated margin of safety and inter-annual and seasonal variability.

The methylmercury allocations and total mercury limits described in this chapter reflect the preferred implementation alternative described in Chapter 4 of the draft Basin Plan Amendment staff report and are designed to address the beneficial use impairment in all subareas of the Delta as well as in the San Francisco Bay. However, as described in the draft Basin Plan Amendment report, a number of alternatives are possible. The Central Valley Water Board will consider a variety of allocation strategies and implementation alternatives as part of the Basin Plan amendment process.

8.1 Methylmercury Load Allocations

Since the June 2006 draft TMDL and Basin Plan Amendment staff reports issued for scientific peer review, staff made the following changes to this section in response to comments made by the scientific peer reviewers and other agencies and stakeholders:

- Developed allocations only for dischargers within the legal Delta and the Yolo Bypass (including the portion north of the legal Delta), versus the legal Delta and all dischargers within 30 miles of the legal Delta boundary.
- Provided additional explanation of, and calculations for, the proposed methylmercury allocations to more directly address expected increases in source loading from predicted population growth and wetland restoration efforts and to acknowledge the efforts of those point sources whose effluent quality demonstrates good performance.
- Changed the methylmercury allocation strategy such that all point and nonpoint sources have load-based (versus load- and concentration-based) allocations to allow for a greater range of implementation options.
- Established percent allocations for tributary inputs based on a methylmercury concentration of 0.05 ng/l (rather than 0.06 ng/l, the proposed methylmercury goal for ambient water) to reserve assimilative capacity for methylmercury flux from sediments in open-water and wetland habitats and agricultural lands, and point source discharges within the Delta/Yolo Bypass with discharge methylmercury concentrations that exceed 0.06 ng/l.

- Re-calculated all allocations based on existing methylmercury discharge concentrations rounded to two decimal places and existing methylmercury loads rounded to two significant digits.
- Re-organized the text to avoid redundancy with allocation strategy explanations provided in Chapter 4 of the draft Basin Plan Amendment staff report and to improve clarity.

Since the February 2008 draft TMDL and Basin Plan Amendment staff reports issued for public review, staff made the following changes to this section in response to input from the 2008-2009 Stakeholder Process and written stakeholder comments submitted before the April 2008 hearing meeting:

- Adjusted the method for calculating the waste load allocations for NPDES facilities to better address regionalization efforts and population growth.
- Updated the waste load allocations for NPDES facilities to reflect that several facilities no longer discharge to surface waters and that new facility discharges have begun since the TMDL period, WY2000-2003.
- Added to text to clarify how the waste load allocations are applied to MS4 service areas and other point and nonpoint sources.
- Adjusted the load allocations for tributary inputs and open-water habitat in all Delta subareas to incorporate the same percent reductions required for other point and nonpoint sources that discharge to those subareas (rather than setting tributary input allocations equal to the load calculated using a methylmercury concentration of 0.5 ng/l, and setting open water allocations equal to existing average annual methylmercury loads, as was done in the February 2008 draft report).
- Added text to clarify how waste load and load allocations are calculated.

8.1.1 Definition of Assimilative Capacity

A water body's loading capacity (assimilative capacity) represents the maximum rate of loading of a pollutant that the water body can assimilate without violating water quality standards. A TMDL typically represents the sum of all individual allocations of the water body's assimilative capacity and must be less than or equal to the assimilative capacity. Allocations are divided among "waste load allocations" for point sources and "load allocations" for nonpoint sources including natural background. The TMDL is the sum of these components:

Equation 8.1:

$$\text{TMDL} = \text{Waste Load Allocations} + \text{Load Allocations}$$

For the Delta methylmercury TMDL, waste load allocations apply to discharges from existing and future NPDES-permitted WWTPs and MS4s within the Delta and Yolo Bypass. Load allocations apply to methylmercury flux from existing and future wetland and open-water sediments and agricultural lands and atmospheric deposition within the Delta and Yolo Bypass, as well as to tributary inputs to the Delta/Yolo Bypass. Natural background sources include atmospheric deposition, methylmercury flux from wetland and open-water sediments, and runoff

from upland areas that existed prior to human-related pollution emissions such as mercury-contaminated sediment from historical mining activities in the tributary watersheds, mercury emissions from local and international industrial and municipal sources, and water management activities. Natural background sources are incorporated in the load allocations for wetlands, open water, and atmospheric deposition because data were not available to distinguish between natural background and nonpoint sources.

A TMDL need not be stated as a daily load (Code of Federal Regulations, Title 40, §130.2[i]). Other measures are allowed if appropriate. The methylmercury allocations proposed in Table 8.4 at the end of Section 8.1.3 are expressed in terms of average annual loads because the adverse effects of mercury occur through long-term bioaccumulation. The allocations are intended to represent annual averages and account for both seasonal and long-term variability. The annual load and waste load allocations can be expressed in daily terms by simply dividing each allocation by 365.[44] However, to best attain and maintain the proposed fish tissue objectives, staff recommends that the allocations be implemented as average annual loads.

Methylmercury allocations were made in terms of the existing assimilative capacity of each of the different Delta subareas. A methylmercury TMDL must be developed for each Delta subarea because the sources and percent reductions needed to meet the proposed implementation goal are different in each subarea. The linkage analysis (Chapter 5) described the calculation of an implementation goal for methylmercury in ambient water that is linked to the fish tissue methylmercury targets. The recommended implementation goal is an annual average concentration of 0.06 ng/l methylmercury in unfiltered water. This goal describes the assimilative capacity of Delta waters in terms of concentration (Section 5.2). Central Valley Water Board staff anticipates that as the average concentration of methylmercury in each Delta subarea decreases to the safe aqueous goal, the targets for fish tissue will be attained. To determine necessary reductions, the existing average aqueous methylmercury levels in each Delta subarea were compared to the methylmercury goal (Table 8.1).

The amount of reduction needed in each subarea is expressed as a percent of the existing concentration. As noted in the linkage analysis, the aqueous methylmercury goal was developed using water data for March to October 2000 because this was the only period for which there was overlap between water data and the lifespan of the fish. Table 8.1 compares the proposed goal to average methylmercury concentrations for March to October 2000 (Scenario A) and for March 2000 to April 2004 (Scenario B). Scenario B is based on a much larger dataset and includes values for all seasons. However, the percent reductions are similar for both scenarios and range from 0 to 80% for the different subareas. Therefore, staff recommends the use of the proposed reductions listed in Scenario B for the calculation of assimilative capacity.

The assimilative capacity of each subarea (Table 8.2) was determined using the proposed reductions listed in Scenario B in Table 8.1 (except for the Central and West Delta subareas, as

[44] In its November 2006 memorandum concerning appropriate time increments for TMDLs, the USEPA recommended that States provide written documentation regarding how the TMDL allocations can be expressed in daily terms (USEPA, 2006).

discussed in the next paragraphs), the sum of existing annual methylmercury inputs from identified sources (see Table 8.4 at the end of Section 8.1.3) and the following equation:

Equation 8.2: *(using the Sacramento subarea as an example)*

$$\text{Assimilative Capacity (g/yr)} = \text{Existing MeHg Inputs (g/yr)} - \left[\text{\% Reduction Needed to Meet Proposed Goal} * \text{Existing MeHg Inputs (g/yr)}\right]$$

$$= 2{,}418 \text{ g/yr} - (44\% * 2{,}418 \text{ g/yr})$$

$$= 1{,}354 \text{ g/yr}$$

The subareas on the eastern boundary of the Delta require substantial reductions in fish and aqueous methylmercury levels. In contrast, ambient methylmercury concentrations in the Central and West Delta subareas equal or approach the proposed aqueous methylmercury goal of 0.06 ng/l, resulting in the need for little-to-no reductions in methylmercury inputs to these subareas. The Central and West Delta subareas receive methylmercury from within-subarea sources, tributaries that drain directly to the subareas, and flows from upstream Delta subareas. The Central Delta subarea receives flows from the Sacramento, Yolo Bypass, Mokelumne, and San Joaquin subareas. The West Delta subarea receives flows from the Central Delta and Marsh Creek subareas. These within-Delta flows have not yet been quantified because additional data are needed for loss rates across the subareas. However, methylmercury in these subarea inflows are expected to decrease substantially (e.g., 40-80%) as upstream methylmercury and mercury management practices take place because methylmercury source load reductions ranging from 44 to 80% are required for the upstream subareas to achieve their assimilative capacities. In addition, the primary within-subarea source of methylmercury in the Central and West Delta subarea is flux from open-water habitat sediments (Table 8.4), which is expected to decrease as mercury reduction projects take place in the tributary watersheds that result in decreasing the mercury concentration of sediment deposited in the Central and West Delta subareas. Therefore, staff recommends that no reduction be required for point and nonpoint source methylmercury discharges within the Central and West Delta subareas. Section 8.1.2 describes an allocation strategy that ensures that fish and water methylmercury concentrations in these subareas remain in compliance with the proposed fish tissue objectives and methylmercury goal for water. The Central Valley Water Board can consider modification of the allocation strategy and the creation of new allocations (e.g., for within-Delta flows between subareas) during the program review proposed to take place in about seven years based on existing and new information that becomes available.

The following three sections describe the strategy and calculations used to determine specific allocations for point and nonpoint sources listed in Table 8.4 for each of the subareas.

Table 8.1: Aqueous Methylmercury Reductions Needed to Meet the Proposed Methylmercury Goal of 0.06 ng/l. [(a)]

	Delta Subarea						
	Central Delta	Marsh Creek	Mokelumne River	Sacramento River	San Joaquin River	West Delta	Yolo Bypass
A. Scenario Based on March to October 2000 Aqueous MeHg Data [(b)]							
Average Aqueous MeHg Concentration (ng/l)	0.055	0.224	0.140	0.120	0.147	0.087	0.305
Percent Reduction Needed to Meet the Proposed MeHg Goal	0%	73%	57%	50%	59%	31%	80%
B. Scenario Based on March 2000 to April 2004 Aqueous MeHg Data [(b)]							
Average Annual Aqueous MeHg Concentration (ng/l)	0.060	0.224	0.166	0.108	0.160	0.083	0.273
Percent Reduction Needed to Meet the Proposed MeHg Goal	0%	73%	64%	44%	63%	28%	78%

(a) The amount of reduction needed in each subarea is expressed as a percent of the existing methylmercury concentration. For example, the percent reduction needed for the Marsh Creek subarea Scenario A is calculated by: (0.244 - 0.06) / 0.244 = 73%. The average March to October 2000 methylmercury concentration for the Central Delta is below the proposed implementation goal of 0.06 ng/l. As a result, Scenario A calculations for the Central Delta result in negative numbers: A (1): (0.055 - 0.06)/0.055 = -9%. No reduction is needed under Scenario A or B for Central Delta ambient methylmercury.

(b) Average concentrations are based on unfiltered MeHg concentration data collected at the following locations: Delta Mendota Canal and State Water Project (Central Delta); Marsh Creek at Highway 4; Mokelumne River near I-5; Sacramento River at Freeport, RM44 and Greene's Landing; San Joaquin River near Vernalis; outflow to San Francisco Bay measured at X2, usually near Mallard Island (West Delta); and Prospect Slough near Toe Drain (Yolo Bypass). The values for the Central Delta, Mokelumne River, Sacramento River, San Joaquin and West Delta subareas are described in Section 5.1 and Table 5.1 in Chapter 5 and are based on monthly average concentrations so that the average concentrations for each study period are not influenced by the unequal number of samples collected in each month. The Yolo Bypass average concentrations also are based on monthly average concentrations. The sampling frequency on Marsh Creek was inadequate to develop averages for each study period, much less to pool data by month; therefore, the average of all available concentration data was used in both scenarios. The Yolo Bypass and Marsh Creek data are described in Chapter 6, Section 6.2.1 and Table 6.3. It was assumed that the sampling locations are representative of the subareas in which they occur.

Table 8.2: Assimilative Capacity Calculations for Each Delta Subarea.

Delta Subarea	**Existing Average Annual MeHg Conc.** [(a)] (ng/l)	**% Reduction Needed to Achieve Proposed Goal of 0.06 ng/l** [(a)]	**Existing Annual MeHg Load from Identified Sources** [(b)] (g/yr)	**Assimilative Capacity** (g/yr)
Central Delta	0.060	0%	668	668
Marsh Creek	0.224	73%	6.14	1.66
Mokelumne River	0.166	64%	146	52.6
Sacramento River	0.108	44%	2,475	1,385
San Joaquin River	0.160	63%	528	195
West Delta	0.083	0%	330	330
Yolo Bypass [North & South]	0.273	78%	1,068	235

(a) No percent reductions are proposed for the Central and West Delta subareas because their fish tissue and aqueous methylmercury levels either currently achieve or are expected to achieve safe levels when actions are implemented to reduce upstream aqueous methylmercury levels. Proposed reductions for other subareas are from Table 8.1 Scenario B.

(b) "Existing Annual MeHg Load" represents the sum of all identified inputs to each subarea (Chapter 6 and Table 8.4).

8.1.2 Allocation Strategy

Table 8.4 at the end of Section 8.1.4 lists waste load and load allocations for each point and nonpoint methylmercury input by subarea and reflects the preferred implementation alternative and resulting allocation strategy described in Chapter 4 of the draft Basin Plan Amendment staff report. This section summarizes key elements of the preferred allocation strategy developed in the draft Basin Plan Amendment staff report. Section 8.1.3 provides detailed explanations of calculation methods for NPDES facility waste load allocations. Section 8.1.4 describes the equations used to calculate the load and waste load allocations for nonpoint and point sources in each Delta subarea.

The available science is adequate to establish individual allocations for point sources in the Delta/Yolo Bypass and tributary inputs to the Delta/Yolo Bypass, and general (subarea) methylmercury allocations for nonpoint sources within the Delta/Yolo Bypass. The preferred allocation strategy specifies the following:

- Atmospheric deposition and discharges from urban areas outside of MS4 service areas in all Delta subareas have load allocations set at their existing average annual methylmercury loads.
- All point and nonpoint sources in the Central and West Delta subareas have waste load and load allocations set at their existing average annual methylmercury loads to ensure that compliance with the fish tissue objectives is maintained.
- Waste load and load allocations integrate expected expansions to existing sources and new sources.
- Waste load allocations acknowledge the efforts of those point sources whose effluent quality demonstrates good performance, and require improvement by other dischargers.

Anticipated population growth, regional water management changes, and wetland restoration efforts could result in increases in methylmercury loading to the Delta. For example, increasing populations will result in increasing total mercury and methylmercury discharges from municipal WWTPs and urban runoff. The California Department of Finance predicts that populations in the Delta/Yolo Bypass counties[45] will increase 76% to 213% by 2050 (CDOF, 2007), with an average increase of about 120%. (For more discussion on potential regional changes, see Section 8.4.3, “Regional and Global Change”.)

The allocations for each existing source apply to the sum of its existing discharge and any expansion to its discharge in the future, with the exceptions noted in Section 8.1.3. The recommended open-water and wetland methylmercury allocations apply to all wetlands and open-water habitat acreage in each Delta subarea, including current wetlands and future wetland restoration projects. The subarea load allocations for agricultural lands apply to the net difference between methylmercury loads discharged by agricultural lands during the irrigation season and methylmercury loads in irrigation water applied to the agricultural lands. Similarly, the subarea load allocations for wetlands apply to the net difference between methylmercury

[45] The CDOF predicts the following population increases by 2050: Contra Costa County - 89%, Sacramento County - 76%, San Joaquin County - 213%, Solano County - 105%, and Yolo County - 93% (CDOF, 2007).

loads discharged by wetlands and methylmercury loads in the wetlands' source water (surface water, groundwater and precipitation). The load allocations for agricultural lands, wetlands, and open-water habitat do not include methylmercury loading from atmospheric wet deposition.

The MS4 waste load allocations apply to all urban land use areas within MS4 service areas within each Delta subarea and similarly address loading from current and future urban areas within the MS4 service areas, including but not limited to Caltrans facilities and rights-of-way (NPDES No. CAS000003), public facilities, properties proximate to banks of waterways, industrial facilities, and construction sites. The MS4 waste load allocations do not apply to non-urban land uses within MS4 service areas. The load allocations for agricultural lands, wetlands, and open-water habitat include methylmercury loading from agricultural lands, wetlands, and open water habitat within MS4 service areas. Some MS4s service areas span multiple Delta subareas and therefore have multiple subarea allocations and are listed more than once. The waste load allocations do not apply to urban land within the MS4 service areas that are outside of the legal Delta and Yolo Bypass boundaries. The Contra Costa County MS4 discharges to both the Delta and San Francisco Bay; the subarea allocations in Table 8.4 apply only to the portions of the MS4 service area that discharge to the Delta within the Central Valley Water Quality Control Board's jurisdiction. The waste load allocations for urban land within MS4 service areas include methylmercury loading from atmospheric wet deposition, consistent with how allocations were developed for the recently-adopted San Francisco Bay and Guadalupe River Watershed mercury TMDLs (Johnson and Looker, 2004; SFBRWQCB, 2008). Urban areas were not included in the atmospheric wet deposition load calculations to avoid double-counting. Urban areas not encompassed by a MS4 service area were grouped into a "urban runoff (nonpoint source)" allocation for each Delta subarea, consistent with USEPA's requirements and guidance for establishing waste load allocations for storm water sources (USEPA, 2002).

Staff recommends that methylmercury waste load allocations for NPDES facilities apply to their annual (calendar year) discharge methylmercury loads with one exception. Staff recommends that assessment of compliance with the waste load allocation for the Oakwood Lake Subdivision Mining Reclamation discharges (CA0082783) be assessed as a five-year average annual methylmercury load because its discharges result from flood-control pumping, which can fluctuate with short-term and long-term precipitation patterns. Similarly, annual loads for tributary inputs, urban discharges, open-water habitat, and atmospheric deposition are based on water years 2000 through 2003, a relative dry period, and expected to fluctuate with rainfall and river flow conditions and other environmental factors. As a result, staff recommends that assessment of compliance with load allocations for the tributary inputs, urban areas outside of MS4 service areas, open-water habitat, and atmospheric deposition, and waste load allocations for the MS4s, be based on five-year average annual loads. As described in the draft Basin Plan Amendment staff report, staff recommends that a Delta mercury control program review take place in about seven years, during which the allocations can be revised to include available wet year data and other new information.

Methylmercury data were not available for inputs to the Yolo Bypass from Willow Slough and runoff from the Dixon area. The average methylmercury concentration for Ulatis Creek was used to estimate their inputs to the Yolo Bypass because they have similar land uses as the Ulatis Creek watershed. This assumption, and the resulting tributary load allocations, may need

to be re-evaluated during the control program review. In addition, no methylmercury load estimates were made for other small drainage areas for which no methylmercury concentration data were available: Manteca-Escalon, Bethany Reservoir, Antioch, and Montezuma Hills areas). These areas contribute only about one third of a percent of all water inputs to the Delta/Yolo Bypass. Their methylmercury inputs to the Delta and Yolo Bypass are encompassed by the margin of safety incorporated in all other allocations (see Section 8.3 for more information about the margin of safety). Their potential methylmercury loading will be evaluated during the control program review and allocations assigned as needed.

8.1.3 Calculation Methods for NPDES Facility Waste Load Allocations

Staff assumed that, in general, NPDES-permitted WWTP discharges throughout the Delta/Yolo Bypass would increase by 120%. Staff assumed that half of that growth will be addressed by expansions to existing facilities in each Delta subarea, and that the remaining half will be serviced by new facilities in each subarea. Table 8.3 at the end of this section illustrates WWTP effluent volumes discharged to each Delta subarea (based on volumes identified in Table 6.5 in Chapter 6 for WWTPs that were discharging to surface water during the WY2000-2003 TMDL period), the amount of discharge volume increase expected in each subarea, and the discharge volume that staff assumed will be addressed by existing and new facilities.

Results from methylmercury monitoring by NPDES facilities in the Delta and upstream tributary watersheds indicate that many facilities have average effluent methylmercury levels that approach or are less than the proposed implementation goal for unfiltered methylmercury in Delta waters (0.06 ng/l), while other facilities have much higher methylmercury levels (see Chapter 6 and Appendix G in the TMDL Report and Bosworth *et al*., 2008). This indicates that some discharges, though they contribute methylmercury loading to the Delta, may act as dilution because of their low methylmercury concentrations.

Staff recommends that source discharges with average methylmercury concentrations below the proposed aqueous methylmercury goal of 0.06 ng/l be considered dilution and assigned a waste load allocation based on their existing discharge methylmercury concentration. There are four NPDES-permitted facilities that discharged during the WY2000-2003 TMDL period with effluent that had methylmercury concentrations less than 0.06 ng/l that still (as of February 2010) discharge to surface water: Brentwood WWTP, Deuel Vocational Institute WWTP, Oakwood Lake Subdivision Mining Reclamation, and Woodland WWTP. The “Concentration Used to Calculate Allocation” in Table 8.4 for these sources was set at the existing discharge methylmercury concentration for each of these dischargers.

Conceptually, there is no need to limit the loading from sources that act as dilution, given the overall extent of impairment throughout the Delta. However, to enable the calculation of allocations required for other sources, load-based allocations must be calculated even for those sources that act as dilution. Staff assumed that the three municipal WWTPs with discharges less than 0.06 ng/l would increase their discharge volume by 60% to account for future population growth, with one exception. The Central Valley Water Board recently adopted new waste discharge requirements for the City of Woodland WWTP (Order No. R5-2009-0010) that allow it to increase its design daily average effluent flow capacity from 7.8 mgd to 10.4 mgd. As a result, staff used 10.4 mgd rather than 160% of the WY2005 effluent flow (1.6 * 6.05 mgd =

9.7 mgd). Staff calculated the methylmercury waste load allocations for the Brentwood WWTP and Deuel Vocational Institute WWTP shown in Table 8.4 by multiplying their existing average effluent methylmercury concentrations by their current discharge volumes (shown in Table 8.3) multiplied by 160%.

Staff also calculated "Unassigned NPDES Facility Allocations" in Table 8.4 for each subarea to address new NPDES discharges. Staff assumed that new WWTPs would be designed to discharge effluent with methylmercury concentrations equal to or less than 0.06 ng/l, and calculated the "Unassigned WWTP allocations" by multiplying the predicted volumes shown in Table 8.3a by 0.06 ng/l methylmercury. As discussed in the footnotes for Table 8.3a, the predicted volumes have been modified since the February 2008 draft report to account for new facility discharges to surface water that recently began or are about to begin and therefore were given facility-specific allocations in Table 8.4.

To calculate allocations for WWTPs with effluent methylmercury concentrations greater than 0.06 ng/l, staff used the existing effluent volumes (rather than multiply the existing volumes by 160%) and the percent allocation calculation method described in the next section. Although these facilities may need to increase their discharged effluent volumes in response to population growth in their service areas, increased effluent volumes at their existing effluent concentrations, if allowed, would worsen the methylmercury impairment. Conceptually, the discharge volume from a WWTP that has an average effluent methylmercury concentration greater than 0.06 ng/L could be allowed to increase so long as its methylmercury load does not increase. [46] This approach is consistent with State Water Board Resolution No. 2005-0060,[47] which required the San Francisco Bay Water Board to incorporate provisions that acknowledge the efforts of those point sources whose effluent quality demonstrates good performance, and require improvement by other dischargers, when establishing waste load allocations.

Several municipal WWTPs in the Delta/Yolo Bypass have ceased discharging to surface waters, others have begun discharging, one is expected to begin discharging in the near future, and two have had substantial changes in their effluent methylmercury levels since WY2003. In summary:

- The San Joaquin County Service Area 31 Flag City WWTP, Walnut Grove WWTP, West Sacramento WWTP, and Rio Vista Trilogy WWTP have ceased discharging to surface water;
- The Mountain House WWTP and Northwest WWTP began discharging to surface water;
- The Ironhouse Sanitary District WWTP is expected to begin discharging to the San Joaquin River within the West Delta subarea within the next year; and

[46] Discharge volume from a WWTP that has average effluent methylmercury concentrations greater than 0.06 ng/l could be allowed to increase so long as its load does not increase above its wasteload allocation. For example, an increase in volume would necessitate a decrease in methylmercury concentration to maintain the load allocation so that the increased volume does not cause an increase in receiving water methylmercury concentration. Under circumstances described in the following pages, WWTPs that expand their discharge may also be allotted a portion of the "Unassigned NPDES Facility Allocations". If an offset program is developed, another option could be for such a WWTP to compensate for increases in its load by completing offset projects upstream.

[47] On September 7, 2005, the State Water Board adopted Resolution No. 2005-0060 ("Remand Order") remanding the San Francisco Bay Water Board's San Francisco Bay Mercury TMDL Amendment with requirements for specific revisions to the TMDL and associated implementation plan.

- The Stockton WWTP and SRCSD Sacramento River WWTP have had substantial reductions in their effluent methylmercury concentrations and loads in recent years.

Because the West Sacramento and Walnut Grove WWTPs discharged to surface waters during the TMDL period, WY2000-2003, their effluent methylmercury loads shown in Table 6.5 are included in the Table 6.2 load summary in Chapter 6. However, as part of regionalization efforts, SRCSD's Sacramento River WWTP now receives influent that had been treated by the West Sacramento and Walnut Grove WWTPs. To address this change, the "Existing Average Annual MeHg Load" in Table 8.4 for the SRCSD Sacramento River WWTP reflects the sum of the effluent methylmercury loads presented in Table 6.5 for the SRCSD Sacramento River, West Sacramento and Walnut Grove WWTPs (160, 0.39, and 0.24 g/yr, respectively, for a sum of 160.63, rounded to 161 g/yr for allocation calculations); this sum was then multiplied by the "Percent Allocation" to calculate the waste load allocation for the SRCSD Sacramento River WWTP. The 2008-2009 Stakeholder Process's NPDES Facility Workgroup evaluated several methods to calculate allocations that would fairly and equitably address regionalization efforts and selected this as the preferred method.

The San Joaquin County Service Area 31 Flag City WWTP was discharging to surface water during the WY2000-2003 period. As a result, its effluent methylmercury load is included in the Table 6.2 summary in Chapter 6. However, the discharger recently completed the construction of a pump station and dual forcemain project that allows for discharge of the Flag City wastewater to the City of Lodi White Slough WWTP. As of 10 April 2008, all wastewater flows from the Flag City area are being directed to the Lodi WWTP, and the Flag City WWTP's discharge to surface waters has ceased. To address this change, the "Existing Average Annual MeHg Load" in Table 8.4 for the Lodi and Flag City WWTPs were summed (0.93 and 0.0066 g/yr, for a sum of 0.94 g/yr) and then multiplied by the "Percent Allocation" to calculate the waste load allocation for the Lodi WWTP. This is the same method used to address the regionalization of the SRCSD and West Sacramento WWTPs.

If other NPDES facilities that have allocations in Table 8.4 regionalize or otherwise consolidate after the adoption of this TMDL, their waste load allocations can be summed.

In 2007 the Trilogy WWTP was closed and the Northwest WWTP began to discharge in its place. Central Valley Water Board Order No. R5-2004-0092 considers the closure of the Trilogy WWTP coinciding with the start-up of the Northwest WWTP as a change in treatment process and location rather than as a new treatment plant. To address this change, the "Existing Average Annual MeHg Load" in Table 8.4 reflects the annual methylmercury load discharged by the Trilogy WWTP, which discharged 0.1 mgd. The Northwest WWTP has not yet completed effluent methylmercury monitoring; however, it has treatment processes in place that have resulted in very low effluent methylmercury concentrations at other WWTPs (see Section 6.2.3.1 in Chapter 6 for more discussion about Northwest WWTP treatment processes and effluent methylmercury concentrations observed at WWTPs with similar treatment processes). As a result, the allocation for the Northwest WWTP in Table 8.4 is based on its current start-up capacity of 1 mgd, which is 10 times greater than the Trilogy WWTP discharge, and the current calibration standard for methylmercury analysis (0.05 ng/l), which results in a load of 0.069 g/yr. Because it is likely that the estimated effluent load for the Northwest WWTP may be an overestimate, given the very low effluent methylmercury concentrations observed at WWTPs

that employ similar treatment processes, its allocation may include a margin of safety. As described in the draft Basin Plan Amendment staff report, staff recommends that a control program review take place after additional Delta-specific studies are completed, during which the Northwest WWTP allocation can be adjusted if needed.

The Mountain House CSD WWTP was not discharging to surface water prior to March 2007 and therefore was not identified in the source analysis for the TMDL period, WY2000-2003. The Mountain House CSD WWTP now discharges to Old River within the San Joaquin River subarea. Because it is now discharging to surface water and has submitted effluent methylmercury concentration data for its discharge (see Section 6.2.3.1 and Appendix L), staff calculated a waste load allocation for its discharge. Between August 2007 and May 2009, 21 monthly effluent samples were analyzed for methylmercury. Four results were reported as equal to the detection limit (0.05 ng/l) and 17 results were reported as "ND" (nondetect) with a method detection limit of 0.05 ng/l. The allocation was calculated using a methylmercury concentration of 0.05 ng/l and the facility's average dry weather design flow of 5.4 mgd to obtain a waste load allocation of 0.37 g/year.

The Ironhouse Sanitary District submitted a Report of Waste Discharge in June 2007 and in April 2008 received a NPDES permit (NPDES No. CA0085260) to discharge up to 4.3 mgd of treated wastewater from the Ironhouse Sanitary District (ISD) WWTP to the San Joaquin River off of Jersey Island in the West Delta subarea. As of February 2010, the ISD had not yet submitted a request for surface water discharge; however, it is expected to begin discharging within the next year. In the February 2008 draft TMDL report, the "unassigned allocation" for the West Delta subarea was based on the expected design flow for the ISD WWTP. Because the ISD WWTP has since received a NPDES permit to discharge, Table 8.4 now includes a waste load allocation specific to the ISD WWTP. The ISD has designed its new WWTP to include: coarse screening, grit removal, fine screening, anoxic basins, aeration basins, membrane filtration and UV disinfection. The effluent will be nitrified and denitrified and meet California Code of Regulations Title 22 disinfection requirements for both the surface water discharge and land disposal. Table 23 in "*A Review of Methylmercury Discharges from NPDES Facilities in California's Central Valley"* (Bosworth *et al.*, 2008) indicated that WWTPs that employed nitrification/denitrification, filtration and UV disinfection had effluent methylmercury concentrations that ranged from nondetect to 0.078 ng/l and average and median effluent methylmercury concentrations of 0.029 and 0.020 ng/l, respectively, based on three facilities and 21 samples, 11 of which had methylmercury concentrations less than the method detection limit. In the absence of monitoring data, it may not be reasonable to calculate a waste load allocation for the ISD WWTP based on a concentration that is less that the current calibration standard for methylmercury analysis (0.05 ng/l). As a result, its waste load was estimated using a concentration of 0.05 ng/l and discharge volume of 4.3 mgd to obtain an annual load of 0.030 g/year.

Any new NPDES-permitted facilities that begin to discharge after this TMDL is adopted but are not identified in Table 8.4 would be allotted a portion of the "unassigned allocation" for the subarea where their discharges are located, so long as the sum of the new facilities' discharge methylmercury loads does not exceed the unassigned allocations. "New" facilities could include newly built facilities that have not previously discharged to land or water as well as existing facilities that previously discharged to land and then began to discharge to surface water or

diverted discharges to another facility that discharges to surface water as part of ongoing regionalization efforts. In addition, staff recommends that existing facilities also be allotted a portion of the unassigned allocations in the subareas where they discharge if they expand beyond their allocations listed in Table 8.4 so long as the additional allocation does not exceed the product of the net increase in flow volume and 0.06 ng/l methylmercury. The 2008-2009 Stakeholder Process's NPDES Facility Workgroup evaluated several approaches for allowing access to the "unassigned allocations" that would fairly and equitably address regionalization efforts and new discharges from existing and newly-built facilities and selected this as the preferred approach. The sum of all new and/or expanded methylmercury discharges from NPDES facilities within each Delta subarea must not exceed the Delta subarea-specific waste load allocation listed in Table 8.4.

Two WWTPs, the City of Stockton WWTP and the SRCSD Sacramento River WWTP, have had marked decreases in effluent methylmercury concentrations and loads in recent years. As discussed previously in Chapter 6 (Section 6.2.3.1), upgrades to the City of Stockton WWTP completed in September 2006 appear to have led to reductions in total mercury and methylmercury as well as ammonia. A comparison of WWTP effluent methylmercury data collected before (August 2004-July 2005) and after (January-July 2009) the treatment plant upgrade indicates that since the WWTP was upgraded, average methylmercury effluent concentrations decreased by 91%. SRCSD's Sacramento River WWTP had effluent methylmercury data for 2001-2007 that illustrated a marked decrease in effluent methylmercury and total mercury concentrations with time. During the April 2008 Board hearing meeting for the Delta mercury control program, the SRCSD District Engineer testified that implementation of the Be Mercury Free Program to reduce inorganic mercury sources to SRCSD's WWTP resulted in reductions in both inorganic mercury and methylmercury discharges from the WWTP. Although more recent effluent data for the Stockton WWTP and SRCSD WWTP discharges indicate a change in the nature of their discharges, the allocations in Table 8.4 were calculated using the earlier data (August 2004 to July 2005 for the City of Stockton; December 2000 to June 2003 for the SRCSD WWTP) because the earlier data are more representative of conditions during the TMDL period, WY2000-2003. In addition, this approach ensures that the dischargers are not unfairly penalized for making early improvements to their discharges.

The City of Davis WWTP (CA0079049) has two discharge locations; wastewater is discharged from Discharge 001 to the Willow Slough Bypass upstream of the Yolo Bypass and from Discharge 002 to the Conaway Ranch Toe Drain in the Yolo Bypass. The methylmercury load allocation listed in Table 8.4 applies only to Discharge 002, which discharges seasonally from about February to June. Discharge 001 is encompassed by the Willow Slough watershed methylmercury allocation. Discharge 001 will be assigned an individual allocation when a control program is developed for the upstream watersheds.

As noted in Section 6.2.3, two of the NPDES-permitted facilities in the Delta are power or heating/cooling facilities that use ambient water for cooling water, Mirant Delta LLC Contra Costa Power Plant and the State of California Heating/Cooling Plant. Methylmercury loads and concentrations in heating/cooling and power facility discharges vary with intake water conditions; the facilities do not appear to act as a source of methylmercury to the Delta. Staff recommends that such facilities have concentration-based allocations equal to 100% of their intake methylmercury concentrations, so that their discharge allocations equal the detected

methylmercury concentration found in their intake water. Outflows from the Mirant Delta plant were not incorporated in the allocation calculations for other sources in Section 8.1.4 and are not listed in Table 8.4. A concentration-based allocation for the Mirant Delta plant is listed in Table B in the proposed Basin Plan amendments provided at the beginning of the draft Basin Plan Amendment staff report. The State of California Heating/Cooling Plant recently ceased discharging and as a result is not assigned an allocation in the proposed Basin Plan amendments.

GWF Power Systems (CA0082309), in the West Delta subarea, acquires its intake water from sources other than ambient surface water and therefore was incorporated in the allocation calculations in Section 8.1.4. GWF effluent methylmercury concentrations are less than the analytical method detection limit (0.03 ng/l; see Table 6.5 in Chapter 6). As a result, staff recommends that its allocation be equal to an annual load of 0.0052 g/yr, calculated by using the methylmercury method detection limit (0.03 ng/l) and GWF's design flow (0.125 mgd) to accommodate potential growth.

Discharge methylmercury data were not available for the Lincoln Center Groundwater Treatment Facility in Stockton, which discharges treated groundwater to Fourteenmile Slough in the Central Delta subarea. Other groundwater treatment facility discharges monitored to date have average methylmercury concentrations below current method detection limits (< 0.03 ng/l; Bosworth *et al.*, 2008). As a result, staff recommends that allocation for the Lincoln Center Facility be equal to an annual load of 0.018 g/yr, calculated by using the design flow (0.43 mgd) and the methylmercury method detection limit (0.03 ng/l). This allocation can be modified at the end of Phase 1, after facility-specific discharge methylmercury data is collected.

Discharge volumes and methylmercury data were not available for the Metropolitan Stevedore Company (CA0084174), a marine bulk commodity terminal on leased land at the Port of Stockton in the Central Delta subarea. Staff recommends that a methylmercury waste load allocation specifically for non-storm water discharges from the Metropolitan Stevedore Company be established in its NPDES permit once it completes at least three sampling events for methylmercury in its discharges. Its discharge will be allotted a portion of the "unassigned allocation" for the Central Delta subarea.

As described in Section 8.1.3, several NPDES-permitted facilities have waste load allocations based on 160% of their existing loads or on their permitted design flows, rather than on their existing discharges. On Table 8.4, their allocations are shown as having two components, their existing loads and their allowable increase ("allowable future growth"). This was done so that a summary table (Table 8.5) could be created that clearly identifies the sum of allowable discharge load increases in each subarea. These two components are summed for each facility-specific allocation for compliance purposes in Table B in the proposed Basin Plan amendments provided at the beginning of the draft Basin Plan Amendment staff report. The "allowable future growth" component of the Northwest WWTP allocation (0.065 g/yr) is based on the difference between the estimated load discharged by the Trilogy WWTP during the WY2000-2003 TMDL period (0.0041 g/yr) and the Northwest WWTP's allocation calculated from its average dry weather flow start-up capacity of 1 mgd and 0.05 ng/l (0.069 g/yr). Because the Mountain House CSD WWTP and Ironhouse Sanitation District WWTP did not discharge to surface water during the WY2000-2003 TMDL period, they have only "allowable future growth"

allocations in Table 8.4. The “unassigned allocations” in Table 8.4 are also listed as “allowable future growth”.

Space intentionally left blank.

Table 8.3a: Total Existing Municipal WWTP Effluent Volume Discharged to Each Delta Subarea, Predicted Increases Due to Population Growth, and Volumes and Methylmercury Loads Predicted to Be Discharged by New WWTPs.

Subarea	Existing Effluent Volume (mgd) [a]	Predicted Increase (mgd) [b]	Effluent Volume Predicted to Be Discharged by New WWTPs (mgd) [c]	Effluent MeHg Load Predicted to Be Discharged by New WWTPs (g/yr) [d]
Central Delta [f]	6.1	7.3	3.7	0.31
Marsh Creek	3.1	3.7	1.9	0.16
Sacramento River	170	204	102	8.5
San Joaquin River	43	52	20.6 [26] [e]	1.7
West Delta [f]	0 [g]	6.9 [g]	2.6 [g]	0.22
Yolo Bypass	8.5	10.2	5.1	0.42

(a) "Existing Effluent Volume" is the sum of effluent volumes discharged by municipal WWTPs in each Delta subarea that discharged during the TMDL period, WY2000-2003, except for the West Delta subarea.

(b) Staff assumed that, in general, NPDES-permitted WWTP discharges throughout Delta/Yolo Bypass would increase by 120% in response to predicted population growth in the region.

(c) Staff assumed that half of the predicted 120% population growth would be addressed by expansions to existing facilities in each Delta subarea, and that the remaining half would be serviced by new facilities in each subarea. Staff predicted discharge volumes to be serviced by new WWTPs by multiplying the "Existing Effluent Volume" discharged to each subarea by 0.6.

(d) "Effluent MeHg Load Predicted to Be Discharged by New WWTPs" was calculated by multiplying the predicted effluent volumes by 0.06 ng/l methylmercury. These loads are the basis for the "Unassigned NPDES Facility Allocations" in Table 8.4.

(e) The Mountain House CSD WWTP recently began to discharge to surface water. To address this new discharger, staff included a facility-specific allocation for the Mountain House CSD WWTP in Table 8.4 and subtracted its design flow of 5.4 mgd from the predicted volume for new WWTPs in the San Joaquin River subarea in this table.

(f) As noted in the previous section, ambient methylmercury concentrations in the Central and West Delta subareas equal or approach the proposed aqueous methylmercury goal of 0.06 ng/l, resulting in the need for little-to-no reductions in methylmercury inputs to these subareas. As a result, staff recommended that methylmercury source inputs to these subareas have allocations set at 100%. The Central Delta subarea receives flows from the Sacramento, Yolo Bypass, Mokelumne, and San Joaquin subareas. The West Delta subarea receives flows from the Central Delta and Marsh Creek subareas. These subarea inflows are expected to decrease substantially (e.g., 40-80%) as upstream mercury management practices take place because methylmercury source load reductions ranging from 44 to 80% are required for the upstream subareas to achieve their assimilative capacities. These reductions will provide ample assimilative capacity for the Unassigned NPDES Facility Allocations based on the "Effluent MeHg Load Predicted to Be Discharged by New WWTPs".

(g) There are no WWTPs currently discharging in the West Delta subarea. However, the Ironhouse Sanitary District submitted a Report of Waste Discharge in 2007 and in April 2008 received a NPDES permit to discharge up to 4.3 mgd of treated wastewater from the Ironhouse Sanitary District (ISD) WWTP to the San Joaquin River within the West Delta subarea. The ISD WWTP will likely begin discharging to the San Joaquin River sometime in 2010 and was given its own waste load allocation in Table 8.4. The ISD WWTP waste load allocation was calculated using its design flow rather than its expected initial discharge flow and therefore its allocation will address expected population growth for its service area. Staff calculated the "Predicted Increase" for the West Delta subarea by multiplying 4.3 mgd by 60% (rather than 120%) and adding the result (2.6 mgd) to 4.3 mgd, for a total of 6.9 mgd. Staff calculated the "Effluent Volume Predicted to Be Discharged by New WWTPs" using 2.6 mgd because the ISD WWTP allocation will accommodate expected population growth in its service area. Staff expects that the ISD WWTP allocation and "unassigned allocation" based on 2.6 mgd will provide adequate accommodation for future population growth. This is because a nearby wastewater district (the Delta Diablo Sanitation District (DDSD), which discharges with the jurisdiction of the San Francisco Bay Water Board) has expressed interest in importing treated water from the Ironhouse Sanitary District for recycling (Darling, 2008). As described in the draft Basin Plan Amendment staff report, staff recommends that a Delta mercury control program review take place in about 7 years, during which the methods for calculating the unassigned allocations can be revised if needed.

Table 8.3b: Predicted Effluent Volumes Used to Calculate Corresponding Methylmercury Loads for Municipal WWTPs that Discharge Effluent with Average Methylmercury Concentrations Less than 0.06 ng/l.

Permittee [(a)]	**NPDES Permit No.**	**Existing Effluent Volume** (mgd)	**Predicted Effluent Volume Used To Calculate MeHg Loads for Allocations in Table 8.4** [(a)] (mgd)
Brentwood WWTP	CA0082660	3.1	5.0
Deuel Vocational Inst. WWTP	CA0078093	0.47	0.75
Woodland WWTP	CA0077950	6.05	10.4

(a) Staff assumed that, in general, NPDES-permitted WWTP discharges throughout Delta/Yolo Bypass would increase by 120% in response to predicted population growth in the region. Staff assumed that half of the population growth would be addressed by expansions to existing facilities in each Delta subarea, and that the remaining half would be serviced by new facilities in each subarea. Discharges from WWTPs with effluent methylmercury concentrations less than 0.06 ng/l act as dilution. Staff recommends that these facilities be assigned allocations calculated using their existing effluent methylmercury concentrations. To determine loads for use in Table 8.4, discharge volumes for these WWTPs were multiplied by 160% to allow for volume and load increases due to predicted population growth, with one exception. The Central Valley Water Board recently adopted new waste discharge requirements for the City of Woodland WWTP that allow it to increase its design daily average effluent flow capacity from 7.8 mgd to 10.4 mgd. As a result, staff used 10.4 mgd rather than 160% of the WY2005 effluent flow (1.6 * 6.05 mgd = 9.7 mgd).

8.1.4 Percent Allocation Calculations

As described in Section 8.1.2, the following sources have allocations set equal to 100% of their existing methylmercury loads: atmospheric deposition and discharges from urban areas outside of MS4 service areas in all Delta subareas; and all point and nonpoint sources in the Central and West Delta subareas. Also, as described in Section 8.1.3, several NPDES-permitted facilities have waste load allocations based on 160% of their existing loads or on their permitted design flows, rather than on their existing discharges.

Allocations for point and nonpoint sources that have their allocations set equal to 100% of their existing effluent methylmercury loads and point sources (NPDES facilities) that are allowed to increase their discharges because they act as dilution are referred to as “Pre-determined Allocations”. The following equation was used to determine the percent allocations and corresponding allocation loads for all other point and nonpoint sources needed to achieve the assimilative capacity in each Delta subarea identified in Table 8.2:

Equation 8.3: *(using the San Joaquin subarea as an example)*

Percent Allocation =

$$= \frac{\text{Assimilative Capacity} - \text{Sum of Pre-determined Allocations}}{\text{All existing loads} - \text{Sum (Existing loads for sources with Pre-determined Allocations)}}$$

$$= \frac{195\ \text{g/yr} - (2.7\ \text{g/yr} + 0.0022\ \text{g/yr} + 0.021\ \text{g/yr} + 0.38\ \text{g/yr} + 0.37 + 1.7\ \text{g/yr})}{528\ \text{g/yr} - (2.7\ \text{g/yr} + 0.0022\ \text{g/yr} + 0.013\ \text{g/yr} + 0.38\ \text{g/yr})}$$

$$= 36.2\%$$

⋆ *Explanation: As shown in Table 8.4e, allocated methylmercury loads for atmospheric deposition and nonpoint urban runoff were set at existing levels (2.7 g/yr and 0.0022 g/yr, respectively). Deuel Vocational Institute WWTP and Oakwood Lake Subdivision Mining Reclamation have average*

discharge methylmercury concentrations less than 0.06 ng/l, and existing annual loads of 0.013 g/yr and 0.38 g/yr, respectively. Both are assigned allocations based on their existing methylmercury concentrations. The Deuel Vocational Institute WWTP's corresponding allocation load of 0.021 g/yr incorporates a percent allocation of 160%. An allocation load of 0.37 g/yr was reserved for the Mountain House CSD WWTP, which began discharging effluent to surface water after the WY2000-2003 TMDL period; the Mountain House CSD WWTP has effluent with low methylmercury concentrations (≤ 0.05 ng/l). In addition, an allocation load of 2.2 g/yr was reserved for new NPDES-permitted discharges expected to service population growth in the San Joaquin subarea ("unassigned NPDES Facility allocation", see Table 8.3).

The percent allocations were applied to every point source discharge methylmercury concentration and load – except those with Pre-determined Allocations – within each subarea to calculate corresponding waste load allocations using Equations 8.4 and 8.5. Methylmercury inputs from agricultural lands, wetlands, and open-water habitat are based on methylmercury loads produced *in situ* and therefore do not have corresponding concentrations. As a result, the percent allocations were applied to such nonpoint source loads within each subarea to calculate corresponding load allocations using only Equation 8.5.

Equation 8.4:
(using City of Stockton WWTP in the San Joaquin subarea as an example)

MeHg Concentration Used to Calculate Allocation (ng/l) =

= % Allocation * Existing average annual effluent MeHg conc.

= 36.2% * 0.94 ng/l

= 0.34 ng/l

Equation 8.5:

MeHg Waste Load Allocation (g/yr)=

= % Allocation * Existing average annual effluent MeHg load

= 36.2% * 36 g/yr

= 13 g/yr

Sometimes Equation 8.4 resulted in an average methylmercury concentration less than 0.06 ng/l, the proposed implementation goal for ambient water. The preferred allocation strategy described in the draft Basin Plan Amendment staff report entails that no discharger (e.g., WWTPs and MS4s) be required to reduce its discharge average methylmercury concentration to less than 0.06 ng/l. If Equation 8.4 resulted in a value less than 0.06 ng/l for a particular point source discharge, the "Concentration Used to Calculate Allocation" was set at 0.06 ng/l and the allocation percent and equivalent load were calculated using the following equations:

Equation 8.6a: *(using the City of Tracy WWTP in the San Joaquin subarea as an example)*

$$\text{\% Allocation} = \frac{\text{Proposed ambient water implementation goal}}{\text{Existing average annual effluent MeHg Conc.}}$$

= 0.06 ng/l ÷ 0.14 ng/l

= 43%

Equation 8.6b:

$$\text{MeHg Allocation Load (g/yr)} = \text{\% Allocation} * \text{Existing Annual MeHg Load}$$
$$= 43\% * 1.8 \text{ g/yr}$$
$$= 0.77 \text{ g/yr}$$

Allocations for sources calculated using Equations 8.6a and 8.6b were then treated as "Pre-determined Allocations" and included in Equation 8.3 to re-calculate the percent allocation. The ultimate purpose of this iterative set of calculations is to ensure that the sum of all methylmercury inputs to each Delta subarea does not exceed the assimilative capacity so that the proposed implementation goal for ambient water and proposed fish tissue mercury targets can be achieved in each subarea. Percent allocations often were calculated to one or more decimal places in order to equitably address a broad range of source loads in a manner that enabled the allocations to be summed without introducing substantial rounding errors.

Table 8.4 is split into separate sections for each Delta subarea. The loads in the "MeHg Load/ Waste Load Allocation (g/yr)" column sum to the assimilative capacity for each subarea. Several loads in this column have more than two significant figures in order to avoid rounding errors when comparing the sum of the loads to the assimilative capacity. For compliance assessment purposes, staff recommends that all loads be rounded to two significant figures. In addition, for NPDES facilities that have two components to their allocations (existing and allowable future growth), the two components should be summed for compliance purposes. The methylmercury concentrations listed in the "MeHg Conc. Used to Calculate Allocation (ng/l)" column should not be used as effluent limits and should not be used to assess compliance with the load-based allocations.

Table 8.5 provides a summary of the sums of existing source loads and allocations for each subarea.

Space intentionally left blank.

Table 8.4a: Allocations for Methylmercury Sources to the Central Delta Subarea

MeHg Source	Tributary or Permittee	Permit #	Existing Average Annual MeHg Conc. (ng/l)	Existing Average Annual MeHg Load (g/yr)	Percent Allocation	MeHg Conc. Used to Calculate Allocation (ng/l)	MeHg Load/ Waste Load Allocation (g/yr)
LOAD ALLOCATIONS							
Agricultural Drainage			*NA* [(a)]	37	100%	*NA*	37
Atmospheric Deposition			*NA*	7.3	100%	*NA*	7.3
Open Water Habitats			*NA*	370	100%	*NA*	370
Wetland Habitats			*NA*	210	100%	*NA*	210
Tributary Inputs	Bear/Mosher Creeks		0.31	11	100%	0.31	11
	Calaveras River		0.14	26	100%	0.14	26
Urban runoff (nonpoint source)			0.24	0.14	100%	0.24	0.14
WASTE LOAD ALLOCATIONS							
NPDES Facilities	Discovery Bay WWTP	CA0078590	0.18	0.37	100%	0.18	0.37
	Lincoln Center Groundwater Treatment Facility	CA0084255	0.030	0.010	100%	0.030	0.010
	Lincoln Center Groundwater Treatment Facility (allowable future growth)	CA0084255	*NA*	*NA*	100%	0.030	0.0080
	Lodi White Slough WWTP	CA0079243	0.15	0.94	100%	0.15	0.94
	Metropolitan Stevedore [(b)]	CA0084174	*To be determined.* [(b)]				
	Unassigned NPDES Facility Allocation (allowable future growth)		*NA*	*NA*	100%	0.06	0.31
NPDES MS4s	Contra Costa (County of)	CAS083313	0.24	0.75	100%	0.24	0.75
	Lodi (City of)	CAS000004	0.24	0.053	100%	0.24	0.053
	Port of Stockton MS4	CAS084077	0.24	0.39	100%	0.24	0.39
	San Joaquin (County of)	CAS000004	0.24	0.57	100%	0.24	0.57
	Stockton Area MS4	CAS083470	0.24	3.6	100%	0.24	3.6
CENTRAL DELTA SUBAREA TOTAL:			**0.060**	**668**	**100%**	**0.060**	**668**

(a) NA: not applicable.

(b) No methylmercury or discharge volume data are available for Metropolitan Stevedore (CA0084174), a marine bulk commodity terminal in the Central Delta subarea. Staff recommends that a methylmercury waste load allocation specifically for non-storm water discharges from the Metropolitan Stevedore Company be established in its NPDES permit once it completes at least three sampling events for methylmercury in its discharges. Its discharge will be allotted a portion of the "unassigned allocation" for the Central Delta subarea.

Table 8.4b: Allocations for Methylmercury Sources to the Marsh Creek Subarea

MeHg Source	Tributary or Permittee	Permit #	Existing Average Annual MeHg Conc. (ng/l)	Existing Average Annual MeHg Load (g/yr)	Percent Allocation	MeHg Conc. Used to Calculate Allocation (ng/l)	MeHg Load/ Waste Load Allocation (g/yr)
LOAD ALLOCATIONS							
Agricultural Drainage			*NA* [(a)]	2.2	18%	*NA*	0.40
Atmospheric Deposition			*NA*	0.23	100%	*NA*	0.23
Open Water Habitats			*NA*	0.18	18%	*NA*	0.032
Wetland Habitats			*NA*	0.34	18%	*NA*	0.061
Tributary Inputs	Marsh Creek		0.25	1.9	18%	0.045	0.34
WASTE LOAD ALLOCATIONS							
NPDES Facilities	Brentwood WWTP	CA0082660	0.02	0.086	100%	0.02	0.086
	Brentwood WWTP (allowable future growth)	CA0082660	*NA*	*NA*	100%	0.02	0.054
	Unassigned NPDES Facility Allocation (allowable future growth)		*NA*	*NA*	100%	0.06	0.16
NPDES MS4s	Contra Costa (County of)	CAS083313	0.24	1.2	25%	0.06	0.30
MARSH CREEK SUBAREA TOTAL:			**0.224**	**6.14**	**27%**	**0.060**	**1.66**

(a) NA: not applicable.

Table 8.4c: Allocations for Methylmercury Sources to the Mokelumne/Cosumnes Rivers Subarea

MeHg Source	Tributary or Permittee	Permit #	Existing Average Annual MeHg Conc. (ng/l)	Existing Average Annual MeHg Load (g/yr)	Percent Allocation	MeHg Conc. Used to Calculate Allocation (ng/l)	MeHg Load/ Waste Load Allocation (g/yr)
LOAD ALLOCATIONS							
Agricultural Drainage			*NA* [(a)]	1.6	35.7%	*NA*	0.57
Atmospheric Deposition			*NA*	0.29	100%	*NA*	0.29
Open Water Habitats			*NA*	4.0	35.7%	*NA*	1.4
Wetland Habitats			*NA*	30	35.7%	*NA*	11
Tributary Inputs	Mokelumne River		0.17	110	35.7%	0.086	39.3
Urban (nonpoint source)			0.24	0.018	100%	0.24	0.018
WASTE LOAD ALLOCATIONS							
NPDES MS4s	San Joaquin (County of)	CAS000004	0.24	0.045	35.7%	0.12	0.016
MOKELUMNE/COSUMNES RIVERS SUBAREA TOTAL:			**0.166**	**146**	**36%**	**0.060**	**52.6**

(a) NA: not applicable.

Table 8.4d: Allocations for Methylmercury Sources to the Sacramento River Subarea

MeHg Source	Tributary or Permittee	Permit #	Existing Average Annual MeHg Conc. (ng/l)	Existing Average Annual MeHg Load (g/yr)	Percent Allocation	MeHg Conc. Used to Calculate Allocation (ng/l)	MeHg Load/ Waste Load Allocation (g/yr)
LOAD ALLOCATIONS							
Agricultural Drainage			*NA* [(a)]	36	55.51%	*NA*	20
Atmospheric Deposition			*NA*	5.6	100%	*NA*	5.6
Open Water Habitats			*NA*	140	55.51%	*NA*	78
Wetland Habitats			*NA*	94	55.51%	*NA*	52
Tributary Inputs	Morrison Creek		0.10	7.5	55.51%	0.056	4.2
	Sacramento River		0.10	2,026	55.51%	0.056	1,125
Urban (nonpoint source)			0.24	0.62	100%	0.24	0.62
WASTE LOAD ALLOCATIONS							
NPDES Facilities	Rio Vista WWTP	CA0079588	0.16	0.10	55.51%	0.089	0.056
	Rio Vista Trilogy / Northwest WWTP	CA0083771	0.06	0.0041	100%	0.06	0.0041
	Rio Vista Northwest WWTP (allowable future growth)	CA0083771	*NA*	*NA*	100%	0.05	0.065
	Sacramento Combined WWTP	CA0079111	0.54	0.95	55.51%	0.30	0.53
	SRCSD Sacramento River WWTP	CA0077682	0.72	161	55.51%	0.40	89
	Unassigned NPDES Facility Allocation (allowable future growth)		*NA*	*NA*	100%	0.06	8.5
NPDES MS4s	Rio Vista (City of)	CAS000004	0.24	0.014	55.51%	0.13	0.0078
	Sacramento Area MS4	CAS082597	0.24	1.8	55.51%	0.13	1.0
	San Joaquin (County of)	CAS000004	0.24	0.19	55.51%	0.13	0.11
	Solano (County of)	CAS000004	0.24	0.073	55.51%	0.13	0.041
	West Sacramento (City of)	CAS000004	0.24	0.65	55.51%	0.13	0.36
	Yolo (County of)	CAS000004	0.24	0.073	55.51%	0.13	0.041
SACRAMENTO RIVER SUBAREA TOTAL:			**0.108**	**2,475**	**56%**	**0.060**	**1,385**

(a) NA: Not applicable.

Table 8.4e: Allocations for Methylmercury Sources to the San Joaquin River Subarea

MeHg Source	Tributary or Permittee	Permit #	Existing Average Annual MeHg Conc. (ng/l)	Existing Average Annual MeHg Load (g/yr)	Percent Allocation	MeHg Conc. Used to Calculate Allocation (ng/l)	MeHg Load/ Waste Load Allocation (g/yr)
LOAD ALLOCATIONS							
Agricultural Drainage			*NA* [(a)]	23	36.1%	*NA*	8.3
Atmospheric Deposition			*NA*	2.7	100%	*NA*	2.7
Open Water Habitats			*NA*	48	36.1%	*NA*	17
Wetland Habitats			*NA*	43	36.1%	*NA*	16
Tributary Inputs	French Camp Slough		0.14	11	36.1%	0.051	4.0
	San Joaquin River		0.16	356	36.1%	0.058	129
Urban (nonpoint source)			0.24	0.0022	100%	0.24	0.0022
WASTE LOAD ALLOCATIONS							
NPDES Facilities	Deuel Vocational Institute WWTP	CA0078093	0.02	0.013	100%	0.02	0.013
	Deuel Vocational Institute WWTP (allowable future growth)	CA0078093	*NA*	*NA*	100%	0.02	0.008
	Manteca WWTP	CA0081558	0.22	1.4	27%	0.06	0.38
	Mountain House CSD WWTP	CA0084271	*NA*	*NA*	100%	0.05	0.37
	Oakwood Lake Subdivision Mining Reclamation	CA0082783	0.03	0.38	100%	0.03	0.38
	Stockton WWTP	CA0079138	0.94	36	36.1%	0.34	13
	Tracy WWTP	CA0079154	0.14	1.8	43%	0.06	0.77
	Unassigned NPDES Facility Allocation (allowable future growth)		*NA*	*NA*	100%	0.06	1.7
NPDES MS4s	Lathrop (City of)	CAS000004	0.24	0.27	36.1%	0.087	0.097
	Port of Stockton MS4	CAS084077	0.24	0.010	36.1%	0.087	0.0036
	San Joaquin (County of)	CAS000004	0.24	2.2	36.1%	0.087	0.79
	Stockton Area MS4	CAS083470	0.24	0.50	36.1%	0.087	0.18
	Tracy (City of)	CAS000004	0.24	1.8	36.1%	0.087	0.65
SAN JOAQUIN RIVER SUBAREA TOTAL:			**0.160**	**528**	**37%**	**0.060**	**195**

(a) NA: Not applicable.

Table 8.4f: Allocations for Methylmercury Sources to the West Delta Subarea

MeHg Source	Tributary or Permittee	Permit #	Existing Average Annual MeHg Conc. (ng/l)	Existing Average Annual MeHg Load (g/yr)	Percent Allocation	MeHg Conc. Used to Calculate Allocation (ng/l)	MeHg Load/ Waste Load Allocation (g/yr)
LOAD ALLOCATIONS							
Agricultural Drainage			*NA* [(a)]	4.1	100%	*NA*	4.1
Atmospheric Deposition			*NA*	2.4	100%	*NA*	2.4
Open Water Habitats			*NA*	190	100%	*NA*	190
Wetland Habitats			*NA*	130	100%	*NA*	130
Urban (nonpoint source)			0.24	0.066	100%	0.24	0.066
WASTE LOAD ALLOCATIONS							
NPDES Facilities	GWF Power Systems	CA0082309	0.03	0.0019	100%	0.03	0.0019
	GWF Power Systems (allowable future growth)	CA0082309	*NA*	*NA*	100%	0.03	0.0033
	Ironhouse Sanitation District (allowable future growth)	CA0085260	*NA*	*NA*	100%	0.05	0.030
	Mirant Delta LLC Contra Costa Power Plant [(b)]	CA0004863	*Concentration-based allocation*. [(b)]				
	Unassigned NPDES Facility Allocation (allowable future growth)		*NA*	*NA*	100%	0.06	0.22
NPDES MS4s	Contra Costa (County of)	CAS083313	0.24	3.2	100%	0.24	3.2
WEST DELTA SUBAREA TOTAL:			**0.083**	**330**	**100%**	**0.060**	**330**

(a) NA: not applicable.

(b) Methylmercury loads and concentrations in heating/cooling and power facility discharges vary with intake water conditions; the facilities do not appear to act as a source of methylmercury to the Delta. Staff recommends that Mirant Delta LLC Contra Costa Power Plant a have concentration-based allocation equal to 100% of its intake methylmercury concentrations, so that its discharge allocation equals the detected methylmercury concentration found in its intake water. Outflows from the Mirant Delta plant were not incorporated in the allocation calculations for other sources. A concentration-based allocation for the Mirant Delta plant is listed in Table B in the proposed Basin Plan amendments provided at the beginning of the draft Basin Plan Amendment staff report.

Table 8.4g: Allocations for Methylmercury Sources to the Yolo Bypass Subarea

MeHg Source	Tributary or Permittee	Permit #	Existing Average Annual MeHg Conc. (ng/l)	Existing Average Annual MeHg Load (g/yr)	Percent Allocation	MeHg Conc. Used to Calculate Allocation (ng/l)	MeHg Load/ Waste Load Allocation (g/yr)
LOAD ALLOCATIONS							
Agricultural Drainage			*NA*	19	21.5%	*NA*	4.1
Atmospheric Deposition			*NA*	4.2	100%	*NA*	4.2
Open Water Habitats			*NA*	100	21.5%	*NA*	22
Wetland Habitats			*NA*	480	21.5%	*NA*	103
Tributary Inputs	Cache Creek Settling Basin Outflow		0.50	140	21.5%	0.108	30
	Dixon Area		0.24	3.6	21.5%	0.052	0.77
	Fremont Weir		0.10	180	21.5%	0.022	39
	Knights Landing Ridge Cut		0.19	100	21.5%	0.041	22
	Putah Creek		0.18	11	21.5%	0.039	2.4
	Ulatis Creek		0.24	9.5	21.5%	0.052	2.1
	Willow Slough		0.24	18	21.5%	0.052	3.9
WASTE LOAD ALLOCATIONS							
NPDES Facilities	Davis WWTP [(a)]	CA0079049	0.61	0.78	21.5%	0.13	0.17
	Woodland WWTP	CA0077950	0.03	0.25	100%	0.03	0.25
	Woodland WWTP (allowable future growth)	CA0077950	*NA*	*NA*	100%	0.03	0. 18
	Unassigned NPDES Facility Allocation (allowable future growth)		*NA* [(b)]	*NA*	100%	0.06	0.42
NPDES MS4s	Solano (County of)	CAS000004	0.24	0.085	25%	0.06	0.021
	West Sacramento (City of)	CAS000004	0.24	1.1	25%	0.06	0.28
	Yolo (County of)	CAS000004	0.24	0.33	25%	0.06	0.083
YOLO BYPASS [North & South] SUBAREA TOTAL:			**0.273**	**1,068**	**22%**	**0.060**	**235**

(a) The City of Davis WWTP (CA0079049) has two discharge locations; wastewater is discharged from Discharge 001 to the Willow Slough Bypass upstream of the Yolo Bypass and from Discharge 002 to the Conaway Ranch Toe Drain in the Yolo Bypass. The methylmercury load allocation listed in this table applies only to Discharge 002, which discharges seasonally from about February to June. Discharge 001 is encompassed by the Willow Slough watershed methylmercury allocation and will be assigned a facility-specific allocation when a control program is developed for the upstream watersheds.

(b) NA: Not applicable.

Table 8.5: Methylmercury Load and Waste load Allocations for Each Delta Subarea by Source Category

Source Type	DELTA SUBAREA													
	Central Delta		Marsh Creek		Mokelumne River		Sacramento River		San Joaquin River		West Delta		Yolo Bypass	
	Current Load (g/yr)	Allocation (g/yr)	Current Load (g/yr)	Allocation (g/yr)	Current Load (g/yr)	Allocation (g/yr)	Current Load (g/yr)	Allocation (g/yr)	Current Load (g/yr)	Allocation (g/yr)	Current Load (g/yr)	Allocation (g/yr)	Current Load (g/yr)	Allocation (g/yr)
Methylmercury Load Allocations														
Agricultural drainage [(d)]	37	37	2.2	0.40	1.6	0.57	36	20	23	8.3	4.1	4.1	19	4.1
Atmospheric wet deposition	7.3	7.3	0.23	0.23	0.29	0.29	5.6	5.6	2.7	2.7	2.4	2.4	4.2	4.2
Open water	370	370	0.18	0.032	4.0	1.4	140	78	48	17	190	190	100	22
Tributary Inputs [(a)]	37	37	1.9	0.34	110	39	2,034	1,129	367	133			462	100
Inputs from Upstream Subareas	(b)	(b)	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	(b)	(b)	- - -	- - -
Urban (nonpoint source)	0.14	0.14	---	---	0.018	0.018	0.62	0.62	0.0022	0.0022	0.066	0.066	---	---
Wetlands [(d)]	210	210	0.34	0.061	30	11	94	52	43	16	130	130	480	103
Methylmercury Waste Load Allocations														
NPDES facilities [(a)]	1.3	1.3	0.086	0.086	0	0	162	90	40	15	0.0019	0.0019	1.0	0.42
NPDES facilities future growth [(a)]	---	0.32 [(b)]	---	0.21	---	0	---	8.6	---	2.1	---	0.25 [(b)]	---	0.60
NPDES MS4 [(a)]	5.4	5.4	1.2	0.30	0.045	0.016	2.8	1.6	4.8	1.7	3.2	3.2	1.5	0.38
Total Loads [(c)] (g/yr)	**668**	**668**	**6.14**	**1.66**	**146**	**52.6**	**2,475**	**1,385**	**528**	**195**	**330**	**330**	**1,068**	**235**

(a) Values shown for Tributary Inputs, NPDES Facilities, NPDES Facilities Future Growth, and NPDES MS4 represent the sum of several individual discharges. See Table 8.4 for allocations for the individual discharges that should be used for compliance purposes.

(b) The Central Delta subarea receives flows from the Sacramento, Yolo Bypass, Mokelumne, and San Joaquin subareas. The West Delta subarea receives flows from the Central Delta and Marsh Creek subareas. These within-Delta flows have not yet been quantified because additional data are needed for loss rates across the subareas. However, these subarea inflows are expected to decrease substantially (e.g., 40-80%) as upstream mercury management practices take place. As a result, reductions for sources within the Central and West subareas and tributaries that drain directly to these subareas are not required. The Central Valley Water Board can consider modification of the allocation strategy and the creation of new allocations (e.g., for within-Delta flows between subareas) during the program review proposed to take place in about seven years based on existing and new information that becomes available.

(c) The sum of all allocations for each subarea equals the assimilative load capacity for that subarea. Because calculations were completed prior to rounding, some columns may not add to totals.

(d) The load allocations apply to the net methylmercury loads, where the net loads equal the methylmercury load in outflow minus the methylmercury loads in source water (e.g., irrigation water and precipitation).

8.2 Total Mercury Load Reduction Requirement for Tributary Watersheds

Methylmercury production is a positive linear function of the inorganic mercury content of sediment (see Chapter 3). Inorganic mercury load reductions elsewhere have resulted in decreases in fish tissue methylmercury concentrations (Table 3.1). It is expected that similar reductions in fish tissue concentration also will occur in the Delta once the mercury content of its sediment decreases. Staff recommends that inorganic (total) mercury requirements be implemented by the Delta mercury control program in addition to the methylmercury allocations for several reasons: (1) to maintain compliance with the USEPA's criterion of 50 ng/l for total mercury in the water column; (2) to prevent increases in total mercury discharges resulting from population growth and other land use changes, which could cause increases in aqueous and fish methylmercury in the Delta, thereby worsening the impairment; (3) to comply with the San Francisco Bay TMDL allocation to the Central Valley; and (4) to help enable compliance with the open-water methylmercury load allocations described in the previous section. The TMDL for San Francisco Bay assigned the Central Valley a five-year average total mercury load allocation of 330 kg/yr or a decrease of 110 kg/yr (Section 2.4.2.3).

As described in Chapter 4 of the draft Basin Plan Amendment staff report, the preferred TMDL implementation alternative entails:

- NPDES Permitted Facilities in the Delta and Yolo Bypass: Implement pollutant minimization programs and maintain performance-based total mercury load limits during the first phase of Delta TMDL control program implementation.
- NPDES Permitted (MS4) Urban Runoff Dischargers in the Delta and Yolo Bypass: Implement best management practices (BMPs) to control erosion and sediment discharges consistent with their existing permits and orders with the goal of reducing mercury discharges (all MS4s), and implement mercury-specific pollution prevention measures and BMPs to minimize inorganic mercury discharges (the largest three MS4s [Sacramento, Contra Costa and Stockton MS4s]).
- Nonpoint Sources in the Delta and Yolo Bypass: Implement reasonable, feasible actions to reduce sediment in runoff with the goal of reducing inorganic mercury loading to the Yolo Bypass and Delta, in compliance with existing Basin Plan objectives and requirements, and Irrigated Lands Regulatory Program requirements.
- Tributary Watershed Inputs to the Delta and Yolo Bypass: Total mercury load reduction of a minimum of 110 kg/yr.

This section of the TMDL report reviews how the total mercury load reduction requirement maybe achieved in tributary watersheds. Total mercury reduction strategies for point and nonpoint sources in the Delta and Yolo Bypass are described in Chapter 4 of the draft Basin Plan Amendment staff report.

The total mercury source analysis described in Chapter 7 indicates that almost all the total mercury loading (>97%) to the Delta and Yolo Bypass comes from tributary inputs. It could be argued that assigning total mercury load reduction requirements could wait until the upstream TMDLs are developed. Also, there is limited information available about total mercury loads contributed by individual sources in the tributary watersheds. However, there is abundant

information about which watersheds contribute the most mercury-contaminated sediment. In addition, substantial mercury reductions – 110 kg/yr – are required for Central Valley inputs to the San Francisco Bay by the San Francisco Bay mercury control program. It is likely that total mercury reduction efforts in the watersheds, and subsequent methylmercury reductions in open-water, wetland and agricultural areas in the Delta, will take place more quickly if watershed total mercury load reduction requirements are included in the Delta mercury control program.

A reduction of 110 kg/yr represents about a 28% decrease in the 20-year average annual loading[48] from Delta tributaries (Table 7.1). Initial reduction efforts should focus on watersheds that export the largest volume of highly contaminated sediment, such as the Cache Creek, Feather River, American River, Cosumnes River, and Putah Creek watersheds (refer to Sections 7.1.1 and 7.4.1 and Tables 7.5 and 7.17 in Chapter 7).

The Cache Creek Settling Basin (CCSB) is a 3,600-acre structure located at the base of the Cache Creek watershed. The U.S. Army Corp of Engineers initially constructed the CCSB in 1937 to contain sediment and maintain the flood capacity of the Yolo Bypass. The CCSB was modified in 1993 to increase its sediment trapping efficiency. However, no provision was made for removing the additional trapped material.

Most of the mercury in Cache Creek is transported on sediment. Therefore, an increase in sediment trapping also results in deposition and retention of mercury. The CCSB currently traps about half of the sediment and mercury transported by Cache Creek (Foe and Croyle, 1998; CDM, 2004; Cooke *et al.*, 2004; CDM, 2004; Appendices F and I). The rest is exported to the Delta through the Yolo Bypass.

Trapping efficiency calculations vary based on the period evaluated and the calculation method. For example, Board staff estimated that the basin receives about 224 kg/yr total mercury from the Cache Creek watershed and discharges about 118 kg/yr to the Yolo Bypass (a trapping efficiency of about 47%), based on annual load estimates for a 20-year period (WY1984-2003, a period with an even mix of wet and dry years) derived from statistically-significant correlations between water column total mercury concentrations and flows (refer to Chapter 7 and Appendix I for load calculation methods). CDM estimated that about 64% of the sediment and total mercury mass input to the basin is trapped when the volumes of sand, uncompacted silt and clay are converted to sediment mass over a modeled 35-year period (see CDM, 2004b, Table 4-3). Although trapping efficiency calculations vary, they all indicate that substantial mercury loads are currently trapped in the basin. However, even though the basin traps a large portion of the mercury that comes into it, Cache Creek still accounts for about 60% of all inorganic mercury that enters the Yolo Bypass.

The sediment/mercury trapping efficiency of the CCSB is expected to decrease as it fills and may reach zero in about 35 years unless a maintenance program is instituted to periodically remove material (CDM, 2004). A non-operational CCSB would result in a mercury discharge to the Yolo Bypass and Delta of about 224 kg/yr, an addition of 106 kg/yr mercury loading (Table 7.6b).

[48] Year-to-year loads are expected to fluctuate with rainfall and river flow conditions and other environmental factors.

Two sets of actions are considered in the draft Basin Plan Amendment staff report (Chapter 4 and Appendix C) for the Cache Creek Settling Basin that would reduce mercury discharges to the Yolo Bypass and Delta. First, mercury loads entering the CCSB from the Cache Creek watershed could be reduced. The Basin Plan Amendment for control of mercury in Cache Creek was adopted by the Central Valley Water Board in October 2005. Implementation actions described in the Basin Plan Amendment report would reduce mercury loads *entering* the Cache Creek Settling Basin by about 60 kg/year (Cooke and Morris, 2005), from a 20-year average of 224 kg/yr to 164 kg/yr. Assuming a long-term basin trapping efficiency of about 47%, the watershed implementation actions would reduce basin total mercury mass discharges to the Yolo Bypass by about 31 kg/yr. Approximately 25 kg of the 60 kg/year reduction in the Cache Creek watershed may come from instituting control programs at all major mercury mines in the watershed.[49] The remainder of the reduction will be achieved by control of erosion in mercury-enriched areas and by remediation/removal of contaminated floodplain sediment in the Cache Creek canyon and in Bear Creek. However, most the total mercury load now leaving the CCSB appears to originate from erosion of mercury contaminated sediment downstream of the mines. The Cache Creek mercury control program requires studies to evaluate in-stream sediment control options. It is unclear whether environmentally acceptable, cost effective control programs can be developed to significantly curtail the movement of this material.

A second set of actions could focus on decreasing the mercury load leaving the Cache Creek Settling Basin. A program should be instituted to (a) periodically excavate the material presently accumulating in the CCSB, and (b) make additional modifications to the CCSB to increase trapping efficiency. Initial modeling results indicate that CCSB operation and design could be modified to improve the mercury mass trapping efficiency of the CCSB from to about 75% (CDM, 2004, Table 4-3, Alternative 5 - Excavate and Raise Weir Early). Decreasing mercury inputs to the CCSB from 224 to 164 kg/yr through the watershed control program and increasing the trapping efficiency of the CCSB from 47% to 75% results in an export to the Yolo Bypass of 41 kg/yr, which represents a decrease of 77 kg/yr from current loading. This reduction is approximately 70% of the 110-kg/yr reduction required by the San Francisco Bay mercury TMDL. Based on these calculations, the February 2008 Basin Plan Amendment draft staff report included a numeric total mercury load limit of 41 kg/yr for outflow from the Cache Creek Settling Basin to the Yolo Bypass.

However, after the release of the February 2008 draft report, DWR staff indicated that a more comprehensive feasibility study must take place to determine whether a 75% trapping efficiency is possible and to incorporate a stakeholder process so that local communities' concerns about potential flood hazards resulting from modifying the basin can be addressed. The 2008-2009 Stakeholder Process participants (including staff from the Central Valley Water Board, DWR and other agencies responsible for basin operations and other stakeholders) developed recommendations for Basin Plan amendment requirements that entail evaluating and implementing feasible total mercury load reductions for basin outflows up to and including a 50% reduction from existing loads in place of a numeric load limit. A 50% reduction in existing loads (118 kg/yr) results in a total mercury load to the Yolo Bypass of about 59 kg/yr, compared to the 41 kg/yr described in the previous paragraph.

[49] The mines are located in Harley Gulch, Sulfur and Bear Creeks and Clear Lake.

Table 8.6 provides a preliminary scoping of potential watershed total mercury load reductions (including the Cache Creek watershed) based on the assumption that it will be possible to reduce mercury loads from watersheds that discharge mercury-contaminated sediment (as indicated by relatively high TotHg:TSS ratios) by at least 50%. Staff used a 50% reduction rate because in watersheds with known, significant anthropogenic sources of mercury (primarily mining), the anthropogenic contribution is more than 50% of the total concentration of mercury in sediment. For example, the Feather River, American River, Cosumnes River have suspended sediment mercury concentrations that are more than twice the mercury concentration of suspended sediment in the Sacramento River upstream of Colusa, a watershed with a much lower density of mine sites (see Table 8.6 at the end of this section and Table 14 in Louie and others' 2008 CalFed study). The sum of potential reductions based on this assumption is about 125 kg/yr. A 50% reduction in total mercury loads contributed by the four watersheds that discharge sediment that is most highly contaminated with mercury – Feather River, Cache Creek, American River and Putah Creek – alone would result in a 104 kg/yr reduction.

The suite of potential total mercury reduction actions identified by the "Regional Mercury Load Reduction Evaluation, Central Valley, California", completed by Tetra Tech EM Inc. under contract to the USEPA (Tetra Tech, 2008), and the review of reasonably foreseeable methods of compliance in Chapter 4 of the draft Basin Plan Amendment staff report, indicates that the potential reductions outlined in Table 8.5 may be possible. However, additional feasibility analyses and stakeholder input are needed in order to evaluate alternatives, funding sources, and potential environmental concerns associated with potential projects.

Given these factors, staff recommends that the Delta mercury control program include a 110 kg/yr total mercury reduction requirement assigned jointly to the tributaries that drain to the Delta to ensure compliance with the San Francisco Bay mercury control program's requirements for the Central Valley. Initial reduction efforts should focus on the four watersheds that discharge the most highly-contaminated sediment (Feather River, Cache Creek, American River and Putah Creek, all in the Sacramento Basin). Although it is not as large a source of total mercury loading, the Cosumnes River watershed in the San Joaquin Basin also would be an effective candidate for total mercury reduction projects because of its high mercury concentrations in suspended sediment. Several other watershed characteristics make the Cosumnes River an attractive candidate for remediation efforts during the initial implementation phases of the Delta and upstream mercury control programs:

- As described in Section 7.1.1.2, not only does the Cosumnes River watershed have a history of hydraulic gold mining, it exports six times as much mercury to the Delta as the Mokelumne River watershed and is the largest river on the west-slope Sierra Nevada without a major dam, allowing unimpaired downstream movement of storm runoff.
- The highest fish tissue levels observed in the Delta were in the lower Cosumnes River (Davis *et al*., 2008; Slotton *et al*., 2007). Extensive multi-year and seasonal fish mercury monitoring conducted in the lower Cosumnes River after the development of this TMDL source analysis observed small fish mercury levels that were 5 to 29 times the small fish mercury objective proposed in Chapter 3 of the draft Basin Plan Amendment report (Slotton *et al.*, 2007). Slotton and others (2007, pages 58-59) observed extreme (400-500%) increases in silverside mercury at the Cosumnes site in July 2006, when

concentrations in 45-75 mm (2-3 inch) silversides reached levels averaging an "astounding" 0.869 ppm, with individual fish as high as 2.0 ppm. According to the authors, "these were concentrations that should be of serious concern, particularly in relation to wildlife exposure." Slotton and others (2007) noted that their extensive seasonal sampling indicated that the very high 2006 silverside mercury concentrations in the lower Cosumnes River were traceable to an extreme, seasonal pulse event of highly elevated exposure linked to episodic flooding of the Cosumnes floodplain and observed that other small fish species with slower turnover rates than silversides (e.g., juvenile bass and prickly sculpin) exhibited much slower declines from peak mercury levels, with highly elevated concentrations persisting for many months.

- Foe and others' 2008 CalFed study found that water methylmercury concentrations in the Cosumnes River were the highest of any tributary to the Delta, consistent with the fish tissue data. The mean and 95% confidence limits for the Cosumnes and Mokelumne Rivers are 0.38±0.12 and 0.11±0.01 ng/l methylmercury, respectively (Foe *et al*., 2008, Table 2), compared to 0.17 ng/l methylmercury for the Mokelumne River downstream of its confluence with the Cosumnes River (Table 6.2 in Chapter 6).
- As illustrated in Figure 6.3, the lower Cosumnes River has numerous wetland areas, and large wetland restoration efforts are planned for the lower Cosumnes River watershed within the Delta in the near future (e.g., Turner, 2009).

Staff recommends that compliance with the proposed 110 kg/yr total mercury reduction requirement be assessed for the tributary inputs based on WY1984-2003 average annual loads. This 20-year period includes a mix of wet and dry years that is statistically similar to water years in the Sacramento Basin in the last 100 years. The proposed reduction will enable Delta waters to maintain compliance with the CTR criterion of 50 ng/l (Section 7.4 in Chapter 7).

Additional total mercury and methylmercury reductions likely will be needed from most if not all of the watersheds to address the methylmercury impairment in each area of the Delta subareas and impairments specific to upstream watersheds. Specific limits for individual watershed exports should not be defined in the Delta mercury control program in order to allow for greater flexibility in developing upstream control strategies. Feasibility studies may show that particular projects could reduce mercury loads by more than 50% without causing other environmental impacts. However, the sum of the load reductions for the watershed exports needs to equal a minimum of 110 kg/yr. Most of the watersheds that drain to the Delta contain waterways already identified on the CWA Section 303(d) List as impaired by mercury. Hence, most will be the focus of future watershed-specific TMDL programs. Specific load reductions for each watershed will be assigned in control programs for the upstream watersheds.

It is important to note that implementing only the inorganic mercury reductions described above will not adequately reduce methylmercury levels in the Delta in the near term (the proposed compliance date in the proposed Basin Plan amendments in the draft Basin Plan Amendment staff report is 2030). Because movement of contaminated sediment in the river channels is relatively slow, it is expected to take many years (e.g., a century or more) before the full benefit of inorganic mercury reductions in tributaries is seen in the Delta. (For additional discussion of the estimated time to reduce inorganic mercury inputs and attain fish tissue objectives, please refer to "Staff's Initial Responses to Board and Stakeholder Questions and Comments at the

April 2008 Hearing", items 3 and 44, available on the Board website.) In addition, many of the tributary input methylmercury allocations developed in Section 8.1 entail methylmercury load reductions of 60% to 80%. Assuming that inorganic mercury loads could be reduced by 50% in these tributaries, reducing inorganic mercury alone would be insufficient to achieve the allocations. Staff expects that methylmercury management practices and very aggressive implementation of inorganic mercury reduction projects will be needed in the tributary watersheds, along with natural erosion, to achieve the tributary methylmercury load allocations.

Table 8.5: Preliminary Evaluation of Potential Watershed Total Mercury Load Reductions

Basin	Watershed	303(d) Listed for Mercury Impairment	Annual TotHg Load (kg/yr)	TotHg:TSS (mg/kg)	Potential % Reduction & Corresponding Load Reduction [a] (kg/yr)	
Sacramento [b]	**American River**	√	**14**	**0.27**	**50%**	**7**
	Cache Creek Settling Basin	√	**118**	**0.45**	**50%**	**59**
	Colusa Basin Drain	(Proposed)	13	0.09	5%	0.65
	Feather River	√	**67**	**0.31**	**50%**	**34**
	Morrison Creek		0.83	0.15	20%	0.17
	Natomas East Main Drain		3.0	0.38 – 0.64	50%	1.5
	Putah Creek	√	**8.8**	**0.55**	**50%**	**4.4**
	Sacramento River above Colusa	√	151	0.12	5%	7.6
	Sacramento Slough / Sutter Bypass	√	25	0.13	5%	1.3
	Ulatis Creek		2.2	0.11	5%	0.11
San Joaquin [c]	French Camp Slough		1.7	0.30 - 0.70	50%	0.85
	Marsh Creek	√	0.54	0.12 - 0.45	50%	0.27
	Cosumnes River upstream of I-5		**48**	**0.41**	**50%**	**24**
	Mokelumne River upstream of the Cosumnes River	√	8.4	0.22	50%	2.3
	San Joaquin River	√	29	0.13	5%	1.5

(a) For scoping purposes only, a conservative 50% reduction was assumed to be likely needed for watershed total mercury loads in order to achieve tributary input allocations assigned by the Delta TMDL as well as to address upstream impairments. A lower percent reduction was assumed for watersheds that may discharge less mercury-contaminated material, as indicated by low TotHg:TSS ratios. Greater or lesser reductions may be determined to be necessary once upstream feasibility analyses have taken place as part of upstream control programs. Total mercury loads were obtained from Tables 7.1 and 7.6b, and TotHg:TSS ratios were obtained from Table 7.17; values for the Cosumnes and Mokelumne Rivers were obtained from Louie and others' 2008 CalFed study. The annual TotHg loads represent the average annual loads estimated for WY1984-2003. This 20-year period includes a mix of wet and dry years that is statistically similar to what has occurred in the Sacramento Basin over the last 100 years. Annual loads are expected to fluctuate with rainfall and river flow conditions and other environmental factors.

(b) A total mercury load estimate is not available for Willow Slough, which drains to the Yolo Bypass in the Sacramento Basin. As a result, although it has a methylmercury allocation that requires substantial reductions, it is not included in this table.

(c) The Calaveras River and Bear and Mosher Creeks in the San Joaquin Basin drain to the Central Delta subarea. Methylmercury allocations for these watersheds do not entail reductions; as a result, they are not included in this table.

8.3 Margin of Safety

Implicit and explicit margins of safety are included in the aqueous methylmercury goal for the Delta. In addition, while not a direct margin of safety, the implementation plan (Chapter 4 in the draft Basin Plan Amendment staff report) calls for updated fish advisories in the Delta and an expanded outreach program to educate humans fishing in the Delta.

The proposed aqueous methylmercury goal of 0.06 ng/l (Chapter 5) incorporates an explicit margin of safety of approximately 10%. The linkage analysis (Section 5.2) predicted a safe level of 0.066 ng/l for average aqueous methylmercury, from which 0.006 was subtracted to provide a margin of safety.

In addition, there is an implicit margin of safety for wildlife species that consume Delta fish. As outlined in the previous paragraph, the aqueous methylmercury goal corresponds to 0.24 mg/kg mercury in large TL4 fish, which was calculated for the protection of humans consuming about one meal per week. As shown in Table 4.9 (Chapter 4), the wildlife targets for smaller and lower trophic level fish correspond to large TL4 fish mercury levels that range from 0.30 mg/kg (for Western grebe) to 1.12 mg/kg (for Western snowy plover). These values correspond to 350-mm largemouth bass mercury levels of 0.31 and 1.34 mg/kg. When entered into the regression equation for largemouth bass and unfiltered average aqueous methylmercury (Figure 5.2[A]), these values translate to aqueous methylmercury concentrations of 0.08 ng/l and 0.19 ng/l, allowing a margin of safety of 25% or more, depending on the wildlife species.

8.4 Seasonal & Inter-annual Variability

8.4.1 Variability in Aqueous Methyl and Total Mercury

Mercury loads in Delta tributary inputs fluctuate because of seasonal and inter-annual variation. Winter precipitation increases the sediment and total mercury loads entering the Delta through erosion and re-suspension of sediment. Most of the total mercury coming from tributaries and direct surface runoff enters the Delta during high flow events. In contrast, methylmercury production is typically higher during the summer months. In addition, greater total mercury and methylmercury loads enter the Delta during wet water years.

Seasonal and inter-annual variability in methylmercury loads were accounted for in the source analysis and methylmercury load allocations by evaluating annual average loads for Delta sources and losses for WY2000 to 2003, a relatively dry period that encompasses the available concentration data for the major Delta inputs and exports. Twenty-year average, annual loads of total mercury were estimated for tributary loads based on flow and precipitation records for WY1984-2003. This 20-year period includes a mix of wet and dry years that is statistically similar to what has occurred in the Sacramento Basin over the last 100 years. However, insufficient data were available at the time the TMDL was developed to estimate 20-year average annual loads for methylmercury sources. Methylmercury allocations and total mercury limits will be re-evaluated as additional information becomes available. Future monitoring programs will accommodate long-term inter-annual variability by evaluating whether sources are meeting allocations on a multi-year basis.

8.4.2 Variability in Biota Mercury

Seasonal and inter-annual variation also occurs in biota. Slotton and others (2003) found that Delta species exhibited both seasonal and inter-annual variability in mercury body burden. Corbicula (clams) had higher mercury concentrations in the spring while inland silversides (representative forage fish species) were higher in fall. In addition, silverside bioaccumulation was greater in 1998 than in 1999 and 2000 at many locations in the Delta. Davis and others (2002) measured higher mercury concentrations in similar sized largemouth bass in 1999 than in 2000. The researchers noted that the winter of 1997 was very wet and speculated that the high flows may have introduced significant quantities of "new" mercury that was methylated and incorporated into forage fish in 1998. Predacious fish like largemouth bass, which feed upon silversides, took an additional year to reflect the higher methylmercury concentrations.

Seasonal and inter-annual variability in large fish was accounted for in the numeric targets and linkage analysis by using data collected over multiple years. Future monitoring will accommodate seasonal and inter-annual variability by sampling large fish about every ten years.

8.4.3 Regional and Global Change

Several ongoing regional and global changes may affect methyl and total mercury loading in the Delta. This section identifies several of these. Central Valley Water Board will continue to research regional and global changes that may affect efforts to achieve the proposed fish tissue targets and incorporate new information and strategies with extensive stakeholder input during periodic Delta TMDL control program reviews using an adaptive management approach throughout the implementation of the control program.

8.4.3.1 Population Growth

The Delta and its tributary watersheds are experiencing substantial population growth. Population in the Central Valley increased by about 20% between 1990 and 2000 (AFT, 2006; CDOF, 2004). This resulted in the conversion of about 98,000 acres of agricultural land to urban uses (AFT, 2006). Four of the five fastest growing cities in the Sacramento Valley are located within about one day's travel time (about 20 to 30 miles by water) of the Delta. The California Department of Finance predicts that populations in the Delta/Yolo Bypass counties[50] will increase 76% to 213% by 2050 (CDOF, 2007), with an average increase of about 120%.

Increasing populations will result in increased discharges from municipal wastewater treatment plants. In addition, urbanization increases both volume and discharge velocity of runoff because of the increase in impervious surfaces. Urbanization also tends to increase pollutant loading because impervious surfaces neither absorb water nor remove pollutants, and urban development tends to create new anthropogenic mercury pollution sources. As Chapters 6 and 7 indicate, urban runoff in the Sacramento, Stockton and Tracy areas has higher

[50] The CDOF predicts the following population increases by 2050: Contra Costa County - 89%, Sacramento County - 76%, San Joaquin County - 213%, Solano County - 105%, and Yolo County - 93% (CDOF, 2007).

methylmercury and total mercury concentrations than ambient river concentrations. However, little is known about how the conversion of agricultural land to urban uses affects methylmercury concentration.

A study of annual and seasonal trends in atmospheric mercury deposition in Maryland found a marked urban influence on mercury deposition; wet depositional fluxes at the urban site were two to three times higher than at the rural sites (Mason *et al.*, 2000). The Maryland study authors noted that local point sources such as air emissions from waste incinerators and power plants may contribute to the mercury deposition at the urban study site. Also, as noted in Chapter 4 in the draft Basin Plan Amendment staff report, reactive gaseous mercury (RGM) is thought to be emitted primarily from anthropogenic point sources or formed by oxidation reactions of gaseous elemental mercury with ozone, hydroxyl radical, nitrate, hydrogen peroxide, and/or halogen containing compounds (e.g., Peterson *et al*., 2009). RGM is more likely than other mercury fractions to be converted to methylmercury that is bioaccumulated in aquatic food chains (Whalin *et al*., 2007). Ground-level ozone is a potent irritant that causes lung damage and a variety of respiratory problems; ozone is the main component of smog and is formed by the reaction of hydrocarbons with nitrogen oxides in the presence of sunlight (USEPA OTAQ, 2007). In typical urban areas, a significant fraction of hydrocarbons comes from cars, buses, trucks, and nonroad mobile sources such as construction vehicles and boats powered by hydrocarbon-based fuels such as gasoline and diesel (USEPA OTAQ, 2007). As a result, increasing vehicle exhaust associated with urbanization would lead to increases in the hydrocarbon emissions, which subsequently could increase the formation of ground-level ozone and the formation of RGM.

MS4 allocations apply to all urban acreage within MS4 service areas within each Delta subarea and apply to the sum of methylmercury loads in existing urban acreage runoff and in runoff from future urbanized lands within the MS4 service areas. Staff assumed that, in general, NPDES-permitted municipal WWTP discharges throughout the Delta/Yolo Bypass would increase by 120%. Staff assumed that half of that growth will be addressed by expansions to existing facilities in each Delta subarea, and that half will be serviced by new facilities in each subarea. As described in Section 8.1.2 and shown in Tables 8.3 and 8.4, the allocation strategy incorporates the assumption that existing municipal WWTPs will increase their discharge volumes by 60% and reserves assimilative capacity for new WWTP discharges.

Chapter 4 in the draft Basin Plan Amendment staff report reviews possible implementation strategies to address the methylmercury allocations and total mercury limits for municipal WWTP discharges and urban runoff in the Delta region.

8.4.3.2 Restoration of Wetlands

Research conducted in the Delta and elsewhere has found that wetlands are efficient sites for methylmercury production. There are currently about 26,600 acres of wetlands within the Delta/Yolo Bypass (USFWS, 2006). The Record of Decision for the CALFED Bay-Delta Program commits it to restore 30,000 to 45,000 acres of fresh, emergent tidal wetlands, 17,000 acres of fresh, emergent nontidal wetlands, and 28,000 acres of seasonal wetlands in the Delta by 2030 (CALFED Bay-Delta Program, 2000a). This is a total of 75,000 to 90,000 acres of additional seasonal and permanent wetlands in the Delta, which represents

about a three to four times increase in wetland acreage from current conditions. The Bay Delta Conservation Plan (BDCP) effort also identifies “priority projects” for near-term implementation that may increase the acreage of wetland and seasonally flooded habitat in the Delta (e.g., BDCP, 2010). In addition, the newly-established Federal Bay-Delta Leadership Committee’s work plan of short-term actions may include expediting habitat restoration projects that are ready to move forward, including coordination with BDCP. (Refer to Sections 6.4.8 and 6.4.9 in Chapter 6 of the draft Basin Plan Amendment staff report for more information about the BDCP and Federal Bay-Delta Leadership Committee.)

Many of the proposed restoration sites are downstream of mercury-enriched watersheds. Marsh restoration efforts below mercury enriched watersheds are proposed for the following locations: Yolo Bypass downstream of Cache and Putah Creeks; Dutch Flats downstream of the Mount Diablo Mercury mine in the Marsh Creek watershed; and Staten Island and the Cosumnes River Wildlife Refuge near the confluence of the Cosumnes River and Mokelumne River.

Mass balance calculations indicated that methylmercury flux from wetland sediments may account for approximately 983 g/year of methylmercury (see Table 6.2 in Chapter 6), or about 19% of the total methylmercury budget for the Delta. A doubling to tripling in methylmercury loading from wetland sediments could increase overall Delta loading by about 16 to 27%. The linkage relationship suggests that such an increase could result in a 28 to 48% increase in mercury concentrations in standard 350-mm largemouth bass (Figure 5.3). CalFed study results released since the TMDL was developed indicate that some wetlands may contribute less methylmercury loading than assumed for the TMDL calculations, and that some wetlands may act as a methylmercury sink. Board staff will continue to track wetland methylmercury research and work with wetland managers and other stakeholders to incorporate new information into the TMDL control program using an adaptive management approach. Chapter 4 in the draft Basin Plan Amendment staff report provides a description of staff’s suggested Central Valley Water Board policy for new wetland creation as well as a schedule for TMDL and control program reviews, during which the implementation strategy and allocations can be modified by the Board as needed to reflect new information.

8.4.3.3 Water and Flood Management Changes

As described in Chapter 3, the transport and deposition of mercury-contaminated sediment and water management activities contribute to the Delta fish mercury impairment. Several state and federal projects affect the transport of mercury and the production and transport of methylmercury in the Delta, including but not limited to:

- Operations to maintain current or future salinity standards in the Delta;
- Current water deliveries to, diversions from, and storage within the Delta;
- Yolo Bypass flood conveyance; and
- Dredging projects throughout the Delta and Yolo Bypass to maintain channel levees for flood conveyance, depths of deep water ship channels, and marina depths.

The source analyses, linkage analysis, methylmercury allocations and total mercury reduction requirements described in this TMDL are based on present water management practices and

channel configurations. However, there are several water and flood management projects being evaluated by federal and state agencies that have the potential to affect methylmercury levels in Delta fish and water, including but not limited to:

- Water supply reliability projects. Public Policy Institute of California and University of California researchers outlined in a 2007 report (Lund *et al*., 2007) a range of potential alternatives for managing the Delta's water supply that could involve:
  - Maintaining the Delta as a fresh water body, e.g., by maintaining and strengthening the current levee system, or strategically focusing levee improvements in key areas and allowing lower-reliability levees to fail, which would lead to some Delta islands flooding;
  - Allowing the Delta to fluctuate between high and low levels of salinity, e.g., by supporting water supply exports with peripheral or through-Delta aqueducts that would allow water exports to circumvent the central Delta on their way to the lower San Joaquin River or directly to Central Valley Project and State Water Project intakes on the southern edge of the Delta, or by creating a major, semi-isolated freshwater conveyance corridor by armoring select islands and tide-gating selected channels within the central-eastern Delta; or
  - Moving toward a Delta that provides high levels of fresh water as needed, e.g., by only allowing exports during times of high discharge of fresh water (generally winter and spring), or otherwise managing the Delta to favor key Delta aquatic and terrestrial species, which would likely result in fluctuating salinity levels in the western Delta and many islands eventually becoming flooded.

  Governor Arnold Schwarzenegger's Delta Vision process concluded at the end of 2008 with a suite of strategic recommendations for long-term, sustainable management of the Delta. The December 2008 Delta Vision Committee Implementation Report identified "fundamental actions" such as:
  - A new system of dual water conveyance through and around the Delta to protect beneficial uses of water, with the goal of breaking ground for new conveyance improvements in 2011;
  - Additional surface and groundwater storage to allow greater system operational flexibility, including surface storage feasibility studies completed for Sites Reservoir, Los Vaqueros expansion, and the San Joaquin River Basin;
  - Revision of the San Joaquin River flow objectives by the State Water Board to improve Delta water quality, as well as the development and implementation of instream flow requirements for the Delta and its tributaries;
  - Strengthen the Delta levee system; and
  - By 2012 develop and implement Total Maximum Daily Load programs for the Delta and its tributary areas to eliminate water quality impairments, including but not limited to reduction of organic and inorganic mercury entering the Delta from tributary watersheds.

  This TMDL report and associated Basin Planning process fulfills the above fundamental action of developing and implementing a mercury TMDL for the Delta. However, the specific details of the other fundamental actions identified by the Delta Vision Committee

or possible alternatives (e.g., as identified in Lund and others' 2007 report), and possible affects on methylmercury levels in Delta water and fish, are not yet known.

- The Sacramento Deep Water Ship Channel Deepening Project, which involves dredging to deeper depths than done in the past to allow deeper-hulled cargo ships to access the Sacramento port. The 2010 Civil Works budget included $10 million for re-launching the Sacramento Deep Water Ship Channel deepening project. As noted on a May 2009 Port of Sacramento press release, the project would involve deepening the 43-mile ship channel connecting the Port of West Sacramento and San Francisco Bay from 30 feet to 35 feet along its entire length. The channel-deepening project, which was initially started in 1989 but later stopped due to since-resolved utility issues, is scheduled to begin in 2010 with completion targeted for 2013. The federal Civil Works funding would support the first phase of construction (Port of West Sacramento, 2009). The project could affect conditions within the ship channel as well as entail increased discharges of return water with elevated methylmercury concentrations from dredge material disposal areas. (See Section 6.2.7 in Chapter 6 for a review of recent return water methylmercury monitoring efforts.)
- Fremont Weir modification to increase flows in the Yolo Bypass. The Blue Ribbon Task Force Delta Vision Strategic Plan included the recommendation to increase the inundation frequency of the Yolo Bypass to promote primary and secondary productivity and splittail spawning by modifying the Fremont Weir. The BDCP has continued to forward the concept of lowering a portion of the Fremont Weir and installing an operable gate facility (often referred to as creating a "notch" in the weir) to increase periods of Yolo Bypass inundation to support native fisheries, particularly splittail and Chinook salmon, through managed flow releases down the Bypass (e.g., BDCP, 2009, Table 3.3 Conservation Measure WOCML2). However, the Lower Yolo Bypass Planning Forum identified several concerns, one of which is the potential increases of methylmercury (Lower Yolo Bypass Planning Forum, 2008).
- The San Joaquin River Restoration Program (SJRRP), a comprehensive long-term effort to restore flows to the San Joaquin River from Friant Dam to the confluence of Merced River. "Interim Flows" began in October 2009. Monitoring is needed to determine how increasing flows (and inundation of associated floodplains) will affect methylmercury levels in San Joaquin River and Delta water and fish.
- The South Delta Improvement Project (SDIP), which is intended to mitigate the water supply and water quality impacts associated with increasing the maximum allowable diversion capacity into Clifton Court Forebay, from which the State Water Project pumps its water. The SDIP could entail the construction of a series of permanent barriers that would reduce the amount of San Joaquin River flow diverted down Old River towards the pumps and away from the San Joaquin River near Stockton. Operation of the permanent barriers would control the ratio of San Joaquin to Sacramento River water in much of the southern Delta. Sulfate concentrations in the San Joaquin are about seven times higher than in the Sacramento River. Therefore, operation of the permanent barriers could exert a strong influence on sediment sulfate concentrations in the southern Delta and may influence ambient methylmercury levels. (See Section 4.3.12.4 in Chapter 4 of the draft Basin Plan Amendment staff report for more discussion on the SDIP.)

To better enable the evaluation and mitigation of negative impacts on water and fish methylmercury levels in the Delta from future water and flood management and dredging projects, Board staff worked with stakeholders to develop language for the proposed Basin Plan amendments included in the draft Basin Plan Amendment report that:

- Assigns the open water methylmercury allocations jointly to the State Lands Commission, the Department of Water Resources, and the Central Valley Flood Protection Board. The open water allocations apply to the methylmercury load that fluxes to the water column from sediments in open-water habitats within channels and floodplains in the Delta and Yolo Bypass. The open water allocations also apply to activities such as water management and storage in and upstream of the Delta and Yolo Bypass; maintenance of and changes to salinity objectives; dredging and dredge materials disposal, dewatering and reuse; and management of flood conveyance flows.
- Requires State and Federal agencies whose projects affect the transport of mercury and the production and transport of methylmercury through the Yolo Bypass and Delta, or manage open water areas in the Yolo Bypass and Delta, to conduct methylmercury control studies during the first phase of the TMDL implementation period.
- Requires State and Federal agencies to include requirements for projects under their authority to implement methylmercury reductions as necessary to comply with the allocations by 2030.

State and Federal agencies required to participate in the control studies and efforts to reduce open water methylmercury include but are not limited to the California Department of Water Resources, State Lands Commission, Central Valley Flood Protection Board, State Water Resources Control Board, U.S. Army Corps of Engineers, and U.S. Bureau of Reclamation. State and federal projects include projects related to flood conveyance, water management, and salinity control that have the potential to increase ambient mercury and/or methylmercury levels in the Delta or Yolo Bypass.

Water management activities also affect the residence time of water in the Delta, which affects the methylmercury loss rate across the Delta from photodegradation and sediment deposition. Changes in water management activities that reduce the methylmercury loss rate across the Delta could result in increases in ambient water and fish methylmercury concentrations even if the activities do not cause an increase in methylmercury source inputs. The 2003 and 2008 CalFed studies indicate that loss processes are an important component of the Delta methylmercury mass balance and resulting fish methylmercury concentrations in different areas of the Delta (see Chapters 3, 5 and 6). It is critical that state and federal agencies evaluate the effect of future water management projects on methylmercury loss processes in the Delta because (1) the suite of activities that affect production processes may be different from the suite of activities that affect loss processes, (2) different agencies may be responsible for these different activities, and (3) as a result, tracking activities that affect methylmercury inputs and methylmercury loss may provide better direction for a variety of methylmercury control methods. The proposed Basin Plan amendment language described in the previous paragraphs was purposefully written in way that encompasses activities that affect methylmercury production, transport, and loss processes.

Board staff will continue to coordinate with the State and Federal agencies to evaluate the potential effects of future water and flood management projects and dredging projects and adapt the Delta mercury control program as needed to incorporate new information and control strategies during program reviews.

8.4.3.4 Decreasing Sediment Loads

The sediment load in the Sacramento River decreased by about 50% between 1957 and 2001 (Wright and Schoellhamer, 2004). The decrease is believed to be caused by the trapping of sediment in reservoirs, a decrease in erodible material from hydraulic mining, changes in land use, and construction of levees (Wright and Schoellhamer, 2004; James, 2004). Mercury loads are likely to have also decreased during the same period because much of the inorganic mercury is transported on sediment particles. It is not known what the magnitude of the decrease in mercury loading has been and whether it will continue in the future. The decrease in sediment loading suggests that the relative proportion of erodible material from upstream watersheds may also be changing. The present 20-year volume-weighted average mercury to TSS ratio of sediment entering the Delta is approximately 0.18 mg/kg. This value may change depending on the new sources of sediment. The mercury content of surficial sediment is important, as it is one of the major factors controlling methylmercury production. Methylmercury production in Delta/Yolo Bypass sediment now accounts for about 36% of the methylmercury in the Delta (Figure 6.11). It is not clear how this proportion may change in the future.

8.4.3.5 Climate Change

Climate change models have predicted several scenarios for global, national and local changes that could affect the Delta, including several direct, individual and cumulative impacts. Warmer temperatures, water abundance and quality, changes in precipitation patterns, frequency and intensity of weather events, and sea level rise are just some of the changes that could impact the Delta, its water supply, habitats, and biota (CAT, 2006; CEC, 2006a and 2008; TRNA, 2009; Brekke *et al.*, 2004; Knowles and Cayan, 2002; Miller *et al.*, 2003; Service, 2004; Stewart *et al.*, 2004). In addition to warmer storms, the Sierra Nevada snow pack, California's largest surface "reservoir" has been reducing each year (CAT, 2006; CAPCOA, 2009; TRNA, 2009). Typically, snowmelt provides an annual average of 15 million acre feet of water between April and July each year (DWR, 2008; TRNA, 2009). Models project the Sierra Nevada snowpack will decrease by 25% to 40% by 2050, which would likely result in regions that rely on surface water for domestic, industrial, and agricultural supply needing to turn to groundwater or additional diversions from the Delta (DWR, 2008; TNRA, 2009). Changes in rainfall and runoff patterns combined with warmer temperatures are expected to change the intensity and frequency of flood events (CAPCOA, 2009).

Drier years could result in more frequent and intense wildfires, depleting the carbon storage that wildlands and forests provide (CAPCOA, 2009; CAT, 2006; CEC, 2006a and 2006c). Warmer temperatures may increase evapotranspiration rates and extend growing seasons, which would require more water (CAPCOA, 2009). High frequency flood events will most likely increase, changing watershed vegetation and erosion patterns (CAPCOA, 2009; CEC 2006a and 2008). Flooding and wildfires would increase sedimentation rates, which would likely negatively affect

reservoir capacity, wildlife habitat and fisheries, and water quality and would likely alter the channel shapes and depths in the Delta. Changes in water quality could include changes in streamflow patterns, dissolved oxygen, and temperatures; higher turbidity; and concentrated pulses of pollutants, all of which could stress fish and increase growth of algae in surface water bodies (DWR 2008; TRNA, 2009). Sea level rise is already occurring; the exact rate is unknown but it is correlated to the melting rate of the ice sheets on the western Antarctica and Greenland, and could result in abrupt changes in sea level conditions (CAT, 2006; CEC, 2006b). Sea level rise would likely ultimately result in increased salt water intrusion in the Delta (CEC, 2006a, 2006d, and 2008; TRNA, 2009).

Other indirect effects of climate change in California that could affect the Delta, and therefore the proposed mercury control program, may include public health impacts; recreational availability; changes in growth rates of weeds, pests, and disease; shifts in distribution and abundance of biota; and response by biota to elevated carbon dioxide levels (CAT, 2006; CAPCOA, 2009; CEC, 2006a).

The net results of climate change may have unpredictable consequences on ecological processes in the Delta including the synthesis and bioaccumulation of methylmercury. The source analyses, linkage analysis, methylmercury allocations and total mercury reduction requirements described in this TMDL are based on present climate conditions. Staff will re-evaluate source analyses and linkage relationships associated with changing environmental conditions as more information becomes available in the future.

8.4.3.6 Global Mercury Emissions

Because of the complexity of atmospheric mercury sources, and because the Central Valley Water Board has limited jurisdiction over these sources, there is greater uncertainty about whether these sources can be addressed in a timely manner. Total mercury concentrations in precipitation in Oregon and rural northern California are consistently very low and, along with Newfoundland, are usually the lowest values in North America (Prestbo and Gay, 2009). Atmospheric wet deposition of methylmercury and total mercury directly to the Delta/Yolo Bypass makes up only about 1% or less of all methylmercury and total mercury loading to the Delta/Yolo Bypass (see Tables 6.2 and 7.1 in the TMDL Report).

However, a rough estimate of the annual contribution of total mercury from atmospheric wet deposition in the tributary watersheds for water year 2001 indicated that wet deposition could account for 23 to 69% of the total incoming total mercury load to the Delta (Foe, 2003). In addition, recent studies indicate that mercury in atmospheric deposition in northern California comes from both local sources (e.g., municipal and industrial emissions, historic mercury and gold mine sites, forest fires, and naturally mercury-enriched geologic formations) and sources outside of California and the United States (e.g., coal-burning power plants in Asia, gold and mercury production, cement production, volcanic emissions, oceans and biomass burning (e.g., forest fires and biofuel to produce energy) (e.g., Prestbo and Gay, 2009; Peterson *et al*, 2009; Jaffe *et al*., 2005; Pacyna *et al.*, 2006; Weiss-Penzias *et al.*, 2007; Seigneur *et al.*, 2004; Steding and Flegal, 2002; Coolbaugh *et al*., 2002; Nacht *et al*., 2004). The largest emissions of mercury to the global atmosphere occur from combustion of fossil fuels, mainly coal in utility, industrial, and residential boilers; as much as two thirds of the total emission of about

2,190 tons of mercury emitted from all anthropogenic sources worldwide in 2000 came from combustion of fossil fuels (Pacyna *et al.*, 2006).

Key Points

- Methylmercury allocations are divided among "waste load allocations" for point sources and "load allocations" for nonpoint sources. The TMDL is the sum of these components. The allocation strategy used in this chapter is based on staff's recommended strategy described in Chapter 4 of the draft Basin Plan Amendment staff report and is designed to remedy the beneficial use impairment in all subareas of the Delta. Total mercury limits were developed to maintain compliance with the USEPA's CTR for total mercury in the water column and to achieve the San Francisco Bay mercury control program's total mercury allocation for the Central Valley, as well as to help enable methylmercury reductions in Delta water and fish.

Methylmercury:

- Methylmercury allocations were made in terms of the existing assimilative capacity of the different Delta subareas. The recommended goal for ambient water is an average annual concentration of 0.06 ng/l methylmercury in unfiltered water (Chapter 5). This goal describes the assimilative capacity of Delta waters in terms of concentration and encompasses a margin of safety of approximately 10%. Central Valley Water Board staff anticipates that as the average concentration of methylmercury in each Delta subarea decreases to the aqueous goal, the targets for fish tissue will be attained.
- To determine necessary reductions, the existing average aqueous methylmercury levels in ambient water in the Delta subareas were compared to the methylmercury goal. The amount of reduction needed in each subarea is expressed as a percent of the existing concentration. Percent reductions required to meet the goal ranged from 0% in the Central Delta subarea to more than 70% in the Yolo Bypass and Marsh Creek subareas.

Total Mercury:

- Central Valley Water Board staff recommends that the 110 kg total mercury reduction allocated by the San Francisco Bay mercury control program to the Central Valley be met by reductions in total mercury entering the Delta from tributary inputs because within-Delta sources comprise only a couple percent of total mercury inputs. Initial mercury reduction efforts should focus on the watersheds that export the largest volume of highly contaminated sediment. Additional reductions may be recommended in future phases of the Delta mercury implementation program and upstream control programs to achieve the proposed methylmercury allocations for open-water and wetland habitat in the Delta/Yolo Bypass and to address mercury impairments in the upstream watersheds.

Options to Consider

- The methylmercury allocations described in this chapter reflect the preferred implementation alternative described in Chapter 4 of the draft Basin Plan Amendment staff report and are designed to address the beneficial use impairment in all subareas of the Delta. However, as described in the draft Basin Plan Amendment staff report, a number of alternatives are possible. The Central Valley Water Board will consider a variety of allocation strategies and implementation alternatives as part of the Basin Plan amendment process.
- Likewise, a variety of total mercury reduction strategies are possible. A total mercury load reduction strategy was developed to comply with the San Francisco Bay mercury TMDL allocation for to the Central Valley and the USEPA's criterion for human health protection, and to help enable compliance with the proposed methylmercury allocations for open-water habitat in the Delta and Yolo Bypass. Staff applied the San Francisco Bay TMDL's allocated reduction of 110 kg total mercury reduction to tributary inputs to the Delta/Yolo Bypass because within-Delta sources comprise only a couple percent of total mercury inputs. Initial mercury reduction efforts should focus on the watersheds that export the largest volume of highly contaminated sediment such as the Cache Creek, Feather River, American River, Cosumnes River, and Putah Creek watersheds. Chapter 4 of the draft BPA staff report describes additional strategies for minimizing increases from total mercury sources that may increase as a result of population growth and regional water management changes.

9 REFERENCES

AFT. 2006. The Future is Now: Central Valley Farmland at the Tipping Point? American Farmland Trust (AFT). Available at: http://www.farmland.org/programs/states/futureisnow/default.asp. Accessed: 24 September 2006.

Alpers, C.N., R.C. Antweiler, H.E. Taylor, P.D. Dileanis, and J.L. Domagalski. 2000. *Metals Transport in the Sacramento River, California, 1996-1997, Volume 1: Methods and Data.* U.S. Geological Survey Water-Resources Investigation Report 99-4286. Sacramento, CA.

AMS. 2010. Methyl Mercury Monitoring in Dredged Material Placement Sites (Sacramento and San Joaquin DWSCs). Field report prepared for Ross Island Sand & Gravel Company and U.S. Army Corps of Engineers by Applied Marine Sciences (AMS). January 2010.

Armstrong F. and D. Scott. 1979. Decrease in mercury content of fishes in Ball Lake, Ontario, since imposition of controls on mercury discharge. *Journal of the Fish Research Board of Canada*, 36: 670-672.

ARB. 2003. Data retrieved from the California Emission Inventory Development and Reporting System (CEIDARS), database year 2002. California Air Resources Board (ARB), Emission Inventory Branch, Sacramento, CA.

Ayers, R.S. and D.W. Westcot. 1985. *Water Quality for Agriculture*. Rome, Food and Agriculture Organization of the United Nations. Irrigation Drainage Paper No. 29, Rev. 1.

BDCP. 2009. *Bay Delta Conservation Plan (BDCDP) Working Draft Conservation Strategy, Chapter 3.* July 27, 2009. Available at: http://www.baydeltaconservationplan.com/CurrentDocumentsLibrary/Chapter_3_Conservation_Strategy_Combined_v2.pdf

Beard, R.R. 1987. *Treating Gold Ores by Amalgamation*. Arizona Department of Mines and Mineral Resources Circular No. 27, March 1987. Text of a presentation given at an Ehrenberg Arizona Miner's Seminar. Available at: http://www.admmr.state.az.us/Publications/circ027amalgam.html

Becker, D.S. and G.N. Bigham. 1995. Distribution of mercury in the aquatic food web of Onondaga Lake, New York. *Water, Air, and Soil Pollution,* 80: 563-571.

Benoit, J.M., C.C. Gilmour, A. Heyes, R.P. Mason and C. L. Miller. 2003. Geochemical and biological controls over methylmercury production and degradation in aquatic ecosystems. *In*: *Biogeochemistry of Environmentally Important Trace Elements*, ACS Symposium Series #835. Y. Chai and O.C. Braids (editors). Washington, D.C.: American Chemical Society, pp.262-297.

Benoit, J.M., C.C. Gilmour, and R. Mason. 2001. The influence of sulfide on solid-phase mercury bioavailability for methylation by pure cultures of Desulfobulbus propionicus (lpr3). *Environmental Science & Technology*, 35: 127-132.

Benoit, J.M., C.C. Gilmour, R. Mason, A. Heyes. 1999. Sulfide controls on mercury speciation and bioavailability to methylating bacteria in sediment and pore waters. *Environmental Science & Technology*, 33: 951-957.

Benoit, J.M., C.C. Gilmour, R.P. Mason, G.S. Riedel, and G.F. Riedel. 1998. Behavior of mercury in the Patuxent River Estuary. *Biogeochemistry*, 40: 249-265.

Benoit, J.M., R.P. Mason, and C.C. Gilmour. 1999. Estimation of mercury-sulfide speciation and bioavailability in sediment pore waters using octanol-water partitioning and implications for

availability to methylating bacteria. *Environmental Toxicology and Chemistry*, 18(10): 2138-2141.

Bloom, N.S. 2003. *Solid Phase Mercury Speciation and Incubation Studies in or Related to Mine-site Runoff in the Cache Creek Watershed (CA)*. Final report submitted to the CALFED Bay-Delta Program for the project: An Assessment of the Ecological and Human Health Impacts of Mercury in the Bay-Delta Watershed (Task 7C). Frontier Geosciences Inc. Available at: http://loer.tamug.tamu.edu/calfed/FinalReports.htm.

Bloom, N.S., G.A. Gill, S. Cappellino, C. Dobbs, L. McShea, C. Driscoll, R. Mason and J. Rudd. 1999. An investigation regarding the speciation and cycling of mercury in Lavaca Bay, Texas, sediments. *Environmental Science & Technology*, 33: 7-13.

Bodaly, R.A., J.W.M. Rudd, and R.J. Flett. 1998. Effect of urban sewage treatment on total and methyl mercury concentrations in effluent. *Biogeochemistry*, 40: 279-291.

Bodaly, R.A., V.L. St. Louis, M.J. Paterson, R.J.P. Fudge, B.D. Hall, D.M. Rosenberg, and J.W.M. Rudd. 1997. Bioaccumulation of mercury in the aquatic food chain in newly flooded areas. In: *Metal Ions in Biological Systems, Vol. 34: Mercury and Its Effects on Environment and Biology*. A. Sigel and H. Sigel (editors). New York: Marcel Dekker, pp. 259-287.

Booth, E. G., J. F. Mount, J. H. Viers. 2006. Hydrologic Variability of the Cosumnes River Floodplain. *San Francisco Estuary and Watershed Science*. Volume 4, Issue 2, Article 2. September 2006. Available at: http://escholarship.org/uc/item/71j628tv

Bosworth, D.H., S.J. Louie, M.L. Wood, D.J. Little, and H. Kulesza. 2008. *A Review of Methylmercury Discharges from NPDES Facilities in California's Central Valley*. California Regional Water Quality Control Board, Central Valley Region, Draft Staff Report. February 2008.

Bradford, G.R., A.C. Chang, A.L. Page, D. Bakhtar1, J.A. Frampton, and H. Wright. 1996. *Background Concentrations of Trace and Major Elements in California Soils*. Kearney Foundation Special Report. Kearney Foundation of Soil Science, Division of Agriculture and Natural Resources, University of California. March 1996. Table 1 A (Series and Location of Benchmark Soils) and Table 2 (Total Concentrations of Elements in Benchmark Soils).

Brekke, L.D., N.L. Miller, K.E. Bashford, N.W.T. Quinn, and J.A. Dracup. 2004. Climate Change Impacts Uncertainty for Water Resources in the San Joaquin River Basin, California. *Journal of the American Water Resources Association*, 40 (1): 149-164.

Brodberg, R. and S. Klasing. 2003. *Evaluation of Potential Health Effects of Eating Fish From Black Butte Reservoir (Glenn and Tehama Counties): Guidelines for Sport Fish Consumption.* California Environmental Protection Agency, Office of Environmental Health Hazard Assessment, Pesticide and Environmental Toxicology Section. Oakland, CA. December 2003. Guidelines for Sport Fish Consumption. Available at: http://www.oehha.ca.gov/fish/pdf/BlackButteDec03final.pdf. Accessed: 19 August 2005.

Brumbaugh, W.G., D.P. Krabbenhoft, D.R. Helsel, J.G. Wiener, and K.R. Echols. 2001. *A National Pilot Study of Mercury Contamination of Aquatic Ecosystems Along Multiple Gradients: Bioaccumulation in Fish*. U.S. Geological Survey Biological Science Report 2001-0009. September 2001.

Byington, A., K. Coale, G. Gill, and K. Choe. 2005. *Photo-degradation of Methyl Mercury (MMHg) in the Sacramento – San Joaquin Delta: A Major Sink.* Poster Presentation, Celebrating Science Stewardship, State of the San Francisco Estuary Conference, 7th Biennial, October 4-6, 2005, Oakland, CA.

CALFED Bay-Delta Program. 2000a. *Ecosystem Restoration Program Plan, Volume II: Ecological Management Zone Visions*. Final Programmatic EIS/EIR Technical Appendix. July 2000. Available at: http://calwater.ca.gov/CALFEDDocuments/Final_EIS_EIR.shtml.

CALFED Bay-Delta Program. 2000b. *Implementation Plan*. Final Programmatic EIS/EIR Technical Appendix. July 2000. Available at: http://calwater.ca.gov/CALFEDDocuments/ Final_EIS_EIR.shtml.

CALFED Bay-Delta Program. 2004a. Storage Program. Multi Year Program Plan (Years 5-8). Available at: http://calwater.ca.gov/programplans_2004/storage_program_Plan_7-04.pdf.

CALFED Bay-Delta Program. 2004b. Conveyance Program. Multi Year Program Plan (Years 5-8). Available at: http://calwater.ca.gov/programplans_2004/conveyance_ program_Plan_7-04.pdf.

CAPCOA. 2009. Model Policies for Greenhouse Gases in General Plans, A Resource for Local Government to Incorporate General Plan Policies to Reduce Greenhouse Gas Emissions. California Air Pollution Control Officers Association (CAPCOA). Sacramento, CA. June 2009.

Cappiella, K., C. Malzone, R. Smith and B. Jaffe. 2001. *Historical Bathymetric Change in Suisun Bay: 1867-1990.* United States Geological Survey (USGS). Available: http://sfbay.wr.usgs.gov/access/Bathy/suisunbay/. Last revised: October 2001.

CAT. 2006. Climate Action Team Report to Governor Schwarzenegger and the Legislature. Climate Action Team (CAT). Sacramento, CA. March 2006.

CDFG. 2000-2001. *Central Valley Salmon and Steelhead Harvest Monitoring Project.* 1999 and 2000 creel survey data queried from the California Department of Fish and Game (CDFG) creel database.

CDFG. 2002. *California Wildlife Habitat Relationships System Version 8*. California Department of Fish and Game. Available at: http://www.dfg.ca.gov/whdab/html/cwhr.html.

CDFG. 2005. *A List of California Wildlife Species That May Be at Risk from Consumption of Mercury-Contaminated Fish in Mercury-Impaired Waters in the Central Valley Region.* Report by W. Piekarski, M. Puckett, and M. Stephenson, California Department of Fish and Game Moss Landing Marine Laboratories, Moss Landing, CA, prepared for the Central Valley Regional Water Quality Control Board. May 2005.

CDHS. 2004. *Research, Outreach, and Education on Fish Contamination in the Sacramento-San Joaquin Delta and Tributaries (AKA Delta Fish Project) Phase 1 Needs Assessment Final Report.* Prepared by the California Department of Health Services (CDHS), Environmental Health Investigations Branch. Oakland. January 2004.

CDHS, 2005. *Report to the State Water Resources Control Board on Task 3 Fish and Shellfish Tissue Consumption Study.* California Department of Health Services Environmental Health Investigations Branch, Oakland, 29 March.

CDHS. 2006. Fish Mercury Project: *Fishing Activities in the North Delta and Sacramento River Watershed 2006.* California Department of Health Services (CDHS). June. Available at: http://www.sfei.org/cmr/fishmercury/2007_Annual_meeting/Report%20on%20Fishing%20Activity%20in%20the%20North%20Delta%20and%20Sacramento%20River.pdf. Accessed: July 2007.

CDM. 2004. *Cache Creek Settling Basin Mercury Study: Phase 2 - Sediment Transport Modeling*. Technical Memorandum Prepared for the Central Valley Regional Water Quality

Control Board in Cooperation with the U.S. Army Corps of Engineers Sacramento District, the State of California Reclamation Board and the California Bay-Delta Authority. July 2004.

CDOF. 2004. State of California, Department of Finance, Population Projections by Race/Ethnicity for California and Its Counties 2000–2050, Sacramento, California, May 2004. Available at: http://www.dof.ca.gov/HTML/DEMOGRAP/ReportsPapers/Projections/P1/P1.asp. Accessed: 24 September 2006.

CDOF. 2007. *New State Projections Show 25 Million More Californians by 2050; Hispanics to Be State's Majority Ethnic Group by 2042.* California Department of Finance (CDOF), Sacramento, California, July 2007. Table 1: County Total Population by Decade. (Updated since May 2004 publication.) Available at: http://www.dof.ca.gov/HTML/DEMOGRAP/ReportsPapers/Projections/P1/P1.asp. Accessed: July 13, 2007.

CEC. 2006a. *Our Changing Climate - Assessing the Risks to California.* A Summary Report from the California Climate Change Center, CEC-500-2006-077. Public Interest Energy Research Program, California Energy Commission (CEC). Sacramento, CA. July 2006.

CEC. 2006b. *Projecting Future Sea Level.* White Paper from California Climate Change Center, CEC-500-2005-202-SF. California Energy Commission (CEC). Sacramento, CA. March 2006.

CEC. 2006c. *Climate Change and Wildfire in and Around California: Fire Modeling and Loss Modeling.* White Paper from California Climate Change Center, CEC-500-2005-190-SF. California Energy Commission (CEC). Sacramento, CA. February 2006.

CEC. 2006d. *Climate Warming and Water Supply Management in California.* White Paper from California Climate Change Center, CEC-500-2005-195-SF. California Energy Commission (CEC). Sacramento, CA. March 2006.

CEC. 2008. The Future is Now, An Update on Climate Change Science, Impacts, and Response Options for California. CEC-500-2008-077, Public Interest Energy Research Program, California Energy Commission (CEC). Sacramento, CA. September 2008.

Choe, K.Y. 2002. *Biogeochemistry of monomethyl mercury in San Francisco Bay Estuary*. Texas A&M University, Galveston, Ph.D. dissertation, 195 p.

Churchill, R. 2000. *Contributions of mercury to California's environment from mercury and gold mining activities – Insights from the historical record.* Manuscript and slides for oral conference presentation at: Assessing and Managing Mercury from Historic and Current Mining Activities, November 28-30, 2000. Cathedral Hill Hotel, San Francisco, CA. Sponsored by the U.S. Environmental Protection Agency, Office of Research and Development.

City of Sacramento. 1996. *Mercury Monitoring Plan per Provision 5 of the City of Sacramento's Combined Sewer System's NPDES Permit No. CA0079111.* Letter report submitted to the Central Valley Water Board by the City of Sacramento Department of Utilities with review of mercury monitoring results. May 23, 1996.

CMP. 2004. Microsoft Access database of Coordinated Monitoring Program water quality data through August 2003. Database and updates provided by Larry Walker Associates (Mike Trouchon) and Sacramento Regional County Sanitation District (Steve Nebozuk, CMP Program Manager) to Central Valley Regional Water Quality Control Board (Michelle Wood, Environmental Scientist, Sacramento).

Compeau, G. and R. Bartha. 1985. Sulfate-reducing bacteria: Principal methylators of mercury in anoxic estuarine sediment. *Applied Environmental Microbiology*, 50: 498-502.

Conaway, C.H., S. Squire, and R. Mason. 2003. Mercury speciation in the San Francisco Bay Estuary. *Marine Chemistry*, 80: 199-225.

Cooke, J., C. Foe, A. Stanish and P. Morris. 2004. *Cache Creek, Bear Creek, and Harley Gulch TMDL for Mercury.* Central Valley Regional Water Quality Control Board Staff Report. November 2004.

Cooke, J. and P. Morris. 2005. *Amendments to The Water Quality Control Plan for the Sacramento River and San Joaquin River Basins for the Control of Mercury Cache Creek, Bear Creek, and Harley Gulch.* Central Valley Regional Water Quality Control Board, Final Staff Report. Sacramento. October. Available at: http://www.waterboards.ca.gov/ centralvalley/programs/tmdl/Cache-SulphurCreek/cache-ck-hg-final-rpt-oct05.pdf

Coolbaugh, M.F., M.S. Gustin and J.J. Rytuba. Annual emissions of mercury to the atmosphere from natural sources in Nevada and California. *Environmental Geology*, 42: 338-349.

CVRWQCB. 1998. *The Water Quality Control Plan (Basin Plan) for the California Regional Water Quality Control Board - Central Valley Region.* Fourth Edition. Central Valley Regional Water Quality Control Board (CVRWQCB). Sacramento, CA.

Dansereau, M., N. Lariviere, D. Du Tremblay, and D. Belanger. 1999. Reproductive performance of two generations of female semidomesticated mink fed diets containing organic mercury contaminated freshwater fish. *Archives of Environmental Contamination and Toxicology*, 36: 221-226.

Darling, G.W. 2008. March 17, 2008 comments on the Tentative Waste Discharge Requirements for Ironhouse Sanitary District submitted by Gary W. Darling (General Manager, Delta Diablo Sanitation District) to Pamela Creedon (Executive Officer, Central Valley Regional Water Quality Control Board). Available at: http://www.swrcb.ca.gov/rwqcb5/board_decisions/tentative_orders/0804/ironhouse/isd_wwtp_ddsd_com.pdf

David, N., L.J. McKee, F.J. Black, A.R. Flegal, C.H. Conaway, D.H. Schoellhamer, and N.K. Ganju. 2009. Mercury concentrations and loads in a large river system tributary to San Francisco Bay, California, USA. *Environmental Toxicology and Chemistry*, 28 (10): 2091-2100.

Davis, J.A., B.K. Greenfield, G. Ichikawa, and M. Stephenson. 2008. Mercury in sport fish from the Sacramento San Joaquin Delta region, California, USA. *Science of the Total Environment*, 391:66-75.

Davis, J.A, B.K. Greenfield, G. Ichikawa and M. Stephenson. 2003. *Mercury in Sport Fish from the Delta Region.* Final report submitted to the CALFED Bay-Delta Program for the project: An Assessment of the Ecological and Human Health Impacts of Mercury in the Bay-Delta Watershed (Task 2A). San Francisco Estuary Institute and Moss Landing Marine Laboratories. Available at: http://loer.tamug.tamu.edu/calfed/FinalReports.htm.

Davis, J.A., M.D. May, G. Ichikawa, and D. Crane. 2000. *Contaminant Concentrations in Fish from the Sacramento-San Joaquin Delta and Lower San Joaquin River – 1998*. San Francisco Estuary Institute report. Richmond, California. September 2000.

Domagalski, J. 2001. Mercury and methylmercury in water and sediment of the Sacramento River Basin, California. *Applied Geochemistry*, 16: 1677-1691.

DPR. 2002. Pesticide Use Report (PUR) Database. Data available for 1990-2001. California Department of Pesticide Regulation (DPR), Sacramento, CA.

DPRec. 1997. *The Delta: Sacramento-San Joaquin Delta Boating and Recreation Survey*. Prepared by the Department of Parks and Recreation for the Delta Protection Commission

and the Department of Boating and Waterways. September. Available at: http://www.delta.ca.gov/recreation/survey/default.asp. Accessed: September 2007.

DWR. 1962. Sacramento River Water Pollution Survey: Appendix A – Hydrography, Hydrology, and Water Utilization. California Department of Water Resources (DWR) Bulletin No. 111. August 1962.

DWR. 1991. Delta Circulation Patterns. California Department of Water Resources (DWR) maps DWR-51A through DWR-51A, as provided in the *Water Quality Control Plan for Salinity, San Francisco Bay / Sacramento – San Joaquin Delta Estuary*, Technical Appendix, 91-16WR, Figures A3.0-9 through A3.0-13, State Water Resources Control Board, May 1991. Available at: http://www.swrcb.ca.gov/waterrights/water_issues/programs/bay_delta/wq_control_plans/1995wqcp/exhibits/ccwd/ccwd-exh-16b.pdf

DWR. 1993-2003. Land Use Data. California Department of Water Resources. Available at: http://www.landwateruse.water.ca.gov/basicdata/landuse/digitalsurveys.cfm.

DWR. 1995. *Sacramento – San Joaquin Delta Atlas.* California Department of Water Resources (DWR), Division of Planning and Local Assistance, Office of Water Education, and DWR Photography. Reprinted July 1995.

DWR. 2003. *Sacramento Valley Flood Control System: Estimated Channel Capacity, Reclamation and Levee Districts.* Department of Water Resources (DWR) map of channel capacities and levees maintained by DWR, reclamation, levee, and drainage districts and municipalities. November 2003.

DWR. 2005. *California Water Plan Update 2005, Volume 3 – Regional Reports: Chapter 12. Sacramento-San Joaquin Delta Region*. California Water Plan Update Bulletin 160-05. Public Review Draft, April 2005. Available at: http://www.waterplan.water.ca.gov/. Accessed: 9 June 2005.

DWR. 2006. *Chronological Reconstructed Sacramento and San Joaquin Valley Water Year Hydrologic Classification Indices.* DWR California Cooperative Snow Surveys. Sacramento, CA. Available at: http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST. Accessed: 24 September 2006.

Foe, C.G. 2003. *Mercury Mass Balance for the Freshwater Sacramento-San Joaquin Bay-Delta Estuary*. Final report submitted to the CALFED Bay-Delta Program for the project: An Assessment of the Ecological and Human Health Impacts of Mercury in the Bay-Delta Watershed (Task 1A). California Regional Water Quality Control Board, Central Valley Region. Sacramento, CA. Available at: http://mercury.mlml.calstate.edu/reports/2003-reports/

Foe, C.G. 2007. *Review of Paper by Peterson et al. entitled "Mercury Concentrations in Fish from Streams and Rivers Throughout the Western United States".* Memorandum from Chris Foe (Staff Environmental Scientist, Central Valley Water Quality Control Board, Sacramento Office) to Pamela C. Creedon (Executive Officer, Central Valley Water Quality Control Board). 23 May 2007.

Foe, C.G. and W. Croyle. 1998. *Mercury Concentrations and Loads from the Sacramento River and from Cache Creek to the Sacramento-San Joaquin Delta Estuary.* California Regional Water Quality Control Board, Central Valley Region. Sacramento, CA. Staff report. June 1998.

Foe, C., S. Louie, and D. Bosworth. 2008. *Methylmercury Concentrations and Loads in the Central Valley and Freshwater Delta.* Final Report submitted to the CALFED Bay-Delta

Program for the project “Transport, Cycling and Fate of Mercury and Monomethylmercury in the San Francisco Delta and Tributaries” Task 2. Central Valley Regional Water Quality Control Board. Available at: http://mercury.mlml.calstate.edu/reports/reports/

Foe, C.G., M. Stephenson, and A. Stanish. 2002. *Pilot Transplant Studies with the Introduced Asiatic Clam, Corbicula fluminea, to Measure Methyl Mercury Accumulation in the Foodweb of the Sacramento-San Joaquin Delta Estuary*. Draft report submitted to the CALFED Bay-Delta Program for the project: An Assessment of the Ecological and Human Health Impacts of Mercury in the Bay-Delta Watershed. Central Valley Regional Water Quality Control Board and California Department of Fish and Game. Available at: http://loer.tamug.tamu.edu/calfed/DraftReports.htm.

Foe, C.G., Davis, J., Schwarzbach, M. Stephenson and S. Slotton, 2003. *Conceptual Model and Working Hypotheses of Mercury Bioaccumulation in the Bay-Delta Ecosystem and its Tributaries.* Final report submitted to the CALFED Bay-Delta Program for the project: An Assessment of the Ecological and Human Health Impacts of Mercury in the Bay-Delta Watershed. Central Valley Regional Water Quality Control Board, San Francisco Estuary Institute, U.S. Geological Survey, California Department of Fish and Game, and University of California. Available at: http://loer.tamug.tamu.edu/calfed/FinalReports.htm.

Francesconi, K.A., R.C.J. Lenanton, N. Caputi and S. Jones. 1997. Long term study of mercury concentrations in fish following cessation of a mercury-containing discharge. *Marine Environmental Research*, 43(1): 27-40.

Gassel, M., S. Klassing, R.K. Brodberg and S. Roberts. 2005. *Fish Consumption Guidelines for Clear Lake, Cache Creek, and Bear Creek (Lake, Yolo, and Colusa Counties).* California Environmental Protection Agency, Office of Environmental Health Hazard Assessment, Pesticide and Environmental Toxicology Section. Oakland, CA. January 2005. Available at: http://www.oehha.ca.gov/fish/so_cal/pdf_zip/ClearLake0105.pdf. Accessed: 23 August 2005.

Gill, G. 2008a. *Monomethylmercury Photodegradation Studies*. Final Report submitted to the CALFED Bay-Delta Program for the project “Transport, Cycling and Fate of Mercury and Monomethylmercury in the San Francisco Delta and Tributaries” Task 5.1. California Department of Fish and Game Moss Landing Marine Laboratories and Pacific Northwest National Laboratory. Available at: http://mercury.mlml.calstate.edu/reports/reports/

Gill, G. 2008b. *Atmospheric Mercury Deposition Studies*. Final Report submitted to the CALFED Bay-Delta Program for the project “Transport, Cycling and Fate of Mercury and Monomethylmercury in the San Francisco Delta and Tributaries” Task 3. California Department of Fish and Game Moss Landing Marine Laboratories and Pacific Northwest National Laboratory. Available at: http://mercury.mlml.calstate.edu/reports/reports/

Gill, G. 2008c. *Air-Water Exchange Studies.* Final Report submitted to the CALFED Bay-Delta Program for the project “Transport, Cycling and Fate of Mercury and Monomethylmercury in the San Francisco Delta and Tributaries” Task 5.4. California Department of Fish and Game Moss Landing Marine Laboratories and Pacific Northwest National Laboratory. Available at: http://mercury.mlml.calstate.edu/reports/reports/

Gill, G.A., K.Y. Choe, R. Lehman and S. Han. 2003. *Sediment-Water Exchange and Estuarine Mixing Fluxes of Mercury and Monomethyl Mercury in the San Francisco Bay Estuary and Delta*. Final report submitted to the CALFED Bay-Delta Program for the project: An Assessment of the Ecological and Human Health Impacts of Mercury in the Bay-Delta Watershed (Task 4B). Laboratory for Oceanographic and Environmental Research, Texas

A&M University, Galveston, TX. Available at: http://loer.tamug.tamu.edu/calfed/ FinalReports.htm.

Gilmour C.C., E.A. Henry and R. Mitchell. 1992. Sulfate stimulation of mercury methylation in freshwater sediments. *Environmental Science & Technology*, 26: 2281-2285.

Gilmour C.C., G.S. Riedel, M.C. Ederington, J.T. Bell, J.M. Benoit, G.A. Gill, and M.C. Stordall. 1998. Methylmercury concentrations and production rates across a trophic gradient in the northern Everglades. *Biogeochemistry,* 40: 327-345.

Hamas, M.J. 1994. Belted kingfisher (*Ceryle alcyon*). *In:* The Birds of North America, No. 84. A. Poole and F. Gill (editors). Philadelphia: The Academy of Natural Sciences; Washington, D.C.: The American Ornithologists' Union.

Hatch, J.J. and D.V. Weseloh. 1999. Double-crested Cormorant (*Phalacrocorax auritus*). *In:* The Birds of North America, No. 441. A. Poole and F. Gill (editors). Philadelphia: The Academy of Natural Sciences; Washington, D.C., The American Ornithologists' Union.

Heim, W. 2004. Personal communication between Wes Heim (Research Associate, Marine Pollution Studies Laboratory, Moss Landing Marine Laboratories) to Michelle Wood (Environmental Scientist, Central Valley Water Board), to develop a method to estimate methylmercury flux (load per acre) from wetlands and open-water areas in the Delta. Telephone and e-mail communications with attached example calculation file. December 2004.

Heim, W.A., K.H. Coale, and M. Stephenson. 2003*. Methyl and Total Mercury Spatial and Temporal Trends in Surficial Sediments of the San Francisco Bay-Delta.* Final report submitted to the CALFED Bay-Delta Program for the project: An Assessment of the Ecological and Human Health Impacts of Mercury in the Bay-Delta Watershed (Task 4A). California Department of Fish and Game Moss Landing Marine Laboratory. Available at: http://mercury.mlml.calstate.edu/reports/2003-reports/.

Heim, W.A., E.R. Sassone, and K.H. Coale. 2004. Mono-Methylmercury production within the Bay-Delta. Abstract in *Northern California Chapter of the Society of Environmental Toxicology and Chemistry (SETAC), Hot Topics in Environmental Toxicology and Chemistry, 14th Annual Meeting, May 11-12, 2004, Davis, CA*. SETAC Press, pp: 18-19.

Herbold, B., A.D. Jassbay, and P.B. Moyle. 1992. *Status and Trends Report on Aquatic Resources in the San Francisco Estuary*. San Francisco Estuary Project. Oakland, CA.

Heyvaert, A.C., J.E. Reuter, D.G. Slotton and C.R. Goldman. 2000. Paleolimnological reconstruction of historical atmospheric lead and mercury deposition at Lake Tahoe, California-Nevada. *Environmental Science & Technology*, 34 (17), 3588-3597.

Hintelmann, H. and R.D. Wilken. 1995. Levels of total and methylmercury compounds in sediments of the polluted Elbe River: Influence of seasonally and spatially varying factors. *Science of the Total Environment*, 166: 1-10.

Hornberger, M.I., S. Luoma, A. Van Geen, C. Fuller and R. Anima. 1999. Historical trends of metal in the sediment of San Francisco Bay, CA. *Marine Chemistry,* 64: 39-55.

Hoyer, M., R.W. Baldauf, C. Scarbro, J. Barres, and G.J. Keeler. 2002. Mercury emissions from motor vehicles. Paper in *13th International Emission Inventory Conference: Working for Clean Air in Clearwater*. June 8-10, 2004, Clearwater, FL. USEPA Office of Air Quality Planning and Standards and Emission Inventory Improvement Program (a partnership between USEPA, the State and Territorial Air Pollution Program Administrators and the

Association of Air Pollution Control Officials). Available at: http://www.epa.gov/ttn/chief/conference/ei13/toxics/hoyer.pdf

Hrabik, T.R. and C.J. Watras. 2002 . Recent declines in mercury concentration in a freshwater fishery: isolating the effects of de-acidification and decreased atmospheric mercury in Little Rock Lake. *The Science of the Total Environment*, 297: 229-237.

Huber, K. 1997. *Wisconsin Mercury Sourcebook: A Guide to Help Your Community Identify & Reduce Releases of Elemental Mercury*. Wisconsin Department of Natural Resources, Bureau of Watershed Management. Madison, WI. May 1997. Available at: http://www.epa.gov/glnpo/bnsdocs/hgsbook/.

Hunerlach, M.P., J.J. Rytuba, and C.N. Alpers. 1999. Mercury Contamination from Hydraulic Placer-Gold Mining in the Dutch Flat Mining District, California. United States Geologic Survey (USGS). U.S. Geological Survey Water-Resources Investigations. Report 99-4018B, pp. 179-189

Hurley, J., J. Benoiit, C. Babiarz, M. Shafer, A. Andren, J. Sullivan, R. Hammond, and D. Webb. 1995. Influences of watershed characteristics on mercury levels in Wisconsin rivers. *Environmental Science & Technology*, 29: 1867-1875.

Hurley J., D.P. Krabbenhoft and L. Cleckner. 1998. System controls on the aqueous distribution of mercury in the northern Florida Everglades. *Biogeochemistry*, 40: 293-311.

Jackman, R.E., W.G. Hunt, J.M. Jenkins and P.J. Detrich. 1999. Prey of nesting bald eagles in Northern California. *Journal of Raptor Research,* 33:87-96.

Jaffe, D., E. Prestbo, P. Swartzendruber, P. Weiss-Penzias, S. Kato, A. Takami, S. Hatakeyana, and Y. Kajii. 2005. Export of atmospheric mercury from Asia. *Atmospheric Environment*, 39: 3029-3038.

James, L.A. 2004. Decreasing sediment yields in northern California: vestiges of hydraulic gold-mining and reservoir trapping. *Sediment Transfer through the Fluvial System. Proceedings of the Moscow Symposium, August 2004*. IAHS Publishers. 288 p. Available at: http://people.cas.sc.edu/ajames/Research/Pubs/IAHS.James.pdf.

Jernelöv A, and B. Åséll. 1975. The Feasibility of Restoring Mercury-Contaminated Waters. *In*: Heavy Metals in the Aquatic Environment: An International Conference. P.A. Krenkel (editor). Oxford: Pergammon Press, Inc. pp. 299-309.

Johnson, B. and R. Looker. 2004. *Mercury in San Francisco Bay: Total Maximum Daily Load (TMDL) Proposed Basin Plan Amendment and Staff Report.* California Regional Water Quality Control Board, San Francisco Bay Region, staff report. April 30, 2004.

Jones, R. 2002. Unpublished mercury concentration data for Morrison Creek and Laguna Creek provided by Roger Jones (Wildlife Biologist, Sacramento Regional County Sanitation District Bufferlands, Sacramento County) to Michelle Wood (Environmental Scientist, Central Valley Water Board) in an emailed Excel file on 22 March 2002.

Jones & Stokes. 2001. *A Framework for the Future: Yolo Bypass Management Strategy*. Final report (J&S 99079) prepared for the CALFED Bay-Delta Program by the Yolo Bypass Working Group, Yolo Basin Foundation, and Jones & Stokes. August 2001. Available at: http://www.yolobasin.org/bypass_strategy.cfm.

Kelley, C., J. Rudd and M. Holoka. 2003. Effect of pH on mercury uptake by aquatic bacteria: Implications for mercury cycling. *Environmental Science & Technology*, 37: 2941-2946.

King J.K., S.M. Harmon, T.T. Fu and J.B. Gladden. 2002. Mercury removal, methylmercury formation, and sulfate reducing bacteria profiles in wetland mesocosms. *Chemosphere*, 46: 859-870.

Knowles, N., and D.R. Cayan. 2002. Potential effects of global warming on the Sacramento/San Joaquin watershed and the San Francisco estuary. *Geophysical Research Letters*, 29(18): 38-1 to 38-4.

Krabbenhoft, D.P. and J.P. Hurley. 1999. The Sun's Detoxifying Effects on Mercury in the Everglades. Abstract in *U.S. Geological Survey Program on the South Florida Ecosystem – Proceedings of South Florida Restoration Science Forum, May 17-19, 1999, Boca Raton, FL*. S. Gerould and A. Higer (compilers). Tallahassee, Florida: U.S. Geological Survey Open-File Report 99-181, pp. 56-57. Available at: http://sflwww.er.usgs.gov/sfrsf/ publications/proceedings/forumproceedings.pdf

Krabbenhoft, D.P., M. Olson, J. Dewild, D. Clow, R. Striegl, M. Dornblaser, and P. Vanmetre. 2002. Mercury loading and methylmercury production and cycling in high-altitude lakes from the Western United States. *Water, Air and Soil Pollution: Focus*, 2 (2): 233-249.

Krabbenhoft D.P., J.G. Wiener, W.G. Brumbaugh, M.L. Olson, J.F. Dewild and T.J. Sabinal. 1999. A National Pilot Study of Mercury Contamination of Aquatic Ecosystems along Multiple Gradients. *In*: U. S. Geological Survey Toxic Substances Hydrology Program--Proceedings of the Technical Meeting, Charleston, SC, March 8-12, 1999 – Volume 2 of 3 – Contamination of Hydrologic Systems and Related Ecosystems, Water-Resources Investigations Report: 99-4018B. D.W. Morganwalp and H.T. Buxton (editors). West 115 Trenton, N. J.: U. S. Dept. Interior, U. S. Geological Survey; Denver: Branch of Information Services (distributor); pp. 147-160. Available at: http://toxics.usgs.gov/pubs/wri99-4018/Volume2/sectionB/2301_Krabbenhoft/pdf/2301_Krabbenhoft.pdf. Accessed: August 24, 2005.

Lawson, N.M. and R.P. Mason. 2001. Concentration of mercury, methylmercury, cadmium, lead, arsenic, and selenium in the rain and stream water of two contrasting watersheds in western Maryland. *Water Resources*, 35 (17): 4039-4052.

Leatherbarrow, J.E., L.J. McKee, D.H. Schoellhamer, N.K. Ganju and A.R. Flegal. 2005. *Concentrations and Loads of Organic Contaminants and Mercury Associated with Suspended Sediment Discharged to San Francisco Bay from the Sacramento-San Joaquin River Delta, California.* RMP Technical Report, prepublication manuscript. SFEI Contribution 405. San Francisco Estuary Institute. Oakland, CA. June 2005.

Lindeström, L. 2001. Mercury in Sediment and Fish Communities of Lake Vänern, Sweden: Recovery from Contamination. *Ambio*, 30: 538-544.

Lindeburg, M.R. 1992. *Civil Engineering Reference Manual*. Sixth Edition. Professional Publications, Inc.: Belmont, CA. Appendix A: Rational Method Runoff Coefficients.

Linthicum, J. 2003. Personal communications from Janet Linthicum (University of California Santa Cruz Predatory Bird Research Group) to Janis Cooke (Environmental Scientist, Central Valley Water Board) regarding nesting sites and prey remains for peregrine falcons in the Cache Creek, Napa valley and Delta areas. April 2003.

Lodenius, M. 1991. Mercury concentrations in an aquatic ecosystem during 20 years following abatement of the pollution source. *Water, Air, and Soil Pollution*, 56: 323-332.

Louie, S., C. Foe, and D. Bosworth. 2008. *Mercury and Suspended Sediment Concentrations and Loads in the Central Valley and Freshwater Delta.* Final Report submitted to the CALFED Bay-Delta Program for the project "Transport, Cycling and Fate of Mercury and

Monomethylmercury in the San Francisco Delta and Tributaries" Task 2. Central Valley Regional Water Quality Control Board. Available at: http://mercury.mlml.calstate.edu/reports/reports/

Lower Yolo Bypass Planning Forum. 2008. Comments submitted to Michael Chrisman (Secretary of the Resources Agency and Chair of the Delta Vision Committee) by Forum members on Delta Vision Strategic Plan Action 3.1.1 (a) regarding modification of the Fremont Weir and periodic planned inundation of the Yolo Bypass. December 15, 2008. Available at: http://deltavision.ca.gov/DV_Committee/PublicComments/Comment_from_Lower_Yolo_Bypass_12-15-08.pdf

Lund, J., E. Hanak, W. Fleenor, R. Howitt, J. Mount, and P. Moyle. 2007. *Envisioning Futures for the Sacramento-San Joaquin Delta.* Public Policy Institute of California report, 325 pages. February 2007. Available at: http://www.ppic.org/main/publication.asp?i=671

LWA. 1996. *Sacramento NPDES Stormwater Discharge Characterization Program 1996 DCP Update Report.* Prepared by Larry Walker Associates (LWA) for the County of Sacramento, the City of Sacramento, the City of Folsom, and the City of Galt. September 1996.

LWA. 2002. Strategic Plan for the Reduction of Mercury-Related Risk in the Sacramento River Watershed. Appendix 1: Mercury Conceptual Model Report – Mercury Quantities, Fate, Transport, and Uptake in the Sacramento River Watershed. Prepared by Larry Walker Associates (LWA), Davis, California, for Delta Tributaries Mercury Council and Sacramento River Watershed Program. December 2002.

LWA. 2003. *Sacramento River Watershed Program Annual Monitoring Report: 2001–2002 (Final Draft).* Larry Walker and Associates (LWA). Davis, CA. June 2003.

Mallory, M. and K. Metz. 1999. Common merganser (*Mergus merganser*). *In:* The Birds of North America, No. 442. A. Poole and F. Gill (editors). Philadelphia: The Academy of Natural Sciences; Washington, D.C., The American Ornithologists' Union.

Marvin-DiPasquale, M.M., J. Agee, R.S. Oremland, M. Thomas, D.P. Krabbenhoft and C.G. Gilmour. 2000. Methylmercury Degradation Pathways- A comparison among three mercury impacted ecosystems. *Environmental Science & Technology*, 34: 4908-4916.

MASCO. 2008. Medical Academic and Scientific Community Organization (MASCO) Mercury Database. The Mercury Database was developed by MASCO with help from the Massachusetts Office of Technical Assistance for Toxics Use Reduction, Massachusetts Water Resources Authority, and Harvard University. Available at: http://www1.netcasters.com/cgi-bin/masco/mercury/view.pl

Mason, R.P., N.M. Lawson, and G.R. Sheu. 2000. Annual and seasonal trends in mercury deposition in Maryland. *Atmospheric Environment*, 34: 1691-1701.

Mason, R.P., N.M. Lawson, and K.A. Sullivan. 1997. The concentration, speciation and sources of mercury in Chesapeake Bay Precipitation. *Atmospheric Environment,* 31 (21): 3541-3550.

Mason, R.P., W. Fitzgerald and F. Morel. 1994. The biogeochemical cycling of elemental mercury: Anthropogenic influences. *Geochimica et Cosmochimica Acta,* 58: 3191-3198.

Mason, R.P. and K.A. Sullivan. 1998. Mercury and methylmercury transport through an urban watershed. *Water Research*, 32 (2): 321-330.

McAlear, J.A. 1996. *Concentrations and fluxes of total mercury and methylmercury within a wastewater treatment plant.* Syracuse, NY: Syracuse University, Masters thesis, 79 p.

McKee, L.J., N.K. Ganju, and D.H. Schoellhamer. 2006. Estimates of suspended sediment entering San Francisco Bay from the Sacramento and San Joaquin Delta, San Francisco Bay, California. *Journal of Hydrology*, 323: 335-352.

Miller, N.L., K.E. Bashford, and E. Strem. 2003. Potential impacts of climate change on California hydrology. *Journal of The American Resources Association,* August 2003: 771-784.

Miskimmin, B.M., J.W.M. Rudd and C.A. Kelly. 1992. Influences of dissolved organic carbon, pH, and microbial respiration rates on mercury methylation and demethylation in lake water. *Canadian Journal of Fish and Aquatic Sciences*, 49: 17-22.

Moyle, P. B. 2002. Inland Fishes of California. Revised and Expanded. Berkeley, CA: University of California Press.

Nacht, D.M. M.S. Gustin, M.A. Engle, R.E. Zehner and A.D. Giglini. 2004. Atmospheric mercury emissions and speciation at the Sulphur Bank Mercury Mine Superfund Site, northern California. *Environmental Science & Technology*, 38: 1977-1983.

NADP. 2004. National Atmospheric Deposition Program (NRSP-3). NADP Program Office, Illinois State Water Survey, 2204 Griffith Dr., Champaign, IL 61820. Mercury Deposition Network available at: http://nadp.sws.uiuc.edu/mdn/.

NAS. 1973. *A Report of the Committee on Water Quality: Water Quality Criteria, 1972*. U.S. Environmental Protection Agency, National Academy of Science-National Academy of Engineers (NAS). EPA R3-73-033.

Nguyen, H.L., M. Leermakers, S. Kurunczi, L. Bozo, and W. Baeyens. 2005. Mercury distribution and speciation in Lake Balaton, Hungary. *Science of the Total Environment*, 340: 231-246.

Nichols, J., S. Bradbury, and J. Swartout. 1999. Derivation of wildlife values for mercury. *Journal of Toxicology and Environmental Health*: 325-355.

NRC. 2000. *Toxicological Effects of Methylmercury*. National Research Council, Committee on the Toxicological Effects of Methylmercury (NRC). Washington, D.C.: National Academy Press. Available at: http://www.nap.edu/books/0309071402/html.

OEHHA. 1994. *Health Advisory on Catching and Eating Fish. Interim Sport fish Advisory for San Francisco Bay.* California Environmental Protection Agency, Office of Environmental Health Hazard Assessment. Berkeley, CA. December 1994.

OEHHA. 1999. *California Sport Fish Consumption Advisories 1999*. Office of Environmental Health Hazard Assessment, California Environmental Protection Agency.

OEHHA. 2000. *Evaluation of Potential Health Effects of Eating Fish from Black Butte Reservoir (Glenn and Tehama Counties): Guidelines for Sport Fish Consumption.* Draft Report. Pesticide and Environmental Toxicology Section, Office of Environmental Health Hazard Assessment, California Environmental Protection Agency. March.

OEHHA. 2006. *Draft Health Advisory for Fish and Shellfish From the Lower Cosumnes and Lower Mokelumne Rivers (Sacramento and San Joaquin Counties).* Office of Environmental Health Hazard Assessment, California Environmental Protection Agency. April. Available at: http://www.oehha.org/fish/so_cal/pdf_zip/FactsDCosMo042806.pdf. Accessed September 2007.

OEHHA. 2007. *Draft Safe Eating Guidelines for Fish From the South Delta and San Joaquin River.* Office of Environmental Health Hazard Assessment, California Environmental

Protection Agency. March. Available at: http://www.oehha.org/fish/pdf/ SJRSDfacts030907.pdf. Accessed September 2007.

Pacyna, E.G. and J.M. Pacyna. 2002. Global emission of mercury from anthropogenic sources in 1995. *Water, Air and Soil Pollution*, 137: 149–165.

Pacyna, E.G., J.M. Pacyna, F. Steenhuisenc and S. Wilson. 2006. Global anthropogenic mercury emission inventory for 2000. *Atmospheric Environment*, 40: 4048-4063.

Paquette, K. and G. Heltz, 1995. Solubility of cinnabar (red HgS) and implications for mercury speciation in sulfidic waters. *Water, Air and Soil Pollution*, 80: 1053-1056.

Parks, J.W. and A.L. Hamilton. 1987. Accelerating recovery of the mercury-contaminated Wabigoon/English River system. *Hydrobiologia*, 149: 159-188.

Parsons, T. and M. Takahashi. 1973. Biological Oceanographic Processes. New York: Pergamon Press, Inc., 186 p.

Peterson, S.A., J. Van Sickle, A.T. Herlihy, and R.M. Hughes. 2007. Mercury concentration in fish from streams and rivers throughout the western United States. *Environmental Science & Technology*, 41(1): 58-65.

Peterson, C., M. Gustin, and S. Lymn. 2009. Atmospheric mercury concentrations and speciation measured from 2004 to 2007 in Reno, Nevada, USA. *Atmospheric Environment*, 43: 4646-4654.

Port of West Sacramento. 2009. Port of West Sacramento Channel-Deepening Funding in President's 2010 Budget. Port of Sacramento Press Release, 26 May 2009. Available at: http://www.cityofwestsacramento.org/civica/inc/displayblobpdf2.asp?BlobID=3985

Prestbo, E.M. and D.A. Gay. 2009. Wet deposition of mercury in the U.S. and Canada, 1996-2005: Results and analysis of the NADP mercury deposition network (MDN). *Atmospheric Environment*, 43: 4223-4233.

Ravichandran, M., G.R. Aiken, J.N. Ryan and M.R. Reddy. 1998. Enhanced Dissolution of Cinnabar (mercuric sulfide) by Dissolved Organic Matter Isolated from the Florida Everglades. *Environmental Science & Technology*, 32: 33305-3311.

Regnell, O. and G. Ewald. 1997. Factors Controlling Temporal Variation in Methyl Mercury Levels in sediment and water in a seasonally stratified lake. *Limnology and Oceanography*, 42(8): 1784-1795.

Regnell, O., T. Hammar, A. Helgée and B. Trodesson. 2001. Effects of anoxia and sulfide on concentrations of total and methylmercury in sediment and water in two Hg-polluted lakes. *Canadian Journal of Fish and Aquatic Sciences*, 58: 506-517.

Regnell, O., A. Tunlid, G. Ewald and O. Sangfors. 1996. Methyl mercury production in freshwater microcosms affected by dissolved oxygen levels: role of cobalamin and microbial community composition. *Canadian Journal of Fish and Aquatic Sciences*, 53: 1535-1545.

Rudd, J.W.M., M.A. Turner, A. Furutani, A.L. Swick and B.E. Townsend. 1983. The English-Wabigoon River system: I. A synthesis of recent research with a view towards mercury amelioration. *Canadian Journal of Fish and Aquatic Sciences*, 40: 2206-2217.

Sanders, R.D., K.H. Coale, G.A. Gill, A.H. Andrews and M. Stephenson. 2008. Recent increase in atmospheric deposition of mercury to California aquatic systems inferred from a 300-year geochronological assessment of lake sediments. *Applied Geochemistry*, 23: 399-407.

Sassone, E.R., W.A. Heim, A. Byington, M. Stephenson, and K.H. Coale. 2004. *Methylmercury export from two experimental ponds on Twitchell Island, California.* Poster Presentation, Northern California Chapter of the Society of Environmental Toxicology and Chemistry (SETAC), Hot Topics in Environmental Toxicology and Chemistry, 14th Annual Meeting, May 11-12, 2004. Davis, CA.

Sassone, E., A. Bonnema, M. Stephenson, W.A. Heim, A. Newman, J. Fleck, and K. Coale. 2008. Task 5.3a Methylmercury Loading Studies in Delta Wetlands – Twitchell Island. Final Report submitted to the CALFED Bay-Delta Program for the project "Transport, Cycling and Fate of Mercury and Monomethylmercury in the San Francisco Delta and Tributaries" Task 5.3a. California Department of Fish and Game Moss Landing Marine Laboratories. Available at: http://mercury.mlml.calstate.edu/reports/reports/

Sassone, E.R., M.D. Stephenson, and K. Coale. 2006. *Methyl Mercury Production in Two California Delta Freshwater Ponds*. Abstract in: Fourth Biennial CALFED Bay-Delta Program Science Conference Abstracts, October 23-25, 2006, Sacramento, CA.

Schaffter, R.G. 1998. Growth of largemouth bass in the Sacramento-San Joaquin Delta. *IEP (Interagency Ecological Program) Newsletter*, 11(3): 27-30.

Schoellhamer, D.H. 1996. Time series of trace element concentrations calculated from time series of suspended solid concentrations and RMP water samples. U.S. Geological Survey, Sacramento. A special study of the San Francisco Estuary Regional Monitoring Program, San Francisco Estuary Institute. September 1996. Available at: http://www.sfei.org/sfeireports.htm.

Schroyer, T. 2003. Meeting with Tom Schroyer (Fisheries Biologist, California Department of Fish and Game, Bay-Delta Division), Janis Cooke (Environmental Scientist, CVRWQCB, Mercury TMDL Unit), and Michelle Wood (Environmental Scientist, CVRWQCB, Mercury TMDL Unit), on 29 April 2003 regarding delta creel surveys and observations of humans' fishing patterns on main and small channels throughout Delta region.

Schuster, P.F., D.P. Krabbenhoft, D.L. Naftz, L.D. Cecil, M.L. Olson, J.F. Dewild, D.D. Susong, J.R. Green and M.L.Abbott. 2002. Atmospheric mercury deposition during the last 270 years: A glacial ice core record of natural and anthropogenic sources. *Environmental Science & Technology*, 36 (11): 231A-232A.

Schwarzbach, S. 2003. Personal communication from S. Schwarzbach (U.S. Geological Survey) to J. Cooke (Environmental Scientist, Central Valley Water Board) regarding presence of clapper rails and brown pelicans as occasional visitors to the Sacramento-San Joaquin River Delta. April 2003.

Schwarzbach, S., L. Thompson and T. Adelsbach. 2001. *An Investigation of Mercury Bioaccumulation in the Upper Cache Creek Watershed, 1997-1998.* USFWS Final Report. U.S. Fish and Wildlife Service, Environmental Contaminants Division, Sacramento Fish and Wildlife Office. Off Refuge Investigations Report FFS #1130 1F22. DEC ID #199710005. July 2001.

SCVWD IMC, 2009. *Santa Clara Valley Water District's Clean, Safe Creeks and Natural Flood Protection Program Independent Oversight Report, Fiscal Year 2007-2008.* Prepared by the Independent Monitoring Committee for the Santa Clara Valley Water District. January. Available at: http://www.valleywater.org/Programs/MonitoringCommittee.aspx

Seigneur, C., K. Vijayaraghavan, K. Lohman, P. Karamchandani, and C. Scott. 2004. Global source attribution for mercury deposition in the United States. *Environmental Science & Technology*, 38 (2): 555-569.

Sellers, C., and C.A. Kelly. 2001. Fluxes of methylmercury to the water column of a drainage lake: The relative importance of internal and external sources. *Limnology and Oceanography,* 46: 623-631.

Sellers, C., C.A. Kelly, and J.W.M. Rudd. 1996. Photodegradation of methylmercury in lakes. *Nature,* 380: 694-697.

Service, R.F. 2004. As the West Goes Dry. *Science,* 303(5661): 1124-1127.

SFBRWQCB, 2006. *Mercury in San Francisco Bay. Adopted Basin Plan Amendment and Final Staff Report for Revised Total Maximum Daily Load (TMDL) and Mercury Water Quality Objectives*. San Francisco Bay Regional Water Quality Control Board, San Francisco. 9 August.

SFBRWQCB. 2008. *Guadalupe River Watershed Mercury Total Maximum Daily Load Project Basin Plan Amendment and Staff Report*. San Francisco Bay Regional Water Quality Control Board, October.

SFEI. 2000. *San Francisco Bay Seafood Consumption Study.* Final Report. San Francisco Estuary Institute. Richmond, CA.

SFEI. 2001. *San Francisco Bay Atmospheric Deposition Pilot Study Part 1: Mercury.* Prepared by the San Francisco Estuary Institute for the San Francisco Estuary Regional Monitoring Program, Oakland, CA. August 2001.

Shilling, F. 2009. *Characterizing High Mercury Exposure Rates of Delta Subsistence Fishers* Environmental Science and Policy and Dept. Human and Community Development, University of California Davis. Report prepared for the Central Valley Regional Water Quality Control Board with data collection funded by the Sacramento Regional County Sanitation District and the California Endowment. May.

Silver, E., J. Kaslow, D. Lee, S. Lee, M.L. Tan, E. Weis, and A. Ujihara. 2007. Fish consumption and advisory awareness among low-income women in California's Sacramento-San Joaquin Delta. *Environmental Research*, 104: 410-419.

SJ/SC. 2007. *San Jose/Santa Clara Water Pollution Control Plant Mercury Fate and Transport Study.* Environmental Services Department, San Jose/Santa Clara (SJ/SC) Water Pollution Control Plant. San Jose, CA. March 2007.

Slotton, D.G. and S.M. Ayers. 2001. Cache Creek Nature Preserve Mercury Monitoring Program, Yolo County, California, Second Semi-Annual Data Report, Spring-Summer 2001, prepared for Yolo County, California. November 2001.

Slotton, D.G., S.M. Ayers, T.H. Suchanek, R.D. Weyland, A.M. Liston, C. Asher, D.C. Nelson, and B. Johnson. 2003. *The Effects of Wetland Restoration on the Production and Bioaccumulation of Methylmercury in the Sacramento-San Joaquin Delta, California.* Final report submitted to the CALFED Bay-Delta Program for the project: An Assessment of the Ecological and Human Health Impacts of Mercury in the Bay-Delta Watershed. University of California, Davis, Dept. of Environmental Science and Policy, Dept. of Wildlife, Fish and Conservation Biology, and Division of Microbiology; U.S. Fish and Wildlife Service, Division of Environmental Contaminants. Available at: http://loer.tamug.tamu.edu/calfed/ DraftReports.htm.

Slotton D.G., S.M. Ayers, T.H. Suchanek, R.D. Weyland, and A.M. Liston. 2004. *Mercury Bioaccumulation and Trophic Transfer in the Cache Creek Watershed, California, in Relation to Diverse Aqueous Mercury Exposure Conditions.* Subtask 5B. Final Report, University of California, Davis, Dept. of Env. Science and Policy and Dept. Wildlife, Fish

and Conservation Biology. Prepared for the CALFED Bay-Delta Program, Directed Action #99-B06. August. Available at: http://mercury.mlml.calstate.edu/.

Slotton, D.G., S.M. Ayers, and R.D. Weyland. 2007. CBDA Biosentinel Mercury Monitoring Program, Second Year Draft Data Report Covering Sampling Conducted February through December 2006. May 29, 2007. Available at: http://www.sfei.org/cmr/fishmercury/DocumentsPage.htm

Sommer, T.R., W.C. Harrell, M. Nobriga, R. Brown, P. Moyle, W. Kimmerer, and L. Schemel. 2001. California's Yolo Bypass: Evidence that flood control can be compatible with fisheries, wetlands, wildlife, and agriculture. *Fisheries*, 26 (8): 6-16.

Southworth, G.R., R.R. Turner, M.J. Peterson, M.A. Bogle and M.G. Ryon. 2000. Response of mercury contamination in fish to decreased aqueous concentrations and loading of inorganic mercury in a small stream. *Environmental Monitoring and Assessment*, 63: 481-494.

SRWP. 2004. Microsoft Access database that compiles Sacramento River Watershed water quality data collected for the Sacramento River Watershed Program. Database provided by Larry Walker Associates (Claus Suverkropp) to Central Valley Regional Water Quality Control Board (Michelle Wood, Environmental Scientist, Sacramento).

St. Louis, V., J. Rudd, C. Kelly, K. Beaty, N. Bloom, and R. Flett. 1994. Importance of wetlands as sources of methyl mercury to boreal forest ecosystems. *Canadian Journal of Fish and Aquatic Sciences*, 51: 1064-1076.

St. Louis, V., J. Rudd, C. Kelly, K. Beaty, R. Flett, and N. Roulet. 1996. Production and loss of methylmercury and loss of total mercury from boreal forest catchments containing different types of wetlands. *Environmental Science & Technology,* 30: 2719-2729.

Steding, D.J. and A.R. Flegal. 2002. Mercury concentrations in coastal California precipitation: Evidence of local and trans-Pacific fluxes of mercury to North America. *Journal of Geophysical Research – Atmospheres*, 107 (D24): 4764.

Stephenson, M. 2009. Presentation at the Delta Methylmercury TMDL/BPA NonPoint Source Workgroup Meeting, 16 November.

Stephenson, M. and A. Bonnema. 2008. *Methylmercury Loss in the Delta Through Particulate Deposition.* Final Report submitted to the CALFED Bay-Delta Program for the project "Transport, Cycling and Fate of Mercury and Monomethylmercury in the San Francisco Delta and Tributaries" Task 5.3a. California Department of Fish and Game Moss Landing Marine Laboratories. Available at: http://mercury.mlml.calstate.edu/reports/reports/

Stephenson, M., A. Bonnema, W. Heim and K. Coale. 2008a. *Methylmercury Loading Studies in Delta Wetlands – Grizzly Island*. Final Report submitted to the CALFED Bay-Delta Program for the project "Transport, Cycling and Fate of Mercury and Monomethylmercury in the San Francisco Delta and Tributaries" Task 5.3a. California Department of Fish and Game Moss Landing Marine Laboratories. Available at: http://mercury.mlml.calstate.edu/reports/reports/

Stephenson, M., A. Bonnema, A. Byington, W. Heim, and K. Coale. 2008b. *Delta Transects and Cross Channel Studies: Estimating MMHg Loss in the Delta using the RMA Particle Tracking Model.* Final Report submitted to the CALFED Bay-Delta Program for the project "Transport, Cycling and Fate of Mercury and Monomethylmercury in the San Francisco Delta and Tributaries" Task 5.2. California Department of Fish and Game Moss Landing Marine Laboratories. Available at: http://mercury.mlml.calstate.edu/reports/reports/

Stephenson, M.D., K. Coale, G. Gill, C.S. Enright, and J.R. Burau. 2006. *Methyl Mercury Import/Exports in Wetlands in the San Francisco Delta and Tributaries - A Mass Balance Assessment Approach.* Abstract in: Fourth Biennial CALFED Bay-Delta Program Science Conference Abstracts, October 23-25, 2006, Sacramento, CA.

Stephenson, M., C. Foe, G.A. Gill, and K.H. Coale. 2007. T*ransport, Cycling, and Fate of Mercury and Monomethyl Mercury in the San Francisco Delta and Tributaries: An Integrated Mass Balance Assessment Approach*. CalFed Mercury Project Annual Report. April 2, 2007.

Stephenson, M, C. Foe, G.A. Gill, and K. H. Coale. 2008c. *Transport, Cycling and Fate of Mercury and Monomethylmercury in the San Francisco Delta and Tributaries: An Integrated Mass Balance Assessment Approach*. CALFED Mercury Project Final Report. September. All chapters of the report are available as separate links at: http://mercury.mlml.calstate.edu/reports/reports/

Stephenson, M., B. Sohst, and S. Mundell. 2002. *Mercury Lagrangian Study Between Colusa and Hamilton City*. Draft final report prepared for the Sacramento Regional County Sanitation District. Marine Pollution Studies Labs, California Department of Fish and Game, and Moss Landing Marine Labs. January 2002.

Stewart, I.T., D.R. Cayan, and M.D. Dettinger. 2004. Changes in Snowmelt Runoff Timing in Western North America Under a 'Business as Usual' Climate Change Scenario. *Climatic Change,* 62: 217-232, 2004.

Storer, R.W., and G.L. Nuechterlein. 1992. Western Grebe and Clark's Grebe. *The Birds of North America*, 26: 1-15

Stratton, J.W., D.F. Smith, A.M. Fan, and S.A. Book. 1987. *Methyl Mercury in Northern Coastal Mountain Lakes: Guidelines for Sport Fish Consumption for Clear Lake (Lake County), Lake Berryessa (Napa County), and Lake Herman (Solano County).* State of California Department of Health Services, Hazard Evaluation Section and the Epidemiological Studies and Surveillance Section, Community Toxicology Unit, Office of Environmental Health Hazard Assessment. Berkley, CA. Fish Advisory Report. April 1987. Available at: http://www.oehha.ca.gov/fish/pdf/CLEARLAKEREPORT.pdf

Suits, B. 2000. Delta Island Consumptive Use Model Delta-wide island consumptive use estimates for October 1998 through September 1999. Provided by Bob Suits (Department of Water Resources, suits@water.ca.gov) to Chris Foe (Central Valley Water Board) *via* email on 7 November 2000.

Sveinsdottir, A.Y. and R.P. Mason. 2005. Factors controlling mercury and methylmercury concentrations in largemouth bass (*Micropterus salmoides*) and other fish from Maryland reservoirs. *Archives of Environmental Contamination and Toxicology*, 49: 528–545.

Sweet, C. 2000. Personal communication between Clyde Sweet (National Atmospheric Deposition Program, Associate Coordinator for Toxics) and Janis Cooke (Central Valley Water Board) regarding use of the Mercury Deposition Network data to estimate total atmospheric deposition of mercury to a lake near Covelo, CA. Additional information available at: http://nadp.sws.uiuc.edu/mdn/.

SWRCB. 1995. Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary. 95-1WR. Sacramento, California. 45 p.

SWRCB. 2007. *State Water Resources Control Board Resolution No. 2007-0045 Approving an Amendment to the Water Quality Control Plan for the San Francisco Bay Region to Establish Mercury Fish Tissue Objectives, Vacate a Mercury Water Quality Objective, and*

Establish a Total Maximum Daily Load (TMDL) for Mercury in San Francisco Bay. Sacramento, 17 July.

SWRCB-DWQ. 1990. *1990 Water Quality Assessment*. April 4, 1990. State Water Resources Control Board, Division of Water Quality (SWRCB-DWQ). Sacramento, California. 89 p.

SWRCB-DWQ. 2002. Toxic Substances Monitoring Program: Freshwater Bioaccumulation Monitoring Program: Data Base. State Water Resources Control Board, Division of Water Quality. Available at: http://www.waterboards.ca.gov/programs/smw/index.html

SWRCB-DWQ. 2003. *Revision of the Clean Water Act Section 303(d) List of Water Quality Limited Segments, Final Staff Report, Volume I.* State Water Resources Control Board, Division of Water Quality (SWRCB-DWQ). February 2003.

SWRCB-DWQ. 2006. Revision of the Clean Water Act Section 303(d) List of Water Quality Limited Segments. State Water Resources Control Board (SWRCB) Division of Water Quality (DWQ) final staff report, November 2006. Volume III, pp. 140-141, provides the rationale for the delineation of Delta water body segments in different "portions". Available at: http://www.waterboards.ca.gov/water_issues/programs/tmdl/303d_lists2006.shtml

Takizawa, Y. 2000. Minamata disease in retrospect. *World Resource Review*, 12(2): 211-223.

Tetra Tech, Inc. 2005a. *Guadalupe River Watershed Mercury TMDL Project Final Conceptual Model Report.* Prepared by Tetra Tech, Inc., Research and Development, Lafayette, CA. Prepared for San Francisco Bay Regional Water Quality Control Board. 20 May 2005. 160 p.

Tetra Tech, Inc. 2005b. *Sacramento River Flood Control System*. Map prepared by Tetra Tech, Inc., based on November 2003 Department of Water Resources (DWR) maps of levees maintained by DWR, reclamation, levee, and drainage districts and municipalities. Map included in the administrative record for the Sacramento River Watershed Model completed in spring 2005.

Tetra Tech, Inc. 2006. *Technical Review of Delta Mercury TMDL.* Prepared for the Delta Mercury TMDL Collaborative. Lafayette, CA. 12 December.

TNRA. 2009. California Climate Adaptation Strategy, A Report to the Governor of the State of California in Response to Executive Order S-13-2008. The Natural Resources Agency (TNRA). Available: http://www.climatechange.ca.gov/adaptation/. Accessed: December 7, 2009.

Turner, M. 2009. Wetland habitat to be created in southern Sacramento County. *Sacramento Business Journal*, 9 October 2009. Available at: http://sacramento.bizjournals.com/sacramento/stories/2009/10/12/story10.html?surround=etf&ana=e_article

Turner, R.R. and G.R. Southworth. 1999. Mercury-contaminated industrial and mining sites in North America: an overview with selected case studies. *In*: Mercury Contaminated Sites: Characterization, Risk Assessment, and Remediation. R. Ebinghaus, R.R. Turner, L.D. de Lacerda, O. Vasiliev and W. Salomons (editors). SpringerVerlag: Heidelberg, pp. 89-108.

Ujihara, A. 2006. Personal communications between Alyce Ujihara (Research Scientist, California Department of Health Services Environmental Health Investigations Branch) and Janis Cooke (Environmental Scientist, Central Valley Water Board) regarding results of the Delta-San Joaquin River Pilot Angler Survey Oct-Nov 2005 and other public outreach information. January-June.

USACE. 2002. “Moisture Content,” personal communication from L. Fade, U.S. Army Corps of Engineers (USACE) to G. Collins, San Francisco Bay Regional Water Quality Control Board, October, as cited in Johnson and Looker, 2004.

USEPA. 1987. Integrated Risk Information System. U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment. Washington, D.C. January 31, 1987. (First File-On-Line) Available at: http://www.epa.gov/iris/subst/0073.htm . Last revised: July 27, 2001. Accessed: June 27, 2005.

USEPA. 1995a. *Great Lakes Water Quality Initiative Technical Support Document for Wildlife Criteria.* U.S. Environmental Protection Agency, Office of Water. EPA-820-B-95-009. March 1995.

USEPA. 1995b. Trophic Level and Exposure Analyses for Selected Piscivorous Birds and Mammals, Volume II: Analyses of Species in the Coterminous United States. Washington, D.C., Environmental Protection Agency, Office of Water.

USEPA. 1995c. Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories. Volume 1: Fish Sampling and Analysis. Second Edition. Washington, D.C., U.S. Environmental Protection Agency (USEPA), Office of Water and Office of Science and Technology. EPA-823-R-95-007.

USEPA. 1997a. *Mercury Study Report to Congress Vol. 6: An Ecological Assessment for Anthropogenic Mercury Emissions in the United States.* U.S. Environmental Protection Agency (USEPA), Office of Air Quality Planning and Standards and Office of Research and Development, Washington, D.C. EPA-452/R-97-008.

USEPA. 1997b. *Mercury Study Report to Congress Vol. 7: Characterization of Human Health and Wildlife Risks from Mercury Exposure in the United States.* U.S. Environmental Protection Agency (USEPA), Office of Air Quality Planning and Standards and Office of Research and Development.

USEPA. 2000a. *Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (2000).* Office of Science and Technology, Office of Water. Washington, D.C. EPA-822-B-00-004. October.

USEPA. 2000b. *Water Quality Standards; Establishment of Numeric Criteria for Priority Toxic Pollutants for the State of California; Rule.* U.S. Environmental Protection Agency (USEPA). Code of Federal Regulations, Title 40, Part 131, Section 38. In *Federal Register*: May 18, 2000 (Volume 65, No. 97), Rules and Regulations, pp. 31681-31719.

USEPA. 2001*. Water Quality Criterion for Protection of Human Health: Methylmercury*. U.S. Environmental Protection Agency, Office of Science and Technology (USEPA). EPA-823-R-01-001. January 2001.

USEPA. 2002. Establishing Total Maximum Daily Load (TMDL) Wasteload Allocations (WLAs) for Storm Water Sources and NPDES Permit Requirements Based on Those WLAs. Memorandum from Robert H. Wayland, III (Director, Office of Wetlands, Oceans and Watersheds) and James A. Hanlon (Director, Office of Wastewater Management) to Water Division Directors, Regions 1 – 10, 22 November 2002. Available at: http://www.epa.gov/owow/tmdl/stormwater/

USEPA. 2003. Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (2000), Technical Support Document Volume 2: Development of National Bioaccumulation Factors. U.S. Environmental Protection Agency (USEPA), Office of Water and Office of Science and Technology. EPA-822-R-03-030. December 2003.

USEPA. 2006. Establishing TMDL "Daily" Loads in Light of the Decision by the U.S. Court of Appeals for the D.C. Circuit in Friends of the Earth, Inc. v. EPA, et al., No. 05-5015, (April 25, 2006) and Implications for NPDES Permits. Memorandum from Benjamin H. Grumbles (Assistant Administrator) to the Directors of the Office of Ecosystem Protection (Region 1), Division of Environmental Planning and Protection (Region 2), Water Divisions (Regions 3-7 and 9), Office of Ecosystems Protection and Remediation (Region 8), and Office of Environmental Cleanup (Region 10). November 15, 2006. Available at: http://www.epa.gov/owow/tmdl/dailyloadsguidance.html.

USEPA OTAQ. 2007. Mobile Source Emissions – Past, Present, and Future. Glossary. USEPA Office of Transportation and Air Quality (OTAQ). Webpage last updated: 9 July 2007. Accessed: 4 January 2009. Available at: http://www.epa.gov/OMS/invntory/overview/definitions.htm.

USFWS. 2002. *Comments on the Clear Lake Total Maximum Daily Load (TMDL) for Mercury – Draft Final Report.* Letter from Michael B. Hoover, Acting Assistant Field Supervisor, U.S. Fish and Wildlife Service (USFWS), to Janis Cooke, Environmental Scientist, Central Valley Regional Water Quality Control Board (FWS/EC-02-026). 8 April 2002.

USFWS. 2003. *Evaluation of the Clean Water Act Section 304(a) Human Health Criterion for Methylmercury: Protectiveness for Threatened and Endangered Wildlife in California.* U.S. Fish and Wildlife Service, Sacramento Fish and Wildlife Office, Environmental Contaminants Division. October 2003. Available at: http://www.fws.gov/sacramento/ec/Methylmercury%20Criterion%20Evaluation%20Final%20Report%20October%202003.pdf

USFWS. 2004. *Evaluation of Numeric Wildlife Targets for Methylmercury in the Development of Total Maximum Daily Loads for the Cache Creek and Sacramento-San Joaquin Delta Watersheds.* U.S. Fish and Wildlife Service, Sacramento Fish and Wildlife Office, Environmental Contaminants Division. March 2004.

USFWS. *2006. Classification of Wetlands and Deepwater Habitats of the United States.* WETDBA.CONUS_wet_poly.shp [GIS shapefile]. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. Available: http://wetlandsfws.er.usgs.gov/imf/imf.jsp?site=extract_tool. Using: ArcGIS [GIS software], Version 9.2, Redlands, CA: Environmental Systems Research Institute, Inc., 1999-2006.

USGS. 2003. Microsoft Excel Spreadsheets of unpublished data for Bear River Mercury Cycling Project. Data provided by USGS (Charlie Alpers, Research Chemist) to Central Valley Regional Water Quality Control Board (Michelle Wood, Environmental Scientist, Sacramento).

Verdon, R., D. Brouard, C. Demers, R. Lalumiere, M. Laperle and R. Schetagne. 1991. Mercury evolution (1978-1988) in fishes of the La Grande Hydroelectric Complex, Quebec, Canada. *Water, Air, and Soil Pollution*, 56: 405-417.

Wallschläger, D., M.V.M. Desai, M. Spengler and R.D. Wilken. 1998. Mercury speciation in floodplain soils and sediments along a contaminated river transect. *J. Environmental Quality*, 27:1034-1044.

Wang, Q., W. Shen and Z. Ma. 2000. Estimation of mercury emission from coal combustion in China. *Environmental Science & Technology*, 34: 2711-2713.

Weast, R. (editor). 1981. *CRC Handbook of Chemistry and Physics*. Second Edition. Boca Raton, FL: CRC Press, Inc, pp. B-205 and B-206.

Weir, W.W. 1952. *Soils of San Joaquin County, California.* California Soil Survey, Inventory of Soil Resources. University of California, College of Agriculture, Agricultural Experiment Station, Berkeley 4, California. June 1952.

Weiss-Penzias, P., D. Jaffe, P. Swartzendruber, W. Hafner, D. Chanda and E. Prestbo. 2007. Quantifying Asian and biomass burning sources of mercury using the Hg/CO ratio in pollution plumes observed at the Mount Bachelor observatory. Atmospheric Environment, 41: 4366-4379.

Whalin, L., E-H. Kim and R. Mason. Factors influencing the oxidation, reduction, methylation and demethylation of mercury species in coastal waters. *Marine Chemistry*, 107: 278-294.

Wiener, J.G., C.C. Gilmour and D.P. Krabbenhoft. 2003a. *Mercury Strategy for the Bay-Delta Ecosystem: A Unifying Framework for Science, Adaptive Management, and Ecological Restoration.* Final Report to the California Bay Delta Authority for Contract 4600001642 between the Association of Bay Area Governments and the University of Wisconsin-La Crosse, 31 December 2003.

Wiener, J.G., Krabbenhoft, D.P. Heinz, G.H., and Scheuhammer, A.M. 2003b. Ecotoxicology of Mercury, Chapter 16. *In* Handbook of Ecotoxicology, 2nd Edition. D.J. Hoffman, B.A. Rattner, G.A. Burton, Jr., and J. Cairns, Jr. (editors). Boca Raton, Florida: CRC Press, pp. 409-463.

Wiener, J.G. and D.J. Spry. 1996. Toxicological Significance of Mercury in Freshwater Fish (Chapter 13). *In*: Environmental Contaminants in Wildlife: Interpreting Tissue Concentrations. SETAC Special Publication. W.N. Beyer, G.H. Heinz and A.W. Redmon-Norwood. Boca Raton: CRC Press, Inc, pp. 297-339.

Willits, N. 2005-2006. Statistical consultation provided by Neil Willits, Ph. D. (Senior Statistician, University of California, Davis, Department of Statistics, Statistical Laboratory) to Greg Marquis (Engineering Geologist, Central Valley Water Board), to develop a method to calculate confidence limits for annual average mercury mass loading estimates based on daily flows and concentration data. E-mail communications with attached example calculation files, November 2005 through February 2006.

Wolfe, M.F., S. Schwarzbach and R.A. Sulaiman. 1998. Effects of mercury on wildlife: A comprehensive review. *Environmental Toxicology and Chemistry*, 17:146-60.

Wright, S.A. and D.H. Schoellhamer. 2004. Trends in the sediment yield of the Sacramento River, California, 1957-2001. *San Francisco Estuary and Watershed Science* [online serial], May 2004 issue, Article 2. Available at: http://repositories.cdlib.org/jmie/sfews/vol2/iss2/art2

Wright, S.A. and D.H. Schoellhamer. 2005. Estimating sediment budgets at the interface between rivers and estuaries with application to the Sacramento – San Joaquin River Delta. Pre-publication manuscript. May 2005. 53 p.