D AVAILABLE AQUEOUS METHYLMERCURY DATA AND POOLED VALUES USED IN DELTA LINKAGE & ALTERNATE BAF-BASED LINKAGE APPROACH

Section D.1 provides tables of methylmercury data, statistical summaries and regressions used in the Delta linkage analysis. Section D.2 describes an alternate approach to the linkage analysis using site-specific BAFs.

D. 1 Tables of Methylmercury Data, Statistical Summaries and Regressions Used in the Delta Linkage Analysis

Table D.1: Summary of Available Raw (Unfiltered) Methylmercury Data (ng/l) (a)

Sample Date	Data Source	Delta Mendota Canal	Mokelumne River @ I-5	Sacramento River @ Freeport	Sacramento River @ Greene's Landing	Sacramento River @ RM44	San Joaquin River @ Vernalis	State Water Project	X2
03/28-29/00	A	0.153	0.171		0.148		0.164	0.139	0.204
04/24/00	A	< 0.022	0.28		0.117		0.147	0.0469	0.0819
05/30/00	A	0.171	0.25		0.336		0.134	0.144	0.241
06/26/00	A	0.0737	0.114		0.0716		0.22	< 0.022	0.109
07/18/00	B			0.06					
07/19/00	A	< 0.022	< 0.022		0.052		0.118	< 0.022	< 0.022
07/21/00	C				0.052 (b)				
08/16/00	B			0.078					
08/21/00	A	< 0.022	0.154		0.11		0.14	< 0.022	< 0.022
09/21/00	C				0.063				
09/26/00	A	< 0.022	< 0.022		0.0514		0.0986	0.0581	0.0233
10/19/00	C				0.071				
10/28-29/00	A	< 0.022	0.13		0.08515 (FD: 0.0847 & 0.0856)		0.158	< 0.022	< 0.022
11/07/00	B			0.127		0.136			
11/08/00	C				0.099				
12/18/00	A	0.0628	0.0955		0.08905		0.102	0.0501	0.0595
12/19/00	B			0.108		0.13			
01/17/01	B, C			0.122	0.095	0.119			
01/28-29/01	A	0.144	0.246		0.244 (FD: 0.24 & 0.248)		0.239	0.113	0.0945
02/21/01	B, C			0.118	0.077	0.123			
02/26/01	A		0.32		0.1765		0.18	0.0767	0.165
03/20/01	B			0.168		0.141			
03/21/01	C				0.097				
03/25-26/01	A	0.0924	0.185		0.08405 (FD: 0.0825 & 0.0856)		0.178	0.0551	
04/11/01	D				0.07				
04/17/01	B			0.058		0.077			
04/18/01	C				0.076				
04/26/01	D				0.097				
04/29/01	A	0.024	0.201		0.113		0.0934	0.0584	< 0.014
05/15/01	B, D			0.122	0.116	0.153			

Table D.1: Summary of Available Raw (Unfiltered) Methylmercury Data (ng/l) (a)

Sample Date	Data Source	Delta Mendota Canal	Mokelumne River @ I-5	Sacramento River @ Freeport	Sacramento River @ Greene's Landing	Sacramento River @ RM44	San Joaquin River @ Vernalis	State Water Project	X2
05/16/01	D				0.164				
05/17/01	C				0.141 (FD: 0.136 & 0.146)				
05/27-28/01	A	0.0555	0.178		0.0986		0.122	0.0503	0.0409
05/29/01	D				0.09				
06/06/01	D				< 0.02				
06/14/01	D				0.122				
06/19/01	B			0.089		0.18			
06/25-26/01	A	0.0607	0.208		0.0878		0.256		0.0369
06/28/01	D				0.0878				
07/17/01	B			0.111		0.101			
07/30-31/01	A	0.0645	0.167		0.108		0.147	0.0213	0.0701
08/14/01	B			0.091		0.097			
08/27/01	A	0.0317	0.065		0.0712		0.194	< 0.014	0.0541
09/19/01	B			0.073		0.098			
10/01/01	A	< 0.014	0.184		0.0953		0.163	0.0321	< 0.014
10/17/01	B			0.072		0.069			
11/14/01	B			0.179		0.143			
12/19/01	B			0.154		0.172			
01/16/02	B			0.202		0.196			
02/05/02	B			0.13					
02/06/02	B					0.083			
03/06/02	B			0.05		0.062			
04/03/02	B			0.052		0.067			
05/08/02	B			0.092		0.107			
06/05/02	B			0.064		0.101			
07/10/02	B			0.144		0.135			
08/07/02	B			0.111		0.108			
09/04/02	B			0.068		0.077			
10/02/02	B			0.081		0.095			
11/06/02	B			0.062		0.076			
12/04/02	B			0.103		0.117			
01/08/03	B			0.111		0.14			
02/05/03	B			0.242		0.251			
02/16/03	B			0.094					
03/05/03	B			0.086		0.081			
03/15/03	B			0.066					
03/18/03	E				0.1687 (FD&LR: 0.168, 0.158, & 0.180)				
04/02/03	B			0.089		0.094			
04/15/03	E						0.122 (FD: 0.112 & 0.132)		
04/21/03	E				0.1115 (FD: 0.1 & 0.123)				

Table D.1: Summary of Available Raw (Unfiltered) Methylmercury Data (ng/l) (a)

Sample Date	Data Source	Delta Mendota Canal	Mokelumne River @ I-5	Sacramento River @ Freeport	Sacramento River @ Greene's Landing	Sacramento River @ RM44	San Joaquin River @ Vernalis	State Water Project	X2
04/28/03	E		0.2605 (LR: 0.278 & 0.243)		0.146		0.105		0.093
05/07/03	B			0.12		0.133			
05/13/03	E						0.122		
05/20/03	E				0.1002 (LR: 0.0993 & 0.101)				
05/27/03	E	0.0555	0.0925		0.0824		0.133		0.0759
06/10/03	E						0.126 (FD&LR: 0.126, 0.143, & 0.109)		
06/11/03	B			0.1		0.096			
06/18/03	E				0.0366				
06/30/03	E	0.0788					0.178	0.0291 (FD&LR: 0.0345, 0.0272 & 0.0256)	0.0856
07/01/03	E		< 0.0228		0.0233				
07/08/03	E						0.1845 (FD: 0.205 & 0.164)		
07/28/03	E	0.0932	0.076		0.0661 (FD: 0.0661 & 0.0924)		0.212	0.0284	0.0697
09/09/03	E						0.137 (FD: 0.134 & 0.140)		
09/17/03	E				0.0716				
09/29/03	E	0.0883					0.181	0.058	0.098
09/30/03	E		0.103		0.0632				
02/19/04	E				0.242				
02/26/04							0.17 (FD: 0.0642 & 0.0723)		
02/29/04					0.126 (FD: 0.132 & 0.12)				
03/24/04					0.122 (FD: 0.118 & 0.126)				
03/29/04							0.165		
04/12/04							0.135		
04/28/04					0.0956				

(a) Data sources: A – Foe, 2002; B – CMP, 2003; C – SRWP, 2003; D – RWQCB, 2004. FD: Average of field duplicates. LR: Average of laboratory replicates.

(b) Regional Board staff collected a sample at Greene's Landing on 19 September 2000 with a value of 0.052 ng/l. Coincidently, the SRWP program also collected a sample at Greene's Landing on 21 September 2000 with a value of 0.052 ng/l.

Table D.2: Monthly Average Methylmercury Concentrations (ng/l) for March 2000 to October 2000 Period Used to Calculate Average and Median Methylmercury Concentrations for Each Delta Subregion.

Month (a)	**Sacramento River**		**San Joaquin River**		**Mokelumne River**		**Central Delta**		**Western Delta**	
	Average Conc.	# of Samples	Average Conc.	# of Samples	Average Conc.	# of Samples	Average Conc.	# of Samples	Average Conc.	# of Samples
March	0.148	1	0.164	1	0.171	1	0.146	2	0.204	1
April	0.117	1	0.147	1	0.280	1	0.029*	2	0.082	1
May	0.336	1	0.134	1	0.250	1	0.158*	2	0.241	1
June	0.072	1	0.220	1	0.114	1	0.042	2	0.109	1
July	0.055	3	0.118	1	0.011*	1	0.011*	2	0.011*	1
Aug.	0.094	2	0.140	1	0.154	1	0.011*	2	0.011*	1
Sept.	0.057	2	0.099	1	0.011*	1	0.035*	2	0.023	1
Oct.	0.078	2	0.158	1	0.130	1	0.011*	2	0.011*	1
Average	0.120	13	0.147	8	0.140	8	0.055	16	0.087	8
Median	0.086		0.144		0.142		0.032		0.053	

(a) Monthly averages are the mean of all data collected during a given month. The Central Delta subregion includes data collected at the Delta Mendota Canal and State Water Project. The Sacramento subregion includes data collected at Freeport, River Mile 44 and Greene's Landing. The raw data are listed in Table D.1. Values with an asterisk were calculated from a water concentration that was below detection. Half the detection limit was used in the calculations.

Table D.3: Monthly Average Methylmercury Concentrations (ng/l) for March 2000 to April 2004 Period Used to Calculate Annual Average and Median Methylmercury Concentrations for Each Delta Subregion.

Month	Sacramento River		San Joaquin River		Mokelumne River		Central Delta		West Delta	
	Ave. Conc.	# of Samples	Ave. Conc.	# of Samples	Ave. Conc.	# of Samples	Ave. Conc.	# of Samples	Ave. Conc.	# of Samples
January	0.15	8	0.24	1	0.25	1	0.13	2	0.09	1
February	0.15	11	0.18	2	0.32	1	0.08	1	0.17	1
March	0.11	12	0.17	3	0.18	2	0.11	4	0.20	1
April	0.09	14	0.12	5	0.25	3	0.04	4	0.06	3
May	0.13	14	0.13	4	0.17	3	0.10	5	0.12	3
June	0.09	12	0.20	4	0.16	2	0.05	5	0.08	3
July	0.09	10	0.17	4	0.07	4	0.04	6	0.05	3
August	0.10	7	0.17	2	0.11	2	0.02	4	0.03	2
September	0.07	9	0.14	4	0.10	3	0.04	6	0.04	3
October	0.08	6	0.16	1	0.13	1	0.01	2	0.01	1
November	0.12	7								
December	0.12	7	0.10	1	0.10	1	0.06	2	0.06	1
Annual Average	0.11	117	0.16	31	0.17	23	0.06	41	0.08	22
Annual Median	0.10		0.17		0.16		0.05		0.06	

(a) Monthly averages are the mean of all data collected during a given month. The Central Delta subregion includes data collected at the Delta Mendota Canal and State Water Project. The Sacramento subregion includes data collected at Freeport, River Mile 44 and Greene's Landing. The raw data are listed in Table D.1. Values with an asterisk were calculated using one or more samples with concentrations below detection. Refer to Table D.1 for detections limits associated with each non-detect value.

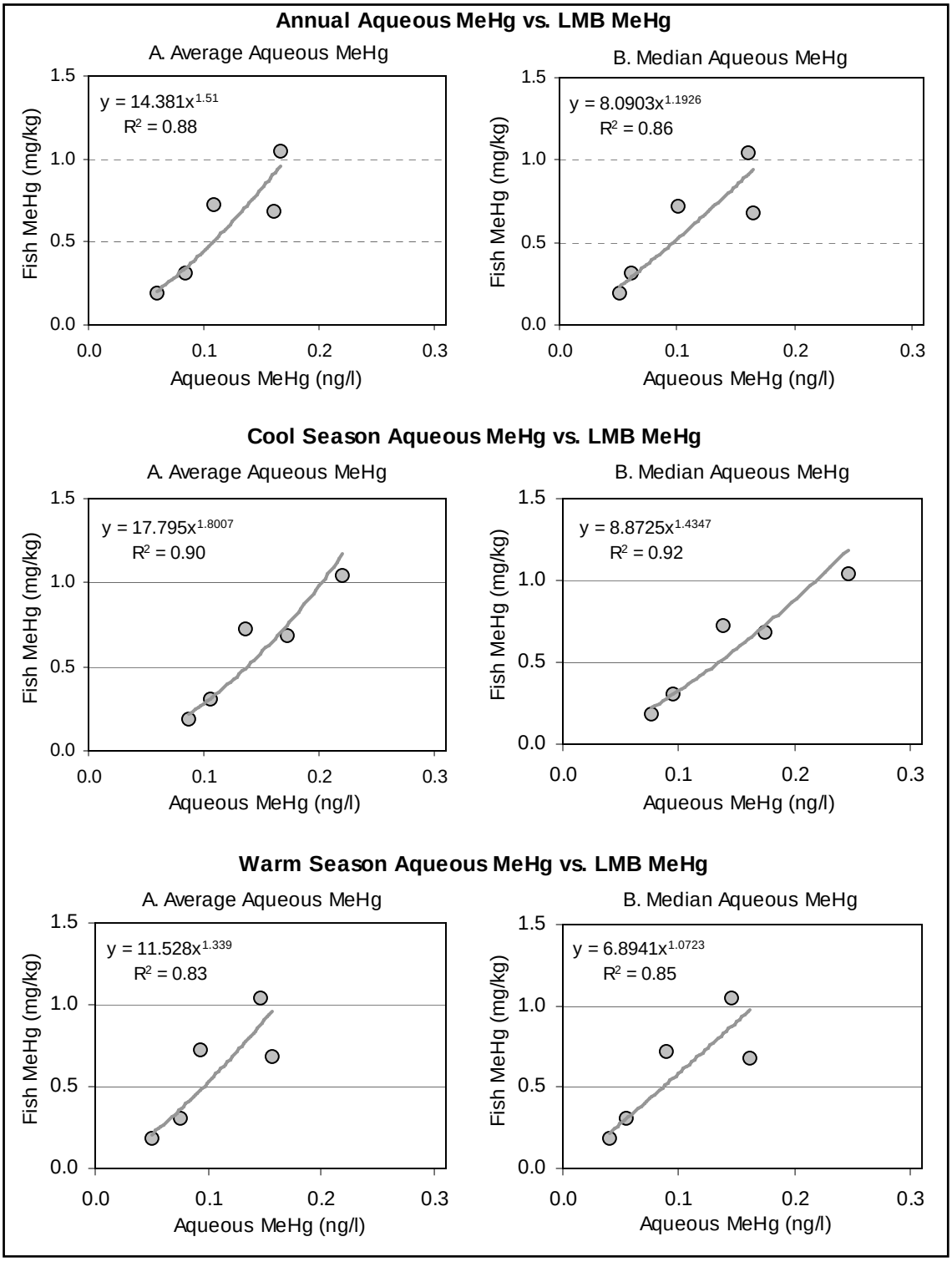

Figure D.1: Relationships between Standardized 350-mm Largemouth Bass Mercury Levels & March 2000 to April 2004 Aqueous Methylmercury.

The warm and cool seasons are defined as March to October and November to February, respectively.

Table D.5: Monthly Average Filtered Methylmercury Concentrations (ng/l) for March 2000 to October 2000 Used to Calculate Annual Average and Median Filtered Methylmercury Concentrations for Each Delta Subarea.

Month (a)	**Sacramento River**		**San Joaquin River**		**Mokelumne River**		**Central Delta**		**Western Delta**	
	Average Conc.	# of Samples	Average Conc.	# of Samples	Average Conc.	# of Samples	Average Conc.	# of Samples	Average Conc.	# of Samples
March	0.039	1	0.051	1	0.074	1	0.077	2	0.058	1
April	0.011*	1	0.036	1	0.165	1	0.016*	2	0.011*	1
May	0.074	1	0.071	1	0.146	1	0.073	2	0.011*	1
June	0.042	1	- - -	0	0.057	1	0.024*	2	0.031	1
July	0.022	1	0.011*	1	0.011*	1	0.011*	2	0.011*	1
August	0.090	1	0.011*	1	0.098	1	0.011*	2	0.011*	1
September	0.039	2	0.033	1	0.011*	1	0.011*	2	0.011*	1
October	0.030*	4	0.042	1	0.063	1	0.011*	2	0.011*	1
Average	**0.043**	**12**	**0.037**	**7**	**0.078**	**8**	**0.029**	**16**	**0.019**	**8**
Median	**0.039**		**0.036**		**0.069**		**0.014**		**0.011**	

(b) Monthly averages are the mean of all data collected during a given month. The Central Delta subarea includes data collected at the Delta Mendota Canal and State Water Project. The Sacramento subarea includes data collected at Freeport, River Mile 44 and Greene's Landing. The raw data are provided in Table D.4. Values noted with an asterisk were calculated using one or more water concentrations that were below detection. Half the detection limit was used in the calculations.

D.2 Alternate BAF-Based Linkage Approach

The linkage method recommended by Central Valley Water Board staff and described in Chapter 5 is based on the statistically significant relationship between standard 350-mm largemouth bass and average water methylmercury concentrations. A second approach that does not rely on the correlation between largemouth bass and water methylmercury concentrations to derive an implementation goal for water makes use of the total bioaccumulation factor (BAF), an approach used in numerous USEPA-approved TMDLs across the country.[2] A BAF is the ratio of the concentration of a chemical in fish tissue to the concentration of the chemical in the water column. As defined in Mercury Study Report to Congress (USEPA, 1997), the BAF is the concentration of the methylmercury in fish divided by the concentration of dissolved methylmercury in water. According to USEPA's 2003 technical support document for the development of national bioaccumulation factors, a total BAF based on the total concentration of a chemical in water also can be used. By definition, BAFs imply a linear relationship between methylmercury in the water column and in fish.

Table D.4 lists the BAFs and safe aqueous methylmercury levels calculated for each Delta subarea and a Delta-wide BAF using standard 350 mm largemouth bass, average unfiltered water methylmercury values, and the following equations. Table D.5 lists BAFs and safe water methylmercury levels based on filtered water data.

Equation 5.1a:

$$BAF = LMB_{MeHgconc} \div Water_{MeHgconc}$$

Where: $Water_{MeHgconc}$ = Water column concentration of unfiltered MMHg (µg/L)

$LMB_{MeHgconc}$ = 350-mm LMB tissue concentration (µg/kg)

Equation 5.b:

$$\text{Safe Level for Water} = LMB_{MeHg\ Proposed}\ \text{Goal} \div BAF$$

Where: $LMB_{MeHgconc}$ = Proposed implementation goal for 350-mm LMB (µg/kg)

Using "Delta-wide" values from Table 5.3 as an example:

$$BAF = (0.59\ \text{mg/kg} \times 1000) \div (0.110\ \text{ng/l} \div 1000)$$
$$= 5.35 \times 10^6$$

$$\text{Safe Level for Water} = (0.180 \div 5.35 \times 10^6) \div 10^6$$
$$= 0.034\ \text{ng/l}$$

The safe aqueous methylmercury concentrations produced by the BAF method are slightly less than but comparable to the safe levels produced using the regression-based approach. This similarity most likely occurs because both methods used the same data, and because the regressions are nearly linear at low fish and water methylmercury levels. However, the regression-based method is preferred because it does not inherently assume a linear relationship between fish and water methylmercury levels.

[2] Refer to: http://www.epa.gov/OWOW/tmdl/index.html.

Table D.4: Delta BAFs and Corresponding Safe Methylmercury Levels in Water Calculated Using Unfiltered Water

	Delta Subarea					Delta-Wide (a)
	Sacramento River	Mokelumne River	Central Delta	San Joaquin River	West Delta	
Standardized 350-mm Largemouth Bass MeHg (mg/kg)	0.72	1.04	0.19	0.68	0.31	0.59
March-October 2000 Average MeHg in Unfiltered Water (ng/l)	0.120	0.140	0.055	0.147	0.087	0.110
BAF	6.00×10^6	7.43×10^6	3.45×10^6	4.63×10^6	3.56×10^6	5.35×10^6
Safe Methylmercury Concentration in Water (b)	0.030	0.024	0.052	0.039	0.051	0.034

(c) Delta-wide largemouth bass and water methylmercury concentrations were estimated by averaging the subarea values. The Delta-wide BAF and safe water concentration were calculated using the Delta-wide largemouth bass and water values.
(d) Safe levels in water correspond to the proposed implementation goal of 0.18 mg/kg methylmercury in standard 350-mm largemouth bass.

Table D.5: Delta BAFs and Corresponding Safe Methylmercury Levels in Water Calculated Using Filtered Water Data

	Delta Subarea					Delta-Wide (a)
	Sacramento River	Mokelumne River	Central Delta	San Joaquin River	West Delta	
Standardized 350-mm Largemouth Bass MeHg (mg/kg)	0.72	1.04	0.19	0.68	0.31	0.59
March-October 2000 Average MeHg in Filtered Water (ng/l)	0.043	0.078	0.029	0.037	0.019	0.041
BAF	1.67×10^7	1.33×10^7	6.55×10^7	1.84×10^7	1.63×10^7	1.43×10^7
Safe Methylmercury Concentration in Water (b)	0.011	0.014	0.027	0.010	0.011	0.013

(a) Delta-wide largemouth bass and water methylmercury concentrations were estimated by averaging the subarea values. The Delta-wide BAF and safe water concentration were calculated using the Delta-wide largemouth bass and water values.
(b) Safe levels in water correspond to the proposed implementation goal of 0.18 mg/kg methylmercury in standard 350-mm largemouth bass.

E METHODS USED TO ESTIMATE WATER VOLUMES FOR DELTA & SACRAMENTO BASIN INPUTS & EXPORTS

Average annual water volume is a critical component of the source assessments described in Chapters 6 and 7 because water volume is multiplied by the concentration of each constituent to determine loads. Also, a balanced water budget indicates that all major water imports and exports have been identified. This appendix contains a hydrologic evaluation of wet and dry years during the methyl and total mercury source assessment study periods (Section E.1) and a description of methods used to estimate water volumes used in the source assessments (Section E.2).

E.1 Hydrologic Evaluation of Source Assessment Study Periods

Water volumes entering the Delta vary from season to season and year to year. A "water year" (WY) is the period between October and September that encompasses the entire wet season; for example, WY2001 is the period between 1 October 2000 and 30 September 2001. The methylmercury load analyses (Chapter 6) focused on the four-year WY2000-2003 period, which encompasses the available methylmercury concentration data. The total mercury and sediment load analyses (Chapter 7) focused on two periods, WY2000-2003 and WY1984-2003. The WY2000-2003 period was selected for comparison to the methylmercury load estimates. Enough information was available to evaluate the twenty-year WY1984-2003 period for the Sacramento Basin tributaries, which input the most total mercury to the Delta of any source. This period was evaluated because it includes a fairly even mix of wet and dry years and better describes long-term average conditions.

Water year types in California are classified according to the natural water production of the major basins. The California Department of Water Resources (DWR) Hydrologic Classification Index (HCI) was used to evaluate the distribution of wet and dry years in the Central Valley. Figure E.1 graphs the Sacramento Valley and San Joaquin Valley indices for the period of record (1901 to 2003). The DWR HCI classifies water years as "wet", "above normal", "below normal", "dry", or "critical dry" (DWR, 2003). For the Sacramento Valley, normal hydrologic conditions equate to an index value of 7.8, wet is ≥9.2, dry is 5.4 to 6.5, and critical dry is ≤5.4. For the San Joaquin Valley, normal hydrologic conditions equate to an index value of 3.1, wet is ≥3.8, dry is 2.1 to 2.5, and critical dry is ≤2.1. The WY2000-2003 period has average indices of 7.3 and 2.7 for the Sacramento and San Joaquin watersheds, respectively, and appears to be a relatively dry period compared to the period of record. In comparison, the WY1984-2003 period appears to encompass a fairly even mix of wet and dry years. The Sacramento River HCI indicates that during the WY1984-2003 period, ten water years were "wet" or "above normal", and ten years were "below normal," "dry," or "critical dry". The San Joaquin River HCI indicates that nine water years were "wet" or "above normal", and eleven years were "below normal," "dry," or "critical dry."

The distribution of wet/dry years in the twenty-year study period was compared to the distribution of wet/dry years during the past century in the Sacramento and San Joaquin River watersheds. The Sacramento River index includes water years 1906 to 2003 and the San Joaquin River index includes

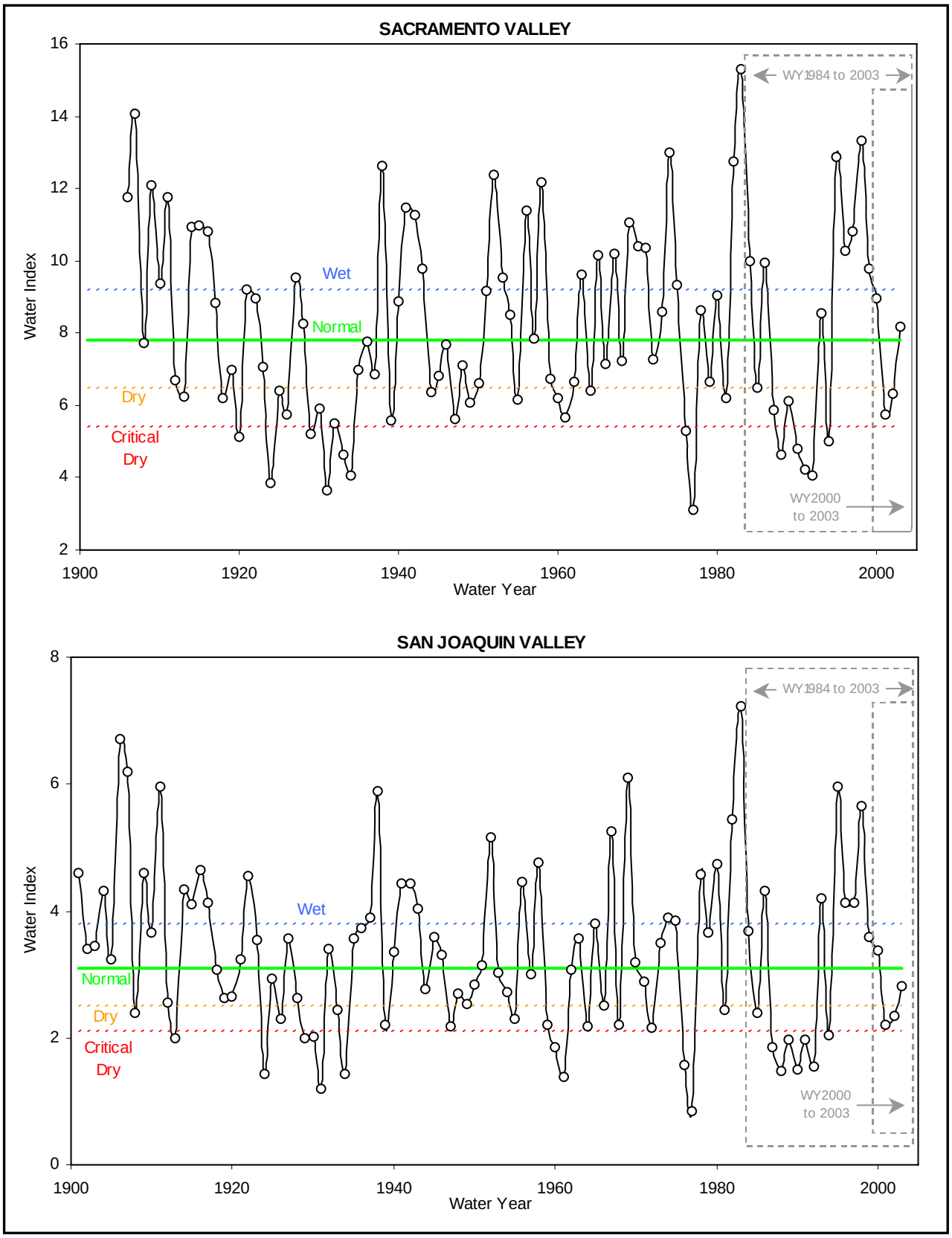

Figure E.1: California Department of Water Resources Chronological Reconstructed Sacramento Valley & San Joaquin Valley Water Year Hydrologic Classification Indices (DWR, 2005)

water years 1901 to 2003. Using the Chi-square test, it was determined that the distribution of water year classifications between the WY1984-2003 period and the entire record was not statistically different (a=0.05) from the distributions for both the Sacramento and San Joaquin River watersheds. Therefore, it was concluded that the WY1984-2003 period is representative of long-term conditions.

E.2 Water Volume Estimation Methods

Average annual water volumes were estimated for the following Delta inputs and exports:

1. Tributary inputs to the Delta;
2. Wastewater treatment plants;
3. Atmospheric deposition;
4. Urban runoff;
5. Delta outflows to San Francisco Bay and diversions to southern California (Delta Mendota Canal and State Water Project);
6. Agricultural diversions;
7. Evaporation; and
8. Dredging.

The WY2000-2003 period is a relatively dry four-year period, while the WY1984-2003 period reflects an even mix of wet and dry years, conditions typical for the last 100 years. As illustrated by Table 6.1 in Chapter 6, the WY2000-2003 water budget balances within 2%. Table E.1 provides the water budget for WY1984-2003, which balances within 1%. This indicates that the major water inputs and exports have been identified.

Water volume information was obtained from a variety of sources. A DWR model, Dayflow, provided daily flow estimates for several of the major Delta exports, including outflow to San Francisco Bay, the Delta Mendota Canal (DMC), State Water Project (SWP), and agricultural withdrawals. Four-year and 20-year precipitation amounts and land use acreages were used to estimate wet weather inputs from urban areas, atmospheric deposition, and tributaries with no flow gages, whenever that duration of data was available for a given monitoring station. Project files were reviewed to determine recent average annual discharges from NPDDES-permitted facilities in the Delta and annual average volumes removed by dredging projects. The following sections describe how each water volume was derived.

E.2.1 Flow-Gage Based Water Volumes

Average annual water volumes were estimated for tributary inputs to the Delta using a variety of methods determined by available data. Flow gages provided daily flows for the major tributaries. If there was no nearby flow gage, Staff used precipitation-based runoff estimates to calculate loads (Section E.2.3).

Table E.3 lists the flow gages used to calculate average annual water volume. The use of multiple flow gages was required to estimate water volumes corresponding to the following monitoring locations: Feather River near Nicolaus, Mokelumne River downstream of I-5, and Yolo Bypass. Because of the complexities of the Yolo bypass hydrology, it is discussed in its own section (Section E.2.2).

Table E.1: Average Annual Water Volumes for Delta Inputs and Losses

	WY2000-2003		WY1984-2003	
	Water Volume (M acre-feet/yr)	**% All Water**	**Water Volume** (M acre-feet/yr)	**% All Water**
INPUTS	**19.4**	**100%**	**23.5**	**100%**
Tributary Sources (% of All Inputs)	*18.87*	*97%*	*22.93*	*98%*
Sacramento River	15.1	78%	16.1	69%
Prospect Slough	1.0	5.3%	2.7	11.5%
San Joaquin River	1.8	9.5%	3.0	12.6%
Mokelumne-Cosumnes River	0.48	2.5%	0.70	3.0%
Calaveras River	0.14	0.7%	0.15	0.6%
Morrison Creek	0.064	0.3%	0.067	0.3%
French Camp Slough	0.063	0.3%	0.066	0.3%
Ulatis Creek	0.030	0.2%	0.031	0.1%
Bear/Mosher Creeks	0.028	0.1%	0.029	0.1%
Marsh Creek (a)	0.0060	0.03%	0.0060	0.03%
Other Small Drainages to Delta (b)	0.094	0.5%	0.097	0.4%
Within-Delta Sources (% of All Inputs)	*0.56*	*3%*	*0.57*	*2%*
Wastewater (Municipal & Industrial)	0.25	1.3%	0.25	1.0%
Atmospheric (Direct)	0.093	0.48%	0.097	0.41%
Atmospheric (Indirect)	0.15	0.79%	0.16	0.68%
Urban	0.064	0.33%	0.066	0.28%
EXPORTS	**19.0**	**100%**	**23.3**	**100%**
X2 (f)	12	63%	17	73%
State Water Project @ Tracy	3.2	17%	2.6	11%
Delta Mendota Canal @ Tracy	2.5	13%	2.4	10%
Agricultural Diversions	0.99	5.2%	0.99	4.3%
Evaporation	0.30	1.6%	0.30	1.3%
Dredging	0.0002	0.001%	0.0002	0.001%
Import - Export (e)	**0.38**		**0.24**	
Exports / Imports	**98%**		**99%**	

(a) Only WY2001-2003 flow data were available for Marsh Creek.
(b) "Other Small Drainages to Delta" include the following areas shown on Figure 6.1, for which total mercury and TSS concentration data are not available: Dixon, Upper Lindsay/Cache Slough, Manteca-Escalon, Bethany Reservoir, Antioch, and Montezuma Hills areas.

Table E.2: Methods Used to Estimate Average Annual Water Volumes for Delta and Sacramento Basin Inputs and Exports

Type	Method	Location of Method Description
Tributary Inputs		
American River @ Discover Park Cache Creek Settling Basin Colusa Basin Drain Feather River nr Nicolaus Marsh Creek Mokelumne River d/s I-5 Putah Creek @ Mace Blvd. Sacramento River abv Colusa Sacramento River @ Freeport San Joaquin River @ Vernalis Sutter Bypass	Flow -Gage Based Method	Section E.2.1
Yolo Bypass Outflows	Flow-Gage Based Method	Section E.2.2
Bear/Mosher Creek Calaveras River/Mormon Slough Coon Creek/Cross Canal French Camp Slough/Lone Tree Creek Morrison Creek Natomas East Main Drain Ulatis Creek Other Small Drainages to the Delta	Precipitation-Based Method	Section E.2.3
Other Inputs		
Wastewater Discharges	Project Files	Tables G.1 and G.2 (Appendix G)
Atmospheric deposition	Precipitation-Based Method	Section E.2.3
Urban runoff	Precipitation-Based Method + Dry Weather Estimate	Section E.2.3
Exports		
Delta Mendota Canal State Water Project Outflows to San Francisco Bay	Dayflow Model	Section E.2.4
Agricultural Diversion	Delta Island Consumptive Use Model	Section 6.2.4 (Chapter 6)
Evaporation	Evaporation Rate x Water Acreage	Section E.2.5
Dredging	Project Files	Section E.2.6

Table E.3: Gage Records Used to Calculate Average Annual Water Volumes for Delta and Sacramento Basin Tributaries.

Gage Name	Gage Operator	Gage ID (a)	Period of Record	Data Type
American River @ Fair Oaks	USGS and DWR	11446500	10/1/1904 - present	Daily
Bear River near Wheatland	USGS and DWR	BRW	1/24/97 - present	Event
Butte Slough near Meridian (Sutter Bypass)	DWR	BSL		
Cache Creek @ Yolo	USGS and DWR	11452500	4/1/1903 - present	Daily
Colusa Drain nr Hwy 20	DWR	CDR	3/12/97 - present	Event
Feather River @ Gridley	DWR	GRL	1/1/93 - present	Daily
Feather River nr Nicolaus	USGS	11425000	4/1/42 – 9/30/83	Daily
Cosumnes River @ Michigan Bar	USGS and DWR	MHB	1/1/93 - present	Daily
Marsh Creek @ Brentwood	USGS	11337600	8/26/2000 - present	Daily
Mokelumne River @ Woodbridge	East Bay Municipal Utility District & USGS	WBR, 11325500	6/1/24 - 9/30/01	Daily
Putah Creek nr Winters	USGS	PUT	3/24/97 - present	Event
Sacramento River @ Colusa	USGS & DWR	COL	1/1/92 -present	Daily
Sacramento River @ Freeport	USGS	FPT	10/1/48 - present	Daily
San Joaquin @ nr Vernalis	USGS & DWR	11303500, VNS	10/1/23 - present (11303500), 1/1/93 - present	Daily
Yolo Bypass nr Woodland	USGS	11453000, YBY	6/29/98 - 7/13/98 (YBY), 10/1/39 - 3/17/03 (11453000)	Daily
Yuba River nr Marysville	USGS	11421000	10/1/43 - present	Daily

(a) Letter-based "Gage ID" records were accessed through the California Data Exchange Center (CDEC) website, http://cdec.water.ca.gov. Numeric "Gage ID" records were accessed through the U.S. Geological Survey Surface-Water Data for the Nation website, http://waterdata.usgs.gov/nwis/sw.

Staff estimated flows for the Feather River at Nicolaus using the formula: 1.11 x [Bear at Wheatland + Yuba at Marysville + Feather at Gridley]. The coefficient of 1.11 was determined by fitting a regression of historical flow data at Nicolaus when flows were rated (1942 to 1983) and historical flow data for the same time period paired by date of the sum of Feather River at Gridley, Yuba River at Marysville and the Bear River at Wheatland. The coefficient of 1.11 compensates for inputs not included by the Gridley, Marysville and Wheatland gages.

The flow of the Mokelumne River near I-5 was estimated by summing the gaged flows of the Mokelumne at Woodbridge and Cosumnes River at Michigan Bar. If Mokelumne at Woodbridge flows were missing for particular days, the sum of Camanche Dam outflow and Cosumnes River at Michigan Bar was used. If both the Mokelumne at Woodbridge flow and Camanche Dam outflow were missing, then those particular days were considered missing values. Flow records for Mokelumne at Woodbridge flow and Camanche Dam outflow for water years 1995 and 1996 were missing more than 20% of their values; all other water years during the study period had either Mokelumne at Woodbridge flow and/or Camanche Dam outflow records available. Therefore, the 20-year flow average was estimated by normalizing the total flows for the WY1984-2003 period. To estimate the missing values, first the number of days in the

20-year period (7305) was divided by the number of days with a recorded value in the flow record (6517). Then the resulting quotient was multiplied by the calculated sum of loads divided by 20 to obtain the average annual load. Normalization was not needed for the WY2000-2003 period.

E.2.2 Yolo Bypass Outflows to the Delta & Hydrologic Conditions in January 1995

The Yolo Bypass is a floodplain on the west side of the lower Sacramento River in Yolo and Solano Counties (Figure E.1) within the levees of the Sacramento River Flood Control Project. The Fremont and Sacramento Weirs route floodwaters to the Yolo Bypass from the Sacramento and Feather Rivers, Sutter bypass and their associated tributary watersheds. Cache and Putah Creeks, Willow Slough, and the Knights Landing Ridge Cut from the Colusa Basin all drain directly to the Yolo Bypass.

The southern portion of the Yolo Bypass lies within the statutory Delta boundary and has some tidally influenced areas. Tidal conditions are observed as far upstream in the Toe Drain as the I-80 causeway (Jones & Stokes, 2001[3]). The Toe Drain, which drains to Prospect Slough, is the primary drainage in the Yolo Bypass. The water elevation in the Toe Drain typically fluctuates tidally between three and seven feet at the Yolo Bypass at Lisbon gage (Figure E.1). A few hundred feet north of this gage, the Lisbon Weir limits the range of tidal fluctuation upstream of the weir. The main part of the weir consists of a sheet piling-reinforced rock mound with three "slap gates" (like trap doors) that allow water to flow northward with incoming tides, but not southward with outgoing tides (Jones & Stokes, 2001; Kirkland, personal communication). The weir impounds upstream inflow and tidal water at an elevation equal to the weir crest elevation (2.5 feet above sea level) (Jones & Stokes, 2001). This provides higher and more stable water levels for upstream agricultural diversion pumps.

When tributary inputs upstream of Lisbon Weir are greater than approximately 800 cfs, water flows southward over the weir (Kirkland, personal communication). During the summer season, the water stage is typically greater to the south of the weir, so that there is a net upstream flow on Toe Drain. However, even during the summer, very high tides cause the pool upstream of the weir to fill and then drain southward across the top of the weir when the tide turns (Kirkland, personal communication). Until recently, the Lisbon gage provided only stage information; it was rated for velocity in spring 2004. Preliminary calculations by DWR and Regional Board staff indicate that there is a monthly net downstream flow from the Yolo Bypass at Lisbon ranging between 56,00 and 152,000 acre-feet per month for the months of March, April and May 2004. However, there was a net upstream flow of 700 to 3,000 acre-feet per month in June and July 2004. That is, there was no net outflow from the Yolo Bypass to the Delta during the summer months.

Aqueous methyl and total mercury sampling took place on Prospect Slough at the Toe Drain to estimate mercury concentrations in outflows from the Yolo Bypass to the central Delta. However, no flow gage is available at that location. Several gages are available upstream that can be used to estimate Yolo Bypass outflows. The "Yolo Bypass near Woodland" flow gage (USGS gage 11453000) represents the sum of inflow from Fremont Weir, Knights Landing Ridge Cut, and Cache Creek Settling Basin (Figure E.1); the USGS Woodland gage record includes only daily mean flows greater than 1,000 cfs. Flow gages are also active on Cache Creek at Yolo (USGS gage 11452500), Sacramento Weir (USGS gage 11426000), Putah Creek near Winters (USGS gage 11454000), and the Putah South Canal (USGS gage 11454210, available

[3] Jones & Stokes. 2001. *A Framework for the Future: Yolo Bypass Management Strategy*. (J&S 99079) August 2001. Sacramento, CA. Prepared for Yolo Basin Foundation, Davis, CA.

after 10/1/94), which diverts water from Putah Creek downstream of the Winters gage. No flow gages are active on Knights Landing Ridge Cut or Willow Slough Bypass and, as noted above, the gage on Toe Drain near Lisbon was only recently rated for velocity.

To estimate total inflows to the Yolo Bypass upstream of Prospect Slough at Toe Drain on the days that average daily flows were greater than 1,000 cfs at Yolo Bypass near Woodland, the following equation was used:

Yolo Bypass Inputs	=	Yolo Bypass near Woodland	+	Putah Creek near Winter	-	Putah South Canal	+	Sacramento Weir Spill

To estimate total inflows to the Yolo Bypass on the days that average daily flows were less than 1,000 cfs at Yolo Bypass near Woodland, the following equation was used:

Yolo Bypass Inputs	=	Cache Creek @ Yolo	+	Fremont Weir	+	Putah Creek near Winter	-	Putah South Canal	+	Sacramento Weir Spill

Total outflow from the Yolo Bypass was estimated by subtracting 800 cfs from the total inflow to account for the amount of flow trapped behind Lisbon Weir. If the estimated total inflow was less than 800 cfs, it was assumed that there was zero net flow past Lisbon Weir. As Figure E.2 illustrates, the average daily outflow estimates indicate that there is generally no net outflow between April and November, which is comparable with the preliminary outflow estimates described earlier that were developed by DWR and Regional Board staff using March-July 2004 flow data for the gage downstream of the Lisbon Weir.

Concentration/Flow Regressions & Hydrologic Conditions in January 1995

Total mercury and TSS samples were collected from Prospect Slough near Toe Drain typically during outgoing tides. As described in Section 7.1.1.1, total mercury and TSS concentrations observed on dates when there appeared to be net outflow from Lisbon Weir were regressed against estimated daily Yolo Bypass outflows at Lisbon Weir lagged by one day to determine if statistically significant correlations might exist (Appendix J, Figure J.1). 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. There is generally no net outflow from the Yolo Bypass's Toe Drain downstream of Lisbon Weir between April and November. 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.

Extremely high total mercury and TSS concentrations were measured in Prospect Slough on 10 and 11 January 1995 (Figure J.1). Cache Creek Settling Basin and Fremont Weir spills were evaluated to determine whether these concentrations were likely to have occurred regularly during the 20-year study period. Flows from the Settling Basin are controlled by the following factors: (1) the Settling Basin can release up to 400 cfs through its low flow outlet; (2) above 400 cfs, the Settling Basin begins to fill at a rate of inflow (measured by the gage at Yolo) minus 400 cfs; and (3) when the basin fills beyond its capacity of approximately 43,200 acre-feet (weir height of 12 feet multiplied by 3,600 acres, the area of the Settling Basin), water begins spilling over the weir. Weir spill continues until inflow to the CCSB

decreases to 400 cfs (CDM, 2004). Settling Basin daily outflows were estimated based on these factors and compared to the timing of Fremont Weir spills (Figure E.3). The high concentrations observed in Prospect Slough on 10 and 11 January 1995 may have resulted from the high releases from the Cache Creek Settling Basin that occurred on 9 January without any dilution flow from Fremont Weir. Although the Settling Basin has had such high releases several times throughout the 20-year record, all occurred concurrently with spills from Fremont Weir. Because the magnitude of Settling Basin release without any dilution that occurred on 9 January appears to have happened only once in the 20-year period, the 10 and 11 January 1995 total mercury and TSS concentration values were not included in the concentration/flow regressions used to predict average annual loads exported by the Yolo Bypass to the Delta.

E.2.3 Precipitation-Based Water Volumes

Atmospheric wet deposition, tributary inputs from ungaged watersheds, and storm runoff from urban areas were estimated using the rational method:

Equation E.1:

$$Q_e = Rf \times A \times RC$$

Where:

Q_e	=	Estimated volumetric runoff rate (acre-feet per year)
Rf	=	Annual precipitation amount in the watershed (feet per year)
A	=	Watershed area (acres)
RC	=	Runoff coefficient

Precipitation data for seventeen gages located throughout the Delta source region (Table E.4) were compiled with a focus on gages that appeared to represent the general precipitation pattern of each region and had records at least 20 years in length. All but one of the gages used in this analysis had records that exceeded 20 years in length. The average annual precipitation amount for WY2000-2003 and WY1984-2003 were calculated for each gage. Land use information was obtained from the California Department of Water Resources Land Use Survey Data and USGS/USEPA National Land Cover Data (DWR, 1993-2002[4], USGS/USEPA, 1993[5]) to determine acreages for each land use in the Delta and its ungaged tributary watersheds. The Delta and its ungaged tributary subwatersheds were delineated into "sub-areas" as defined by (1) proximity to a precipitation gage, and (2) land use category. Because of their size, tables of the land use acreages by subarea are not included in this appendix but can be provided electronically upon request. Table E.5 provides just the urban acreage in the Delta. Then runoff coefficients were assigned to each land use type (Table E.6). Using a combination of software programs (Microsoft Excel and ESRI ArcView), 4-year and 20-year average annual stormwater runoff amounts were calculated for each subarea using Equation E.1.

Dry weather urban runoff was estimated by adapting the daily dry season runoff values developed by Larry Walker Associates (LWA, 1996) for the Sacramento region. Larry Walker Associates determined

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

[5] USEPA/USGS Multi-Resolution Land Characterization Program National Land Cover Data available at: http://www.epa.gov/mrlc/nlcd.html.

average dry season runoff to be 49 mgd and inter-storm runoff to be 58 mgd in the greater Sacramento region. LWA estimated that there were 302 square miles (193,280 acres) of urban area in the Sacramento region. The daily dry season runoff value was divided by the acreage to obtain dry season runoff volume per acre:

$$\text{Dry Season Runoff} = 49 \times 10^6 \text{ gallons/day} \div 193{,}280 \text{ acres}$$
$$= 254 \text{ gallons/acre/day}$$

It was assumed that the dry season runoff amounts in the greater Sacramento region are representative of all urban areas within the statutory Delta boundary and its ungaged tributary watersheds. LWA's dry season runoff estimates were used for dry days in both the dry season and wet season to estimate the annual average non-storm urban runoff in the Delta. The average number of non-rain days per year for the WY1984-2003 period (305 days) was multiplied by 254 gallons/acre/day and the Delta urban acreage (~61,000 acres), to obtain an average annual runoff volume of 4,700 mg/year (14,000 acre-feet/year).

E.2.4 Dayflow Model

Output from the Dayflow Model was used to estimate the average annual water volume of outflows to San Francisco Bay and diversions south of the Delta *via* the Delta Mendota Canal (Central Valley Project pumping at Tracy) and State Water Project (Clifton Court Intake). Dayflow is a computer program maintained by the California Department of Water Resources Interagency Ecological Program (http://www.iep.ca.gov/dayflow/index.html). It was developed in 1978 as an accounting tool for determining historical Delta boundary hydrology (mean daily flows). In 2000, the software used to perform Dayflow calculations was rewritten in Java. The input data include the principal Delta stream inflows, Delta precipitation, Delta exports, and Delta gross channel depletions. These data include both monitored and estimated values. Input data is stored in a HEC-DSS file, and output is written to an ASCII file. Dayflow output is used extensively in studies initiated by the Department of Water Resources, the Department of Fish and Game, and by other State and Federal agencies and private consultants. Dayflow output files can be downloaded from the IEP Dayflow website, http://www.iep.ca.gov/dayflow/output/index.html.

E.2.6 Evaporation

The amount of water lost through evaporation from Delta water surfaces was estimated by multiplying the average evaporation rate for the region by the water surface acreage. Mean evaporation at Brannan Island and Grizzly Island near Rio Vista is approximately 73.4 inches per year. Mean evaporation at the Oakdale Woodward Dam Station south of Stockton is approximately 78.43 inches per year. Staff used an evaporation rate of 73.4 inches per year and a water surface acreage of approximately 48,600 acres (1.97×10^8 square meters) (see Section 4.4.3) to estimate an evaporation water loss of about 300,000 acre/feet per year.

E.2.7 Dredging

Sediment is dredged at various locations in the Delta to maintain ship channels and marinas. Table 6.18 in Chapter 6 provides details on recent dredge projects within the Delta and Figure 6.9 shows their

approximate locations. Approximately 533,400 cubic yards per year (cy/yr) of sediment are dredged on average. The amount of water removed by dredge projects was estimated using weight-volume relationships for saturated soils described by Das (1990)[6], specific gravity values of 1 and 2.65 for water and solids, respectively, and the assumption that the water content of the dredged material is 100% (50% water and 50% sediment by weight[7]):

$$\begin{aligned} \text{Water Volume} &= (\text{dredged material [cy/yr]}) \times (1 + (1 \div 2.65)) \times (\text{cy to acre-feet conversion factors}) \\ &= 533{,}400 \text{ cy} \times (1 \div 1.3774) \times (27 \div 43{,}560) \\ &= 240 \text{ acre-feet/yr} \end{aligned}$$

[6] Das, B.M. 1990. Principles of Geotechnical Engineering. Second Edition. PWS-Kent Publishing Company, Boston, 665 pp.

[7] This is a common assumption for dredging operations. (U.S. Army Corps of Engineers. 2002. "Moisture Content," personal communication from L. Fade to G. Collins, San Francisco Bay Regional Water Quality Control Board, October.)

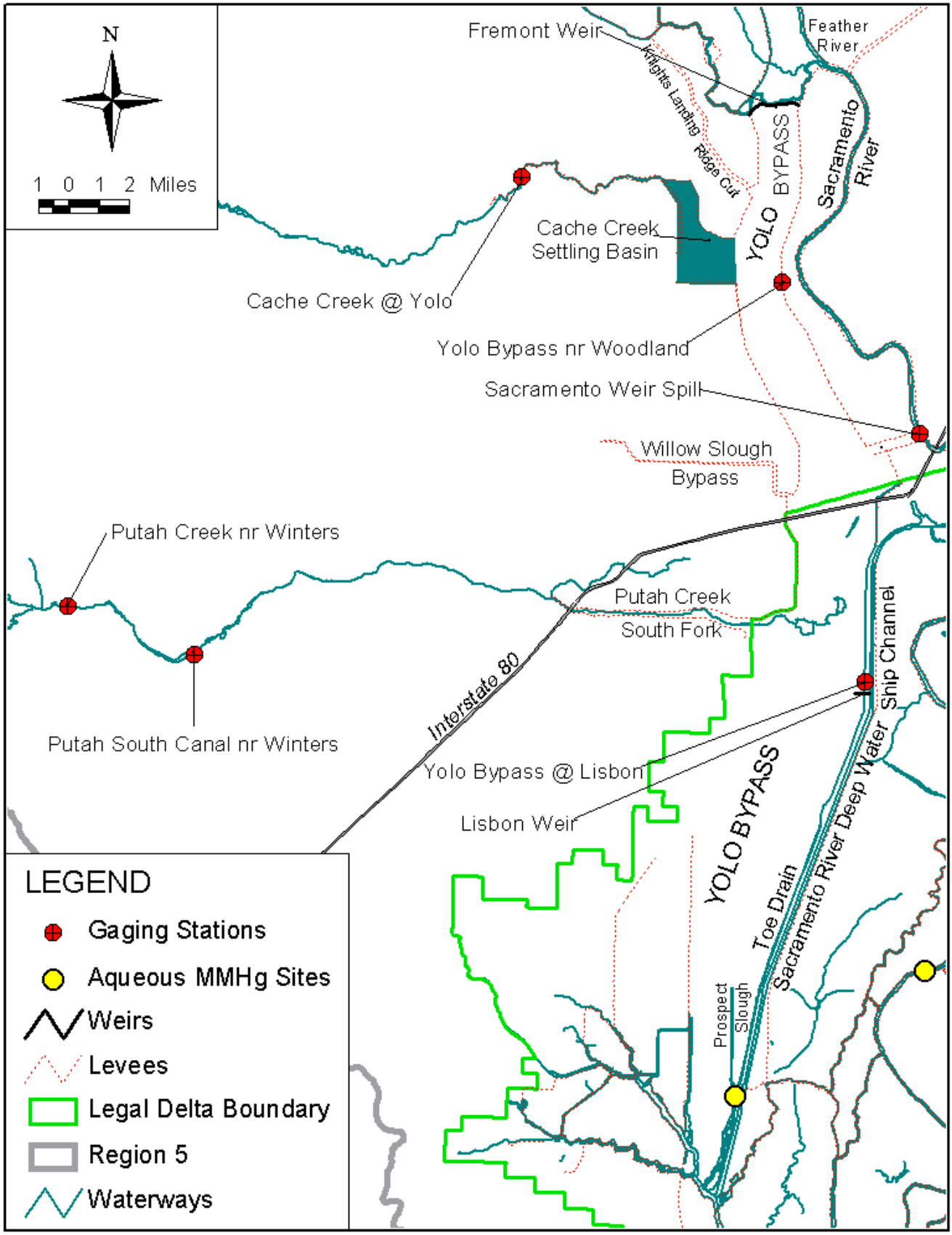

Figure E.1: Hydrologic Features of the Yolo Bypass.

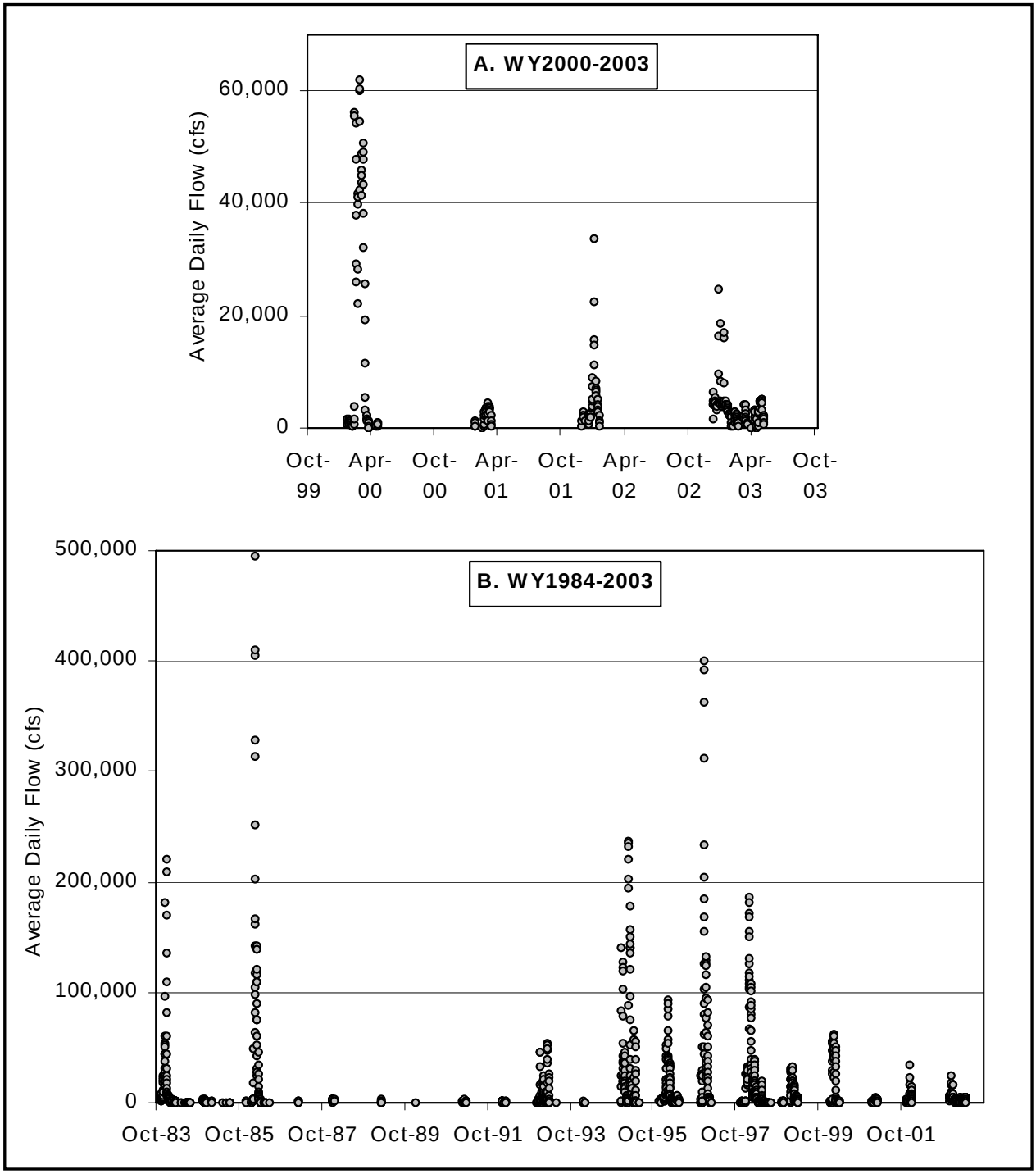

Figure E.2: Estimated Average Daily Outflows from the Yolo Bypass below Lisbon Weir during [A] WY2000-2003 and [B] WY1984-2003.

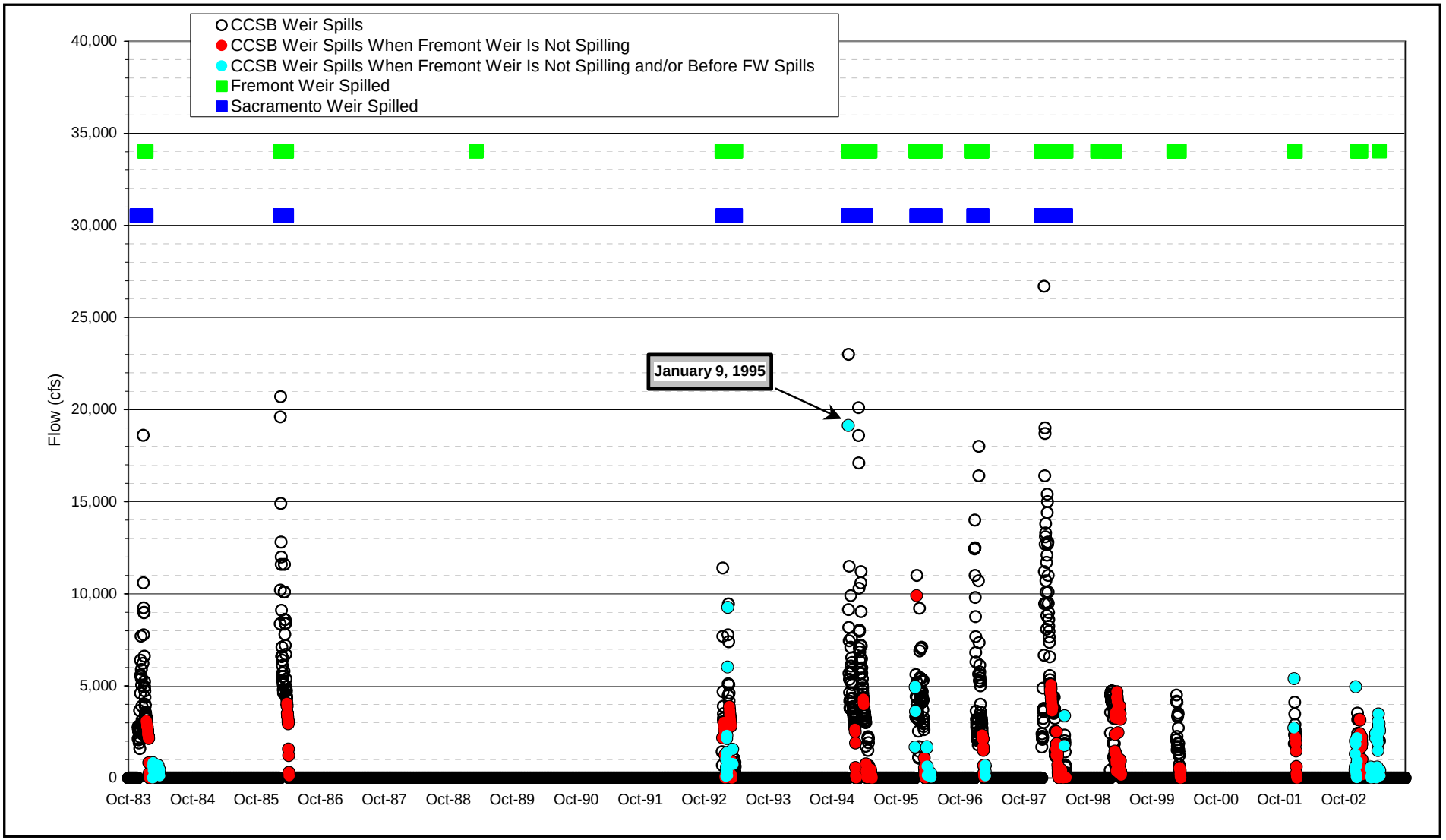

Figure E.3: Comparison of Estimated Cache Creek Settling Basin (CCSB) Outflows Compared to Fremont Weir Spills

Table E.4: Summary of Precipitation Data Used to Estimate Runoff

Station	Code	Latitude	Longitude	Record	Data Type	WY2000-2003 Average	WY1984-2003 Average
Adin RS	ADN	41.19400	-120.94400	10/01/1943 to present	monthly accumulated	11.5	15.1
Calaveras Big Trees	CVT	38.28300	-120.31700	10/01/1929 to present	monthly accumulated	48.6	53.1
Capay	CPY	38.73000	-122.13000	01/01/1905 to present	monthly accumulated	20.4	22.5
Englebright (USACE)	ENG	39.23900	-121.26700	03/01/1989 to present	monthly accumulated	33.0	34.5
Fiddletown	FDD	38.53300	-120.70000	12/01/1937 to present	monthly accumulated	33.2	35.5
Folsom Dam	FLD	38.70000	-121.16700	10/01/1955 to present	monthly accumulated	22.2	24.2
Foresthill R S	FRH	39.01700	-120.85000	10/01/1936 to present	monthly accumulated	46.1	50.4
Los Banos	LSB	37.05000	-120.86700	01/01/1905 to present	monthly accumulated	7.8	9.5
New Exchequer-Lk McClure	EXC	37.58500	-120.27000	10/01/1935 to present	monthly accumulated	18.8	19.4
North Fork R S	NFR	37.23300	-119.50000	01/01/1905 to present	monthly accumulated	30.1	33.0
Orland	ORL	39.75000	-122.20000	01/01/1905 to present	monthly accumulated	18.7	21.6
Quincy RS (USFS)	QNC	39.96000	-120.95000	01/01/1905 to present	monthly accumulated	36.9	36.4
Sacramento WB City	SCR	38.58300	-121.50000	01/01/1905 to present	monthly accumulated	18.7	19.5
Shasta Dam (USBR)	SHA	40.71800	-122.42000	10/01/1957 to present	daily incremental	63.6	61.4
Stockton Fire Station 4	STK	38.00100	-121.31700	01/01/1905 to present	monthly accumulated	16.6	17.2
Stony Gorge Reservoir	STG	39.58300	-122.53300	10/01/1926 to present	monthly accumulated	20.2	20.9
Yosemite Headquarters	YSV	37.74000	-119.58300	01/01/1905 to present	monthly accumulated	32.3	36.3

(a) All precipitation records were obtained from CDEC, http://cdec.water.ca.gov.

Table E.5: Urban Acreage within the Statutory Delta (a) (DWR, 1993-2002)

Delta Subregion	Precipitation Gage Region / Land Use Code																Grand Total
	Los Banos				Sacramento WB City						Stockton Fire Station 4						
	U	UI	UR	UV	U	UC	UI	UL	UR	UV	U	UC	UI	UL	UR	UV	
Central Delta						51	6		9		13256	278	1362	1290	392	1602	18247
Cos. / Mok. Rivers										30	43		59			27	159
Sacramento River					6011	190	405	130	799	1182	9	60	12		19		8818
San Joaquin River	0.2										1846	266	736	238	451	839	4375
South Delta	9	1	0.3	21							4964	210	1690	83	1669	1592	10239
West Delta					29	5					11188	71	574	325	715	2370	15277
Yolo Bypass					1214	115	917	11	346	827							3431

(a) Acreages rounded after water volume and load calculations were made.

Table E.6: Land Uses and Runoff Coefficients (a)

Code Definition	Urban Land Use Code	Runoff Coefficient
Agriculture - Other, mixed, or uncategorized		0.175
Barren		0.300
Crop & Pasture - uncategorized		0.175
Entry Denied		0.175
Native Vegetation - uncategorized		0.150
Open Recreation		0.175
Orchard		0.200
Orchard & Vineyard - uncategorized		0.200
Pasture		0.175
Rangeland		0.150
Rice Fields		0.175
Row and Field Crops		0.175
Strip Mine or Quarry		0.3
Transportation, Communication, Utilities		0.700
Vineyard		0.200
Water		1.000
Wetland and Marsh		0.150
Transitional		0.70
Urban unclassified (includes mixed use)	U	0.56
Commercial	UC	0.71
Industrial	UI	0.70
Landscaped (irrigated lawns, cemeteries, parks)	UL	0.22
Residential	UR	0.50
Vacant (paved & unpaved roads, airport runways, RR Right-of-Ways)	UV	0.70

(a) Staff adapted runoff coefficients provided by: Lindeburg, M.R. 1992. Civil Engineering Reference Manual. Sixth Edition. Professional Publications, Inc.: Belmont, CA. Appendix A: Rational Method Runoff Coefficients.