Appendix 8I
Mercury

8I.1 Mercury Methodology

Mercury and methylmercury in water were modeled quantitatively for the Delta. A quantitative assessment utilizing a mass-balance approach (DSM2 fingerprinting data combined with historical source water quality data) was employed. Additionally, bioaccumulation models were used to convert methylmercury in the water to fish tissue concentrations. Section 8.3.1.3, the mercury discussion under section 8.3.1.7, and the discussion of the bioaccumulation models below provide more detailed information regarding the assessment methodology for ~~boron~~ mercury and methylmercury and the details of the quantitative approach.

8I.1.1 Bioaccumulation Models Used for Predicting Mercury in Fish

The purpose of this bioaccumulation model is to provide an evaluation of the potential for the BDCP to affect concentrations of mercury in Delta water and potential for bioaccumulation in fish. Two bioaccumulation models to convert between water and fish tissue concentrations of mercury were used:

1. Linear regression between DSM2 output of methylmercury concentrations in water (modeled) and bass tissue mercury concentrations (measured) using either annual average or quarterly water values. This model was developed specifically for this analysis and is described in detail in the sections below.

2. The Central Valley Regional Water Quality Control Board (CVRWQCB) Total Maximum Daily Load (TMDL) model was based on the concentration averages of measured fish mercury and water concentrations of methylmercury over broad areas of the Delta. The CVRWQCB model was used in addition to the above described here as a separate predictive tool to link to DSM2 model output.

Both models can be used to estimate fish tissue mercury directly from waterborne methylmercury concentrations and, therefore, result in the same general pattern and relative magnitude of concentrations across BDCP Alternative conditions.

The CVRWQCB used the general approach of linking waterborne mercury concentrations and largemouth bass mercury concentrations for broad areas of the Delta as part of developing the Methylmercury TMDL (Wood 2010). The Regional Board modeling goal was to estimate water concentrations that would relate to their fish tissue TMDL target. However, for BDCP, it was desirable to determine the linkages between modeled mercury or methylmercury water concentrations and resulting fish tissue concentrations at specific defined locations, rather than general Delta conditions over broad areas. Thus, the linear regression model described in (1) above was developed. The intent of the regression was to establish a predictive tool for fish tissue mercury based on DSM2 model estimates of waterborne methylmercury concentrations. The prediction was not assumed to be a measure of bass bioaccumulation physiology, but rather, a useful, predictive tool based on post-processing of DSM2 water concentration modeling for Alternatives evaluations.

Both the existing Regional Board model and the newly-developed model were used to convert DSM2 estimated methylmercury concentrations to predicted fish tissue mercury concentrations. The use of the two models shows a range of possible predicted fish tissue values as might be expected in the Delta as a result of project implementation. The benchmark used for evaluations to assess impacts of Alternatives was the CVRWQCB TMDL tissue concentration goal of 0.24 mg/kg wet weight (ww) of mercury for normalized 350-mm total length largemouth bass tissue (CVRWQCB 2011).

8I.1.2 Linear Regression of DSM2 Modeled Methylmercury to Measured Fish Tissue Mercury Model Development

As described above, a linear regression between DSM2 output of methylmercury concentrations in water (modeled) and bass tissue mercury concentrations (measured) was developed specifically for this analysis. Water concentrations were estimated by assigning mercury and methylmercury concentrations to five source waters (averaged over the 2000 to 2010 period) that contribute to the Delta (based on sampling data; see **Table I-1** and **I-2**), and using DSM2 to model the mixing and hydrodynamics of these contributing source waters in the system using historical year 2000 conditions. DSM2 was used to model year 2000 hydrologic conditions since fish tissue data were from 1999 and 2000, as discussed below. Mercury and methylmercury water sample data used to characterize the five source waters were each averaged over the years indicated in **Table I-1** to produce the long term averages used for source water blending.

The DSM2 model results provided an estimate of the resulting concentrations of mercury and methylmercury in water at specific locations (see **Table I-3**). Note that the first quarter DSM2 model results were discarded because the model "ramps up" for a new year and the average values from those first months were distinctly lower than for the other quarters. Ramping in water quality models is based on the use of previous months in the subsequent months' values and the use of unrealistically-low startup values. Therefore, a surrogate for the annual average for the year was computed from the last 3 quarters. The next step in the evaluation was to identify a model that linked these water concentrations to fish tissue concentrations in samples collected from the same location.

Largemouth bass were chosen for this analysis because they are popular sport fish, top predators, live for several years, and tend to stay in the same area (that is, they exhibit high site fidelity). Consequently, they are excellent indicators of long-term average mercury exposure, risk, and spatial pattern for both ecological and human health. Also a fish tissue mercury dataset was available for largemouth bass from defined locations across the Delta. The largemouth bass tissue mercury concentrations were presented as edible fillet concentrations for fish normalized to 350 mm in total length as supplied directly by SFEI (SFEI 2010). It is important to standardize concentrations to the same length fish at each location because of the well-established positive relationship between fish length and age and tissue mercury concentrations (Alpers et al. 2008). This same normalization technique was used by the Regional Board for their model (CVRWQCB 2011).

Standard, linear regression analyses were created using the SAS institute's Statview 5 analytic software (SAS 1998). DSM2 model outputs of mercury or methylmercury concentrations in water were graphed against fish tissue concentrations of total mercury (assumed to be all as methylmercury) at the exact same nodes and approximate dates. The data were log-transformed to improve normality. The positive relationships between fish tissue and waterborne mercury were not as strong as with waterborne methylmercury and therefore methylmercury was retained as the best predictor. The best fit for a predictive model was the linear regression with the transformed data between average waterborne methylmercury concentrations in water from the third quarter of the year and largemouth bass tissue mercury concentrations (**Figure A1**). Each point in the figure represents one fish sample paired with the DSM2 prediction of methylmercury concentrations from the nearest Delta location for that year. Although the explanation of variance is not strong, it is statistically significant, the third quarter data from the year 2000 produced the best fit. The regression equation (below) was used as the best identified predictor of mercury in fish tissue based on DSM2 modeled methylmercury water concentrations for period average concentrations.

$$\text{Fish mercury (mg/kg ww)} = 10^{(4.217 + (\text{Log methylmercury in water, } \mu g/L \times 1.164))} \quad \textbf{[Eq.1]}$$

($r^2 = 0.383$, $P = 0.024$)

It is evident from Figure A1 that there is considerable variability in tissue mercury levels at lower methylmercury concentrations in water, and there is limited data at higher methylmercury concentrations in water. Thus, both and lower and higher water column methylmercury concentrations, there is notable uncertainty in the above equation. In fact, there are numerous sources of uncertainty in the above approach, including: analytical variability in the original measurements; temporal and/or seasonal variability in Delta source water concentrations of merthylmercury; interconversion of mercury species (i.e., the non-conservative nature of methylmercury as a modeled constituent); fish tissue mercury being an aggregator of methylmercury concentrations that vary in time, space, and diet; a limited sample size (n = 13); low coefficient of determination ($r^2 = 0.383$); and lack of a rigorous validation study, as well as others.

8I.1.3 Central Valley Regional Water Quality Control Board Model

The results of the regression model in **Figure A1** can be compared to those using the alternative from the CVRWQCB TMDL model, which also predicts 350-mm normalized largemouth bass fillets from methylmercury in water. This comparison is shown in **Table I-4**.

The CVRWQCB developed a nonlinear model based on largemouth bass as grouped in major, large areas of the Delta (rather than specific locations) compared to average methylmercury concentrations in water for those same, general areas (CVRWQCB 2011):

$$\text{Fish mercury (mg/kg ww)} = 20.365 \times ((\text{methylmercury in water, ng/L})^{1.6374}) \quad \textbf{[Eq. 2]}$$

($r^2 = 0.910$, $P < 0.05$)

The difference between the model results and the actual fish tissue results were more variable for the CVRWQCB model, **Eq. 2** (-0.399 to 0.85 mg/kg ww) compared to the regression model of **Eq. 1** (-0.505 to 0.299 mg/kg ww) (**Table I-4**). It is possible the averaging used in the Regional Board model parameters contributed to this relative imprecision; in contrast, the DSM2 based model (**Eq. 1**) was specifically constructed to work for DSM2 output at our specific locations of interest. In addition, Note that the CVRWQCB TMDL model was not established to predict fish tissue concentrations, but to provide the linkage between the 0.24 mg/kg tissue mercury TMDL target to the waterborne goal of 0.066 ng methylmercury/L.

As with Equation 1, there is considerable uncertainty in the application of this model. It is likely that because there was more averaging (both in time and space) in the derivation of Equation 2, the coefficient of determination was higher than for Equation 1, making the model appear to be more accurate. However, Equation 2 was applied to site and time-specific modeled methylmercury concentrations, so it is unknown whether this apparent higher degree of accuracy is meaningful when the model is applied in this way. In reality, many of the same uncertainties present in Equation 1 are also present for Equation 2: analytical variability; temporal and/or seasonal variability in Delta source water concentrations of merthylmercury; interconversion of mercury species (i.e., the non-conservative nature of methylmercury as a modeled constituent); limited sample size (both in number of fish and time span over which the measurements were made). The CVRWQCB did not attempt to estimate the errors and propogate them from correlation to correlation in their application of the model for deriving the aqueous methylmercury goal (CVRWQCB 2011).

8I.1.4 Notes Regarding Application of the Models and Interpretation of Results

Although there is considerable uncertainty in both modeling approaches outlined above, mechanistically, there is reason to expect fish tissue methylmercury concentrations may increase when water column methylmercury concentrations increase, and to that end, the equations both serve as a reasonable approximations of a very complex process. Considering the uncertainty, small (i.e., < 20-25%) increases or decreases in modeled fish tissue mercury concentrations at a low number of Delta locations (i.e., 2-3) should be interpreted to be within the uncertainty of the overall approach, and not predictive of actual adverse effects. Larger increases, or increases evident throughout the Delta, can be interpreted as more reliable indicators of potential adverse effects. Finally, the relatively large errors inherent in both model predictions mean that the models are most useful for ranking Alternatives and comparing areas of the Delta within Alternatives rather than as an accurate predictor of actual, future bass tissue mercury concentrations.

~~8I.1.4~~8I.1.5 General Findings

Both models show exactly the same pattern of fish tissue mercury as compared among Alternatives and sites because both models are regression equations based on the same underlying estimates of waterborne methylmercury concentrations. Note that in the fish tissue chemistry estimate results presented in Tables I-7a,b to I-16a,b, all Eq. 2 results are uniformly higher than Eq.1 results. All measured fish tissue concentrations (Table I-4) and all Eq. 1 and Eq. 2 –based fish tissue mercury concentrations exceed the Regional Board TMDL target goal of 0.24 mg/kg tissue mercury. Nevertheless, clear patterns of differences among Alternatives are apparent in Tables I-7 to I-16. The highest estimated tissue mercury concentrations (from both equations) ~~were~~occurred at Buckley Cove for Alternatives 1-5, 7 and 8; and at Contra Costa Pumping Plant #1 for Alternatives 6 and 9. ~~for Alternative 8, North Bay Aqueduct at Barker Slough, all years (Table I-15a,b).~~

~~8I.1.5~~8I.1.6 References

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ABBREVIATIONS

BDAT	Bay Delta and Tributaries Project
μg/L	microgram(s) per liter
CVRWQCB	Central Valley Regional Water Quality Control Board
Hg	mercury
MeHg	methylmercury
mg/kg ww	milligrams/kilogram, wet weight
ng/L	nanogram(s) per liter
SFBRWQCB	San Francisco Bay Regional Water Quality Control Board
SFEI	San Francisco Estuary Institute
SWRCB	State Water Resources Control Board

Table I-1. Modeled Methyl Mercury Concentrations in Water for Existing Conditions, No Action Alternative Late Long Term, and All Alternatives

Location	Period *	Period Average Concentration (ng/L)													
		Existing Conditions	No Action Alternative-LLT	Alternative 1-LLT	Alternative 2-LLT	Alternative 3-LLT	Alternative 4-LLT H1	Alternative 4-LLT H2	Alternative 4-LLT H3	Alternative 4-LLT H4	Alternative 5-LLT	Alternative 6-LLT	Alternative 7-LLT	Alternative 8-LLT	Alternative 9-LLT
Delta Interior															
Mokelumne River (SF) at Staten Island	ALL	0.135	0.134	0.142	0.143	0.140	0.142	0.142	0.142	0.142	0.139	0.146	0.143	0.143	0.127
	DROUGHT	0.121	0.121	0.126	0.127	0.126	0.126	0.127	0.127	0.127	0.126	0.130	0.128	0.127	0.115
San Joaquin River at Buckley Cove	ALL	0.159	0.164	0.162	0.160	0.162	0.160	0.160	0.160	0.160	0.161	0.161	0.161	0.161	0.145
	DROUGHT	0.161	0.167	0.167	0.163	0.167	0.163	0.163	0.163	0.163	0.165	0.165	0.164	0.165	0.138
Franks Tract	ALL	0.117	0.117	0.122	0.125	0.121	0.123	0.124	0.125	0.126	0.122	0.140	0.133	~~0.139~~0.134	0.140
	DROUGHT	0.109	0.110	0.112	0.115	0.112	0.113	0.114	0.115	0.115	0.113	0.131	0.125	~~0.132~~0.125	0.132
Old River at Rock Slough	ALL	0.121	0.122	0.126	0.130	0.126	0.127	0.129	0.130	0.132	0.126	0.155	0.145	~~0.149~~0.147	0.154
	DROUGHT	0.113	0.116	0.118	0.121	0.117	0.119	0.120	0.121	0.122	0.118	0.153	0.142	~~0.147~~0.143	0.154
Western Delta															
Sacramento River at Emmaton	ALL	0.103	0.103	0.103	0.104	0.102	0.103	0.104	0.104	0.104	0.103	0.109	0.106	~~0.168~~0.106	0.103
	DROUGHT	0.101	0.101	0.100	0.101	0.100	0.100	0.101	0.101	0.101	0.100	0.106	0.104	~~0.132~~0.104	0.101
San Joaquin River at Antioch	ALL	0.102	0.103	0.105	0.108	0.104	0.106	0.107	0.108	0.109	0.105	0.119	0.114	~~0.138~~0.114	0.111
	DROUGHT	0.093	0.094	0.094	0.096	0.094	0.095	0.096	0.096	0.097	0.095	0.107	0.104	~~0.123~~0.104	0.101
Sacramento River at Mallard Island	ALL	0.082	0.083	0.082	0.085	0.081	0.083	0.083	0.085	0.085	0.083	0.093	0.089	~~0.134~~0.090	0.085
	DROUGHT	0.072	0.073	0.072	0.073	0.072	0.072	0.073	0.073	0.074	0.073	0.081	0.079	~~0.100~~0.080	0.074
Major Diversions (Pumping Stations)															
North Bay Aqueduct at Barker Slough Pumping Plant	ALL	0.112	0.112	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.106	0.105	~~0.229~~0.104	0.105
	DROUGHT	0.113	0.113	0.104	0.105	0.104	0.105	0.105	0.105	0.105	0.104	0.106	0.105	~~0.167~~0.105	0.105
Contra Costa Pumping Plant #1	ALL	0.129	0.129	0.133	0.136	0.132	0.134	0.135	0.136	0.137	0.132	0.164	0.151	~~0.156~~0.153	0.163
	DROUGHT	0.121	0.122	0.124	0.126	0.123	0.124	0.126	0.126	0.127	0.124	0.160	0.147	~~0.152~~0.149	0.162
Banks Pumping Plant	ALL	0.133	0.135	0.122	0.121	0.126	0.123	0.124	0.123	0.123	0.128	0.100	0.110	~~0.114~~0.113	0.125
	DROUGHT	0.128	0.131	0.128	0.128	0.128	0.128	0.125	0.128	0.125	0.129	0.100	0.108	~~0.116~~0.114	0.119
Jones Pumping Plant	ALL	0.138	0.141	0.129	0.126	0.133	0.130	0.128	0.128	0.127	0.135	0.100	0.111	~~0.113~~0.112	0.125
	DROUGHT	0.134	0.138	0.135	0.132	0.134	0.135	0.132	0.133	0.132	0.136	0.100	0.109	~~0.111~~0.109	0.119

* All: Water years 1975-1991 represent the 16-year period modeled using DSM2. Drought: Represents a 5 consecutive year (water years 1987-1991) drought period consisting of dry and critical water year types (as defined by the Sacramento Valley 40-30-30 water year hydrologic classification index).

Notes:

LLT = late long term

ng/L = nanogram per liter

SF = south fork

Table I-18a. Summary Table for Mercury Concentrations in 350 mm Largemouth Bass Fillets, and Comparisons to Baseline Conditions and Benchmark for Alternative 8. Estimates presented as based on Equation 1.

Location	Period [a]	Estimated Concentrations of Mercury (mg/kg, ww)	% Change In Mercury Concentrations Compared to Baseline[b]		Exceedance Quotients[c]
		Alt. 8	EX	NAA-LLT	Alt. 8
Delta Interior					
Mokelumne River (South Fork) at Staten Island	All	0.55	6	8	2.3
	Drought	0.48	6	6	2.0
San Joaquin River at Buckley Cove	All	0.63	2	-2	2.6
	Drought	0.65	3	-1	2.7
Franks Tract	All	0.51~~0.53~~	17~~22~~	16~~21~~	2.1~~2.2~~
	Drought	0.47~~0.50~~	18~~26~~	16~~24~~	2.0~~2.1~~
Old River at Rock Slough	All	0.57~~0.58~~	25~~27~~	23~~26~~	2.4~~2.4~~
	Drought	0.55~~0.57~~	31~~35~~	28~~32~~	2.3~~2.4~~
Western Delta					
Sacramento River at Emmaton	All	0.39~~0.67~~	4~~77~~	3~~76~~	1.6~~2.8~~
	Drought	0.38~~0.50~~	3~~36~~	3~~36~~	1.6~~2.1~~
SJR at Antioch	All	0.43~~0.53~~	14~~41~~	13~~40~~	1.8~~2.2~~
	Drought	0.38~~0.46~~	13~~37~~	12~~36~~	1.6~~1.9~~
Sacramento River at Mallard Island	All	0.32~~0.51~~	11~~77~~	9~~75~~	1.3~~2.1~~
	Drought	0.28~~0.36~~	12~~46~~	11~~44~~	1.2~~1.5~~
Major Diversions (Pumping Stations)					
North Bay Aqueduct at Barker Slough PP	All	0.38~~0.95~~	-8~~129~~	-8~~131~~	1.6~~4.0~~
	Drought	0.38~~0.66~~	-8~~57~~	-8~~57~~	1.6~~2.7~~
Contra Costa Pumping Plant #1	All	0.60~~0.61~~	23~~25~~	23~~25~~	2.5~~2.5~~
	Drought	0.58~~0.59~~	27~~31~~	26~~29~~	2.4~~2.5~~
Banks Pumping Plant	All	0.42~~0.42~~	-17~~-16~~	-18~~-18~~	1.8~~1.8~~
	Drought	0.42~~0.43~~	-12~~-11~~	-15~~-14~~	1.8~~1.8~~
Jones Pumping Plant	All	0.42~~0.42~~	-22~~-21~~	-24~~-23~~	1.7~~1.7~~
	Drought	0.40~~0.41~~	-21~~-20~~	-24~~-23~~	1.7~~1.7~~

Notes:

[a] All: Water years 1975-1991 represent the 16-year period modeled using DSM2. Drought: Represents a 5 consecutive year (water years 1987-1991) drought period consisting of dry and critical water year types (as defined by the Sacramento Valley 40-30-30 water year hydrologic classification index).

[b] % change indicates a negative change (increased concentrations) relative to baseline when values are positive and a positive change (lowered concentrations) relative to baseline when values are negative. Changes of 10% or more are highlighted.

[c] Exceedance Quotient - All concentrations exceed total maximum daily load guidance concentration of 0.24 mg/kg ww Hg.

Alt. - alternative

EX - Existing Conditions

mg/kg - milligram per kilogram

NAA-LLT - No Action Alternative Late Long Term

ww - wet weight

Table I-19b. Summary Table for Mercury Concentrations in 350 mm Largemouth Bass Fillets, and Comparisons to Baseline Conditions and Benchmark for Alternative 8. Estimates presented as based on Equation 2.

Location	Period [a]	Estimated Concentrations of Mercury (mg/kg, ww)	% Change In Mercury Concentrations Compared to Baseline[b]		Exceedance Quotients[c]
		Alt. 8	EX	NAA-LLT	Alt. 8
Delta Interior					
Mokelumne River (South Fork) at Staten Island	All	0.84	9	11	3.5
	Drought	0.70	8	9	2.9
San Joaquin River at Buckley Cove	All	1.03	2	-3	4.3
	Drought	1.07	4	-2	4.5
Franks Tract	All	0.76~~0.80~~	24~~32~~	24~~31~~	3.1~~3.3~~
	Drought	0.68~~0.74~~	26~~38~~	24~~35~~	2.8~~3.1~~
Old River at Rock Slough	All	0.88~~0.90~~	37~~41~~	34~~38~~	3.7~~3.8~~
	Drought	0.84~~0.88~~	46~~53~~	41~~47~~	3.5~~3.7~~
Western Delta					
Sacramento River at Emmaton	All	0.52~~1.10~~	6~~124~~	5~~122~~	2.2~~4.6~~
	Drought	0.50~~0.74~~	4~~54~~	4~~54~~	2.1~~3.1~~
SJR at Antioch	All	0.59~~0.79~~	20~~62~~	19~~60~~	2.4~~3.3~~
	Drought	0.50~~0.66~~	19~~56~~	18~~54~~	2.1~~2.7~~
Sacramento River at Mallard Island	All	0.39~~0.76~~	16~~124~~	13~~119~~	1.6~~3.2~~
	Drought	0.32~~0.47~~	18~~71~~	15~~67~~	1.4~~2.0~~
Major Diversions (Pumping Stations)					
North Bay Aqueduct at Barker Slough PP	All	0.50~~1.82~~	-11~~221~~	-11~~224~~	2.1~~7.6~~
	Drought	0.51~~1.08~~	-12~~89~~	-12~~89~~	2.1~~4.5~~
Contra Costa Pumping Plant #1	All	0.94~~0.97~~	33~~37~~	33~~37~~	3.9~~4.0~~
	Drought	0.90~~0.94~~	40~~46~~	38~~44~~	3.7~~3.9~~
Banks Pumping Plant	All	0.57~~0.58~~	-23~~-22~~	-25~~-24~~	2.4~~2.4~~
	Drought	0.58~~0.60~~	-17~~-15~~	-20~~-19~~	2.4~~2.5~~
Jones Pumping Plant	All	0.56~~0.57~~	-29~~-29~~	-32~~-31~~	2.4~~2.4~~
	Drought	0.54~~0.55~~	-29~~-27~~	-32~~-31~~	2.3~~2.3~~

Notes:

[a] All: Water years 1975-1991 represent the 16-year period modeled using DSM2. Drought: Represents a 5 consecutive year (water years 1987-1991) drought period consisting of dry and critical water year types (as defined by the Sacramento Valley 40-30-30 water year hydrologic classification index).

[b] % change indicates a negative change (increased concentrations) relative to baseline when values are positive and a positive change (lowered concentrations) relative to baseline when values are negative. Changes of 10% or more are highlighted.

[c] Exceedance Quotient - All concentrations exceed total maximum daily load guidance concentration of 0.24 mg/kg ww Hg.

Alt. - alternative

EX - Existing Conditions

mg/kg - milligram per kilogram

NAA-LLT - No Action Alternative Late Long Term

ww - wet weight