Appendix 6.A. Quantitative Methods for Biological Assessment of Delta Smelt

6.A Quantitative Methods for Biological Assessment of Delta Smelt

6.A.1 Introduction

This appendix describes the methods for the main quantitative analyses undertaken for Delta Smelt in Chapter 6, *Effects Analysis for Delta Smelt and Terrestrial Species*. The appendix is divided into methods related to North Delta Exports, South Delta Exports, and Habitat Effects. In general, only the methods are reported in this appendix; the results are described in Chapter 6. Exceptions include more detailed results for certain analyses.

6.A.2 North Delta Exports

6.A.2.1 Migrating Adult Movement Upstream (DSM2-PTM)

Of concern related to the construction and operation of the NDD is the potential for Delta Smelt to occur close to the NDD. In addition to survey data, a DSM2-PTM analysis was undertaken to assess the potential for upstream migration of adult Delta Smelt to the vicinity of the NDD. The analysis essentially sought to reproduce the methods of Sommer et al. (2011), who applied a tidally varying vertical migration behavior to assess potential upstream migration rate of Delta Smelt in order to validate empirical estimates of migration rate from salvage data.

6.A.2.1.1 Methods

The methods for the DSM2-PTM analysis of migrating adult Delta Smelt upstream migration are provided in Appendix 5.B, Section 5.B.3.6, *DSM2-PTM for Adult Delta Smelt*.

6.A.2.1.2 Results

The principal results of the upstream migration analysis are presented in Chapter 6, Section 6.1.3.2.2.1.2, *Population-Level Effects*. This section provides additional results for the geographic subregions that particles were found in at the end of the 30-day simulation period (Table 6.A-1, Table 6.A-2, Table 6.A-3, and Table 6.A-4).

Table 6.A-1. Adult Delta Smelt Upstream Movement Analysis Based on DSM2-PTM: Fate (Mean Percentage) of Particles by Release Location, Water Year Type, and Geographic Subregion (West Suisun Bay to San Joaquin River at Twitchell Island) After 30 Days

Release Location	Water Year Type	West Suisun Bay			Mid Suisun Bay			Suisun Marsh			Honker Bay			Lower San Joaquin River			San Joaquin River at Twitchell Island		
		NAA	PA	PA vs. NAA	NAA	PA	PA vs. NAA	NAA	PA	PA vs. NAA	NAA	PA	PA vs. NAA	NAA	PA	PA vs. NAA	NAA	PA	PA vs. NAA
Cache Sl. at Liberty Island (Node 323)	W	0.6	0.6	0.0 (-4%)	3.2	2.9	-0.3 (-10%)	3.1	2.8	-0.3 (-9%)	1.5	1.7	0.3 (18%)	2.2	2.5	0.3 (15%)	1.0	1.0	0.0 (2%)
	AN	1.0	1.2	0.2 (23%)	3.1	3.9	0.7 (24%)	2.8	3.1	0.3 (12%)	1.1	1.3	0.2 (18%)	1.9	2.0	0.1 (3%)	0.8	0.9	0.0 (5%)
	BN	0.2	0.2	0.0 (-22%)	3.9	3.5	-0.4 (-10%)	2.8	2.6	-0.3 (-10%)	1.6	1.9	0.3 (21%)	2.8	3.6	0.9 (31%)	1.0	1.5	0.5 (45%)
	D	0.3	0.3	0.0 (-1%)	1.7	1.7	0.0 (2%)	1.4	1.3	-0.1 (-5%)	1.2	0.9	-0.2 (-21%)	2.0	1.9	-0.1 (-4%)	1.0	1.0	0.0 (1%)
	C	0.0	0.0	0.0 (-50%)	0.8	0.7	-0.1 (-7%)	0.9	0.7	-0.2 (-21%)	0.7	0.4	-0.3 (-37%)	1.2	1.1	-0.1 (-8%)	0.5	0.6	0.1 (16%)
Decker Island (Node 353)	W	0.5	0.5	0.0 (-7%)	4.4	4.5	0.2 (4%)	6.4	6.3	-0.1 (-1%)	1.0	1.5	0.4 (43%)	1.9	2.5	0.6 (34%)	0.8	1.1	0.3 (41%)
	AN	0.4	0.5	0.1 (26%)	2.0	1.9	-0.1 (-3%)	4.7	4.3	-0.3 (-7%)	0.9	0.7	-0.1 (-16%)	3.1	3.3	0.1 (4%)	1.2	1.0	-0.1 (-10%)
	BN	0.1	0.2	0.1 (89%)	4.9	7.1	2.2 (44%)	5.9	7.7	1.8 (30%)	2.7	3.5	0.8 (29%)	5.2	6.5	1.3 (25%)	2.8	3.5	0.7 (26%)
	D	0.4	0.4	0.0 (5%)	4.9	4.0	-0.9 (-18%)	5.7	4.7	-1.0 (-17%)	3.4	3.2	-0.2 (-6%)	7.0	7.2	0.2 (3%)	4.5	5.3	0.7 (16%)
	C	0.1	0.0	0.0 (-67%)	2.0	1.5	-0.4 (-22%)	3.2	2.9	-0.3 (-10%)	1.7	1.5	-0.2 (-13%)	6.7	6.5	-0.2 (-3%)	5.4	5.4	0.1 (1%)
Montezuma Slough (Node 420)	W	0.1	0.1	0.0 (1%)	0.2	0.2	0.0 (-6%)	80.8	81.1	0.4 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)
	AN	0.0	0.0	0.0 (92%)	0.3	0.4	0.1 (54%)	99.1	99.0	-0.2 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)
	BN	0.0	0.0	0.0 (-100%)	0.5	0.1	-0.5 (-88%)	99.2	99.9	0.7 (1%)	0.0	0.0	0.0 (-94%)	0.0	0.0	0.0 (-75%)	0.0	0.0	0.0 (0%)
	D	0.0	0.0	0.0 (-59%)	0.7	0.4	-0.3 (-39%)	98.8	99.3	0.5 (0%)	0.1	0.1	0.0 (-18%)	0.0	0.0	0.0 (-26%)	0.0	0.0	0.0 (0%)
	C	0.1	0.0	0.0 (-40%)	2.6	2.2	-0.4 (-16%)	95.6	96.6	1.0 (1%)	0.4	0.3	-0.1 (-28%)	0.2	0.1	-0.1 (-35%)	0.0	0.0	0.0 (-33%)
Chipps Island (Node 465)	W	0.4	0.4	0.0 (13%)	4.2	4.6	0.4 (10%)	6.1	6.7	0.5 (9%)	0.9	1.2	0.3 (34%)	1.1	1.8	0.7 (59%)	0.4	0.6	0.2 (48%)
	AN	0.3	0.4	0.1 (39%)	1.2	1.3	0.0 (4%)	6.6	6.5	-0.1 (-1%)	0.7	0.5	-0.2 (-28%)	2.2	2.4	0.2 (11%)	0.7	0.7	0.0 (-5%)
	BN	0.1	0.2	0.1 (138%)	5.8	8.0	2.2 (37%)	9.8	11.1	1.3 (13%)	2.9	3.2	0.4 (13%)	4.8	5.6	0.8 (16%)	2.7	3.3	0.6 (21%)
	D	0.5	0.4	-0.1 (-15%)	6.3	5.7	-0.6 (-9%)	11.4	10.4	-1.0 (-9%)	3.6	3.6	0.1 (2%)	6.6	7.5	0.9 (13%)	4.3	5.1	0.8 (17%)
	C	0.1	0.0	-0.1 (-57%)	2.6	2.3	-0.3 (-10%)	11.4	10.6	-0.7 (-6%)	2.0	1.9	-0.1 (-5%)	7.9	8.3	0.5 (6%)	6.0	6.3	0.2 (4%)

Note: Grey shading indicates that no particles had this fate for either the NAA or PA.

Table 6.A-2. Adult Delta Smelt Upstream Movement Analysis Based on DSM2-PTM: Fate (Mean Percentage) of Particles by Release Location, Water Year Type, and Geographic Subregion (Franks Tract to Old River) After 30 Days

Release Location	Water Year Type	Franks Tract			San Joaquin River at Prisoners Point			Holland Cut			Mildred Island			Rock Slough and Discovery Bay			Old River		
		NAA	PA	PA vs. NAA	NAA	PA	PA vs. NAA	NAA	PA	PA vs. NAA	NAA	PA	PA vs. NAA	NAA	PA	PA vs. NAA	NAA	PA	PA vs. NAA
Cache Sl. at Liberty Island (Node 323)	W	0.4	0.5	0.1 (29%)	1.2	1.3	0.1 (11%)	0.6	0.6	0.1 (11%)	0.5	0.7	0.2 (32%)	0.1	0.1	0.0 (8%)	0.3	0.3	0.0 (4%)
	AN	0.4	0.5	0.1 (25%)	0.8	0.8	0.1 (8%)	0.4	0.5	0.1 (19%)	0.4	0.4	0.0 (-1%)	0.1	0.1	0.0 (-3%)	0.2	0.2	0.0 (13%)
	BN	0.4	0.6	0.2 (43%)	1.3	1.6	0.3 (24%)	0.6	0.8	0.2 (38%)	0.5	0.5	0.0 (9%)	0.1	0.1	0.0 (60%)	0.2	0.2	0.0 (16%)
	D	0.5	0.5	0.0 (8%)	1.4	1.5	0.1 (9%)	0.7	0.7	0.0 (1%)	0.7	0.6	-0.1 (-9%)	0.1	0.1	0.0 (-11%)	0.3	0.3	0.0 (-2%)
	C	0.2	0.2	0.0 (15%)	0.5	0.5	0.0 (5%)	0.2	0.2	0.0 (12%)	0.2	0.2	0.0 (-3%)	0.0	0.0	0.0 (0%)	0.1	0.1	0.0 (0%)
Decker Island (Node 353)	W	0.5	0.7	0.2 (36%)	1.3	1.8	0.5 (44%)	0.6	0.9	0.3 (45%)	0.6	0.7	0.1 (15%)	0.1	0.1	0.0 (30%)	0.3	0.3	0.1 (23%)
	AN	0.8	0.9	0.0 (3%)	2.0	2.0	0.0 (0%)	1.1	1.1	0.0 (-1%)	1.2	1.2	0.0 (-3%)	0.2	0.2	0.0 (19%)	0.5	0.5	0.0 (4%)
	BN	1.7	2.0	0.3 (15%)	5.1	5.9	0.8 (15%)	2.8	3.1	0.3 (12%)	3.3	3.3	0.0 (-1%)	0.5	0.5	0.0 (-5%)	1.2	1.2	-0.1 (-6%)
	D	2.8	3.2	0.4 (14%)	7.6	8.9	1.3 (17%)	3.7	4.4	0.7 (19%)	4.7	4.8	0.1 (2%)	0.7	0.8	0.1 (8%)	1.7	1.9	0.2 (9%)
	C	3.2	3.4	0.1 (4%)	10.2	10.4	0.2 (2%)	5.1	5.4	0.2 (5%)	6.8	7.1	0.3 (4%)	1.0	1.1	0.1 (12%)	2.2	2.5	0.3 (12%)
Montezuma Slough (Node 420)	W	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)
	AN	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)
	BN	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)
	D	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (-100%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)
	C	0.0	0.0	0.0 (-50%)	0.0	0.0	0.0 (-100%)	0.0	0.0	0.0 (-100%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)
Chipps Island (Node 465)	W	0.2	0.3	0.1 (29%)	0.5	0.8	0.2 (44%)	0.2	0.3	0.1 (46%)	0.2	0.2	0.0 (9%)	0.0	0.0	0.0 (-24%)	0.1	0.1	0.0 (28%)
	AN	0.6	0.6	0.0 (-7%)	1.4	1.4	0.0 (-1%)	0.8	0.7	-0.1 (-7%)	0.9	0.8	-0.1 (-9%)	0.2	0.2	0.0 (8%)	0.3	0.3	0.0 (-12%)
	BN	1.6	1.8	0.2 (12%)	4.9	5.4	0.5 (10%)	2.3	2.5	0.2 (7%)	2.6	2.0	-0.6 (-22%)	0.3	0.3	0.0 (9%)	0.8	0.8	-0.1 (-7%)
	D	2.5	2.9	0.4 (17%)	6.8	7.9	1.1 (17%)	3.3	3.7	0.5 (14%)	3.4	3.2	-0.2 (-7%)	0.5	0.6	0.0 (5%)	1.2	1.4	0.2 (18%)
	C	3.6	3.6	0.0 (0%)	10.7	11.5	0.8 (8%)	5.2	5.5	0.3 (5%)	5.5	5.4	-0.1 (-2%)	0.8	0.8	0.0 (0%)	1.9	2.1	0.2 (9%)

Note: Grey shading indicates that no particles had this fate for either the NAA or PA.

Table 6.A-3. Adult Delta Smelt Upstream Movement Analysis Based on DSM2-PTM: Fate (Mean Percentage) of Particles by Release Location, Water Year Type, and Geographic Subregion (Middle River to San Joaquin River Near Stockton) After 30 Days

Release Location	Water Year Type	Middle River			Victoria Canal			Grant Line Canal and Old River			North and South Forks Mokelumne River			Disappointment Slough			San Joaquin River Near Stockton		
		NAA	PA	PA vs. NAA	NAA	PA	PA vs. NAA	NAA	PA	PA vs. NAA	NAA	PA	PA vs. NAA	NAA	PA	PA vs. NAA	NAA	PA	PA vs. NAA
Cache Sl. at Liberty Island (Node 323)	W	0.2	0.2	0.0 (15%)	0.2	0.2	0.0 (-10%)	0.0	0.0	0.0 (83%)	0.1	0.1	0.0 (-3%)	0.0	0.0	0.0 (-43%)	0.2	0.1	-0.2 (-72%)
	AN	0.2	0.1	0.0 (-18%)	0.1	0.1	0.0 (-17%)	0.0	0.0	0.0 (0%)	0.1	0.1	0.0 (-12%)	0.0	0.0	0.0 (0%)	0.1	0.0	-0.1 (-68%)
	BN	0.2	0.2	0.0 (9%)	0.1	0.1	0.0 (16%)	0.0	0.0	0.0 (60%)	0.1	0.2	0.0 (24%)	0.0	0.0	0.0 (200%)	0.1	0.1	0.0 (-44%)
	D	0.2	0.2	0.0 (-1%)	0.2	0.2	0.0 (-3%)	0.0	0.0	0.0 (146%)	0.2	0.2	0.0 (-7%)	0.0	0.0	0.0 (13%)	0.4	0.2	-0.2 (-53%)
	C	0.1	0.1	0.0 (9%)	0.1	0.0	0.0 (-12%)	0.0	0.0	0.0 (700%)	0.1	0.1	0.0 (28%)	0.0	0.0	0.0 (-100%)	0.1	0.1	-0.1 (-44%)
Decker Island (Node 353)	W	0.3	0.2	0.0 (-13%)	0.2	0.2	0.0 (9%)	0.0	0.0	0.0 (65%)	0.2	0.2	0.0 (26%)	0.0	0.0	0.0 (225%)	0.2	0.1	-0.2 (-71%)
	AN	0.5	0.4	-0.1 (-14%)	0.4	0.3	-0.1 (-19%)	0.0	0.0	0.0 (-11%)	0.3	0.2	-0.1 (-19%)	0.0	0.0	0.0 (-67%)	0.4	0.3	-0.1 (-31%)
	BN	1.1	1.0	-0.1 (-11%)	0.8	0.8	0.0 (-3%)	0.1	0.1	0.1 (107%)	1.5	1.6	0.1 (4%)	0.2	0.1	-0.1 (-42%)	1.7	0.6	-1.2 (-66%)
	D	1.8	1.7	-0.1 (-7%)	1.4	1.5	0.1 (6%)	0.1	0.3	0.1 (98%)	1.2	1.4	0.2 (15%)	0.2	0.2	0.0 (6%)	2.5	1.3	-1.2 (-49%)
	C	2.7	2.8	0.1 (3%)	2.0	2.2	0.2 (12%)	0.3	0.6	0.3 (127%)	2.2	2.5	0.3 (16%)	0.5	0.6	0.0 (2%)	4.6	2.8	-1.7 (-38%)
Montezuma Slough (Node 420)	W	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)
	AN	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)
	BN	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)
	D	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)
	C	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)
Chipps Island (Node 465)	W	0.1	0.1	0.0 (-26%)	0.0	0.0	0.0 (-21%)	0.0	0.0	0.0 (40%)	0.1	0.1	0.0 (41%)	0.0	0.0	0.0 (25%)	0.1	0.0	-0.1 (-85%)
	AN	0.4	0.3	-0.1 (-18%)	0.3	0.3	0.0 (0%)	0.0	0.0	0.0 (-48%)	0.2	0.2	0.0 (-15%)	0.0	0.0	0.0 (-33%)	0.4	0.3	-0.1 (-17%)
	BN	0.7	0.5	-0.2 (-30%)	0.5	0.4	0.0 (-7%)	0.0	0.1	0.0 (125%)	1.2	1.3	0.1 (7%)	0.1	0.1	0.0 (-47%)	0.9	0.3	-0.6 (-63%)
	D	1.1	0.9	-0.2 (-18%)	0.8	0.8	0.0 (-5%)	0.1	0.1	0.0 (47%)	1.0	1.3	0.2 (20%)	0.1	0.1	0.0 (-21%)	1.6	0.7	-0.9 (-55%)
	C	1.5	1.3	-0.2 (-16%)	1.2	1.2	-0.1 (-6%)	0.1	0.2	0.1 (123%)	2.3	2.6	0.3 (13%)	0.3	0.3	0.0 (-11%)	3.0	1.9	-1.2 (-38%)

Note: Grey shading indicates that no particles had this fate for either the NAA or PA.

Table 6.A-4. Adult Delta Smelt Upstream Movement Analysis Based on DSM2-PTM: Fate (Mean Percentage) of Particles by Release Location, Water Year Type, and Geographic Subregion (Upper San Joaquin River to Upper Sacramento River) After 30 Days

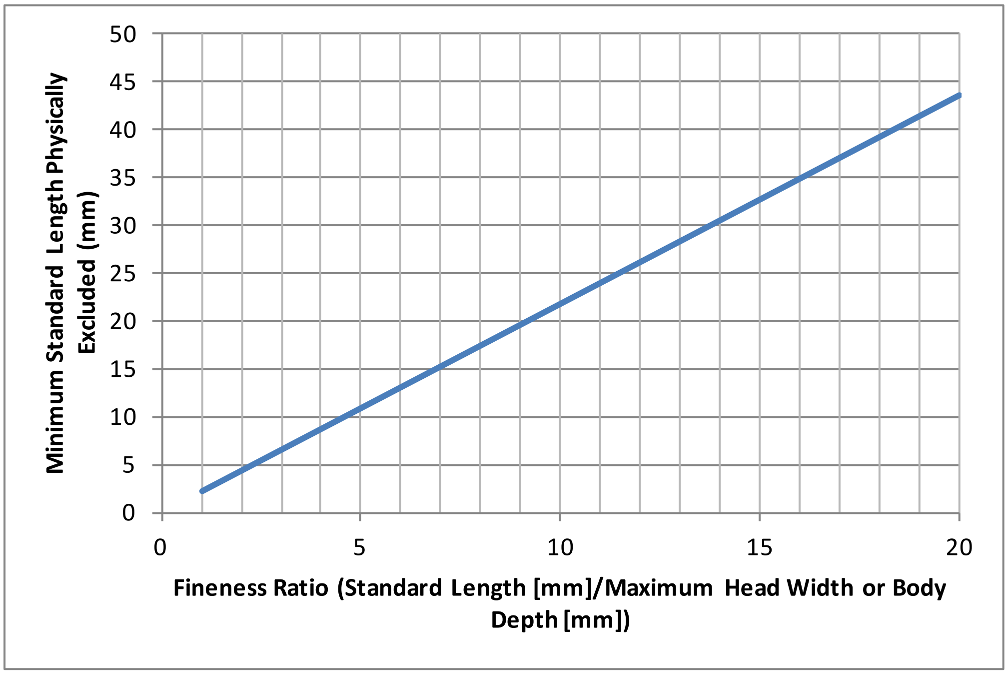
Release Location	Water Year Type	Upper San Joaquin River			Lower Sacramento River			Sacramento River Near Rio Vista			Cache Slough and Liberty Island			Sacramento River Ship Channel			Sacramento River Near Ryde			Upper Sacramento River		
		NAA	PA	PA vs. NAA	NAA	PA	PA vs. NAA	NAA	PA	PA vs. NAA	NAA	PA	PA vs. NAA	NAA	PA	PA vs. NAA	NAA	PA	PA vs. NAA	NAA	PA	PA vs. NAA
Cache Sl. at Liberty Island (Node 323)	W	0.0	0.0	0.0 (0%)	1.4	1.8	0.4 (33%)	0.5	0.6	0.1 (24%)	11.2	12.5	1.3 (12%)	4.5	4.6	0.1 (2%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)
	AN	0.0	0.0	0.0 (0%)	1.1	1.3	0.2 (17%)	0.8	0.8	0.0 (2%)	12.6	12.8	0.2 (2%)	7.9	7.9	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)
	BN	0.0	0.0	0.0 (0%)	2.0	3.5	1.5 (72%)	0.4	0.7	0.3 (84%)	42.7	45.0	2.3 (5%)	17.1	16.6	-0.5 (-3%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)
	D	0.0	0.0	0.0 (0%)	1.8	2.0	0.2 (13%)	1.3	1.3	0.0 (1%)	49.2	51.7	2.5 (5%)	21.3	21.4	0.1 (0%)	0.0	0.0	0.0 (-100%)	0.0	0.0	0.0 (0%)
	C	0.0	0.0	0.0 (0%)	1.4	1.6	0.2 (16%)	0.8	0.8	0.1 (10%)	63.2	64.3	1.1 (2%)	27.2	26.8	-0.4 (-2%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (-100%)
Decker Island (Node 353)	W	0.0	0.0	0.0 (0%)	1.0	1.6	0.7 (67%)	0.1	0.2	0.1 (72%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)
	AN	0.0	0.0	0.0 (0%)	0.7	0.8	0.1 (13%)	0.0	0.1	0.0 (8%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)
	BN	0.0	0.0	0.0 (0%)	3.7	4.9	1.2 (33%)	0.6	0.7	0.1 (25%)	2.9	3.5	0.5 (18%)	0.1	0.1	0.0 (-14%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)
	D	0.0	0.0	0.0 (0%)	5.2	6.2	1.0 (19%)	1.8	2.3	0.5 (29%)	1.1	1.5	0.4 (36%)	0.0	0.0	0.0 (42%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (50%)
	C	0.0	0.0	0.0 (0%)	6.3	6.3	-0.1 (-1%)	3.9	4.0	0.1 (2%)	2.7	4.3	1.6 (59%)	0.1	0.1	0.0 (30%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (-100%)
Montezuma Slough (Node 420)	W	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)
	AN	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)
	BN	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (-83%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)
	D	0.0	0.0	0.0 (0%)	0.1	0.0	0.0 (-68%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)
	C	0.0	0.0	0.0 (0%)	0.2	0.1	-0.1 (-38%)	0.0	0.0	0.0 (-20%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)
Chipps Island (Node 465)	W	0.0	0.0	0.0 (0%)	0.8	1.3	0.5 (57%)	0.1	0.1	0.1 (63%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)
	AN	0.0	0.0	0.0 (0%)	0.4	0.5	0.1 (26%)	0.0	0.1	0.0 (8%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)
	BN	0.0	0.0	0.0 (0%)	3.7	4.5	0.7 (19%)	1.0	1.1	0.1 (13%)	1.8	2.0	0.1 (7%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)
	D	0.0	0.0	0.0 (0%)	5.0	6.4	1.3 (26%)	1.9	2.5	0.6 (32%)	0.5	0.7	0.2 (45%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (0%)
	C	0.0	0.0	0.0 (0%)	6.6	7.1	0.5 (7%)	3.9	4.2	0.3 (9%)	1.5	3.1	1.6 (104%)	0.0	0.0	0.0 (0%)	0.0	0.0	0.0 (-100%)	0.0	0.0	0.0 (0%)
Note: Grey shading indicates that no particles had this fate for either the NAA or PA.																						

6.A.2.2 Screening Effectiveness Analysis

The size of larval and juvenile Delta Smelt theoretically vulnerable to entrainment through the proposed north Delta fish screens (i.e., passing through the screen) is a function of the slot opening of the screen mesh and the size (length and depth) of the fish (Turnpenny 1981; Margraf et al. 1985; Young et al. 1997). The analysis of the effectiveness of the north Delta intake screens in preventing entrainment through the proposed North Delta Diversion (NDD) fish screens was based on the proposed 1.75-millimeter (mm) smooth vertical wedgewire screen design. The minimum size (standard length) of Delta Smelt that would be excluded from entrainment was based on the equation originally formulated by Turnpenny (1981), as rearranged by Margraf et al. (1985) and presented by Young et al. (1997:19 (Figure 6.A-1):

$$SL = (0.06564 \times M + 1.199 \times M \times F)/(1 - 0.0209 \times M)$$

Where SL = standard length (mm), M = screen vertical opening size, F = fineness ratio (i.e., standard length/head width or body depth).



Source: Based on equation provided by Young et al. 1997.

Figure 6.A-1. Minimum Standard Length of Fish Physically Excluded by 1.75 mm Vertical Wedgewire Screens

For most species, head width would be smaller than body depth and, given the vertical openings of the proposed screens, would be the most appropriate denominator for the fineness ratio. Fineness ratios for Delta Smelt were calculated based on morphometric relationships presented by Young et al. (1997), specifically rearrangement of the formula predicting total length from standard length, followed by application of the formula predicting head width from total length[1].

$$\text{Total length (mm)} = (SL - 0.003)/0.84$$

$$\text{Head width (mm)} = -2.66 + (0.28 \times TL) - (0.004 \times TL^2) + (0.000028 \times TL^3)$$

Fineness ratios (standard length/head width) were then calculated for Delta Smelt from 20- to 80-mm SL in 0.1-mm SL increments, and the required vertical opening size for each size of Delta Smelt was estimated from rearrangement of the relationship between mesh size, standard length, and fineness ratio.

$$\text{Required vertical opening (mm)} = SL/(0.0209 \times SL + 0.06564 + 1.199 \times F)$$

This formula indicated that the proposed 1.75-mm screens would be expected to exclude Delta Smelt of approximately 20.45 mm (Figure 6.A-2). Thus, Delta Smelt larger than ~20-21 mm could be impinged but most likely not entrained all the way through the fish screens, whereas Delta Smelt less than ~20-21 mm long could be either impinged on or entrained all the way through the fish screens. For fish near 20 mm, the result would probably be mortality in either case, unless no water was being diverted through the screen at the time of screen contact. The potential for Delta Smelt to swim away from the screens after impingement would be expected to increase with increasing body size (above 20 mm), although this was not observed in experiments using 25-40-mm-long Delta Smelt (Swanson et al. 2005).

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[1] The formula relating head width to standard length that is presented by Young et al. (1997) did not give results consistent with their Figure 1. Therefore it was necessary to first use the formula predicting total length from standard length, followed by the formula predicting head width from total length, in order to obtain a predicted head width for a given standard length.

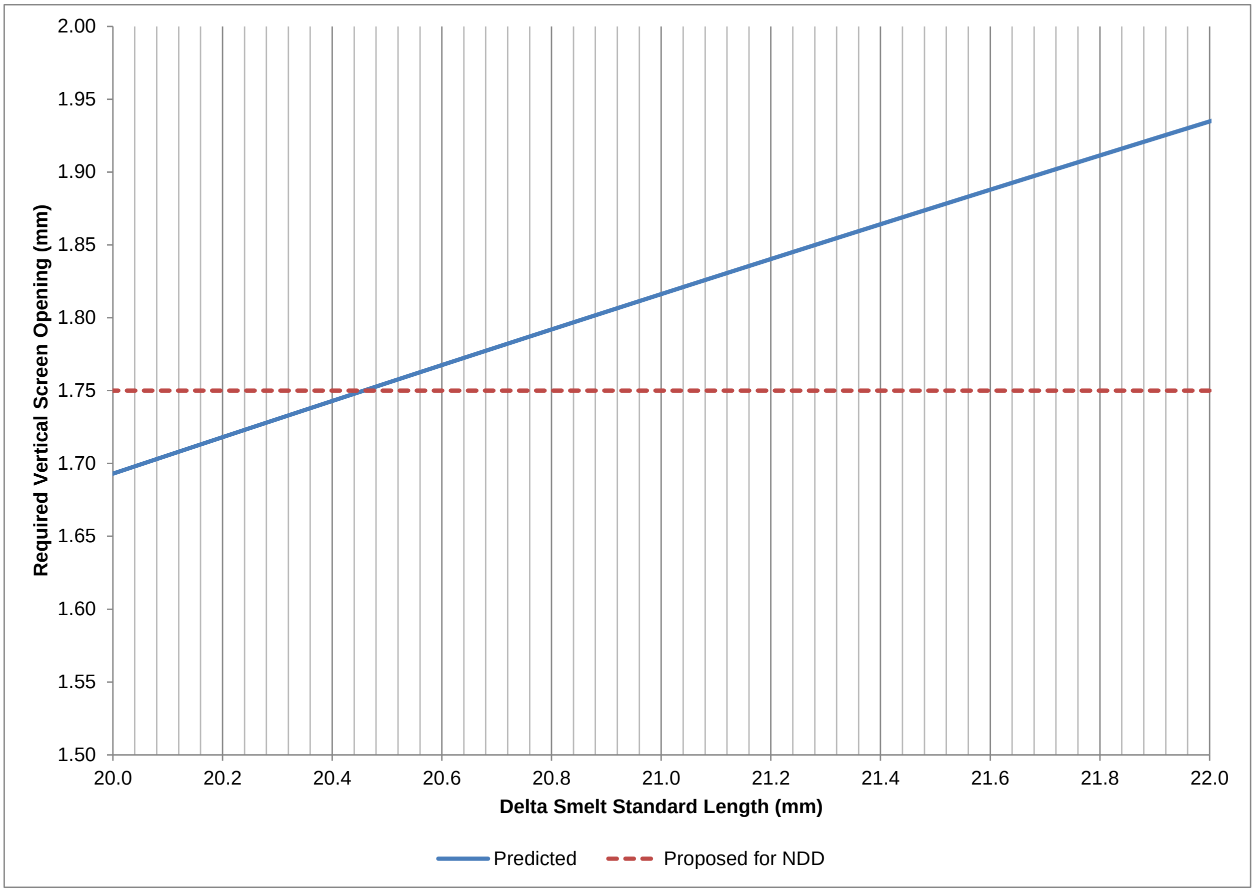


Figure 6.A-2. Predicted Vertical Screen Opening Required for Delta Smelt, in Relation to Proposed NDD Opening

6.A.2.3 Impingement and Screen Contact

The potential for effects of the proposed north Delta diversions in terms of injury and mortality caused by impingement and screen contact was assessed in a series of experiments conducted at the University of California, Davis (UC Davis) Fish Treadmill Facility (Swanson et al. 2005; White et al. 2007; Young et al. 2010). These studies examined the effects of various approach and sweeping velocities during daytime and nighttime at different temperatures on swimming behavior and screen interactions, injury and physiological stress indicators. The effects analysis of the proposed north Delta intake screens is qualitative because sweeping velocities near the screens have not been modeled with simulated operation of the screens. As described in Chapter 3, *Description of the Proposed Action*, the proposed NDD would include fish screens that are 1,350 feet long (intakes 2 and 5) or 1,110 feet long (intake 3). The screens would be operated to an approach velocity of 0.2 feet per second, which is often used as a criterion to protect Delta Smelt from excessive impingement.

The number of fish screen contacts and resulting injury and mortality was estimated for several different environmental conditions that represent a range that could occur at the proposed NDD screens. The calculations were made for the lengths of screen proposed at intakes 2, 3, and 5, with calculations made for day and night, at sweeping velocities between 0.1 and 2 feet per second. The analysis was standardized to a temperature of 12°C, which is representative of ambient water temperatures in February/March. Key terms in these analyses include approach velocity (water velocity towards and perpendicular to the screen face), sweeping velocity (water velocity parallel to the screen face), swimming velocity (velocity through the water but not over the bottom), and screen passage velocity (velocity of fish moving past the screen, either upstream or downstream). Note that the final quantity of interest (i.e., percentage mortality) in these analyses is estimated from a series of linked equations that explain different quantities of variation in the underlying experimental data and often comparatively low amounts of variation (e.g., less than 50 percent). The analyses do not propagate the uncertainty introduced from combining equations. Note also that the experiments upon which the equations are based were conducted in relatively benign laboratory conditions and do not account for environmental conditions that could influence fish swimming performance (e.g., water quality other than temperature, or reduced visibility during the day because of turbidity). In addition, the fish treadmill studies were conducted in a channel that measured approximately 0.44 meter deep, 1.2 meters wide, and 10.5 meters in circumference (Swanson et al. 2005); the NDD would be located in a river channel that is more than 100 meters wide, and the screens would be 12 to 17 feet tall (Chapter 3, *Description of the Proposed Action*).

Two of the analyses presented below (Section 6.A.2.3.1.1 *Adult Delta Smelt (Number of Screen Contacts)*; Section 6.A.2.3.1.2, *Juvenile and Adult Delta Smelt (Percentage Mortality)*) were based on an assessment methodology undertaken as part of the BDCP Fish Facilities Technical Team planning effort (Webb, pers. comm.). The other analysis (Section 6.A.2.3.1.3 *Adult Delta Smelt (Screen Passage and Survival)*) was adapted from an analysis provided by USFWS following review of an earlier draft of this BA.

As described in Section 3.2.2.2, *Fish Screen Design*, 22-foot-wide refugia could be provided between each of the six screen bay groups at the three intakes, which, if effective, could provide resting areas and predator refuge for Delta Smelt occurring near the intakes. However, given that the refugia are still in the conceptual design phase and there is uncertainty as to their effectiveness for Delta Smelt, the analyses presented here only account for the refugia by excluding the refugia length from the estimates of overall screen length at each intake.

6.A.2.3.1.1 Adult Delta Smelt (Number of Screen Contacts)

The screen contact rate has a positive correlation with physiological stress (measured as plasma cortisol) in adult Delta Smelt (Young et al. 2010). For adult Delta Smelt (fish greater than 5 centimeters [cm] SL), calculations were made of the number of contacts with a screen, based on the equations of Young et al. (2010). These experiments were conducted only during the day. The contact rate was calculated as follows:

> Contact rate (contacts/fish/min) = 0.042 + 0.009 (approach velocity, cm/s) – 0.001 (sweeping velocity, cm/s); $r^2 = 0.421$

Total number of contacts was calculated as contact rate multiplied by exposure duration, which was calculated based on screen length and swimming velocity, with the latter estimation based on the equation of Young et al. (2010).

> Swimming velocity (cm/s) = 14.283 + 0.459 (approach velocity, cm/s) + 0.117 (sweeping velocity, cm/s) – 0.003 (approach velocity × sweeping velocity, cm/s); $r^2 = 0.410$

6.A.2.3.1.2 Juvenile and Adult Delta Smelt (Percentage Mortality)

For juvenile and adult Delta Smelt (4.6–6.3 cm SL), calculations were made of percentage mortality based on the equations of Swanson et al. (2005). Note that "percentage mortality" refers only to the Delta Smelt occurring in the reach of the Sacramento River where the proposed NDD would be situated and, of those, only the ones attempting to move upstream past the intakes near the left (east) bank of the river.

> 48-hour % mortality (day) = -26.59 + 171.90 (contact rate, contacts/fish/min) + 1.31 (temperature, °C) + 1.04(approach velocity, cm/s); n= 56, $r^2 = 0.4815$, SEE = 13.31
>
> 48-hour % mortality (night) = -35.09 + 7.63 (contact rate, contacts/fish/min) + 1.75 (temperature, °C) + 2.16 (approach velocity, cm/s) + 0.05 (approach velocity × sweeping velocity, cm/s); n= 56, $r^2 = 0.7667$, SEE = 13.77

Contact rates in the above equations were calculated from the equations of Swanson et al. (2005).

> Contact rate (day, contacts/fish/min) = 0.0035 (approach velocity, cm/s) + 0.0001 (approach velocity × sweeping velocity, cm/s); n = 95, $r^2 = 0.6454$, SEE = 0.0556
>
> Contact rate (night, contacts/fish/min) = 0.0164 (approach velocity, cm/s) + 0.0002 (approach velocity × sweeping velocity, cm/s); n = 61, $r^2 = 0.4315$, SEE = 0.5405

Percentage mortality estimates assume a 2-hour screen exposure because this was the standard duration of the Fish Treadmill experiments. Mortality was adjusted to reflect estimated exposure duration. Exposure duration was estimated as a function of screen passage velocity, which was calculated from the equations of Swanson et al. (2005).

> Screen passage velocity (day, cm/s) = -12.11 + 0.92 (sweeping velocity, cm/s) + 1.32 (swimming velocity, cm/s); n = 87, $r^2 = 0.9689$, SEE = 3.78
>
> Screen passage velocity (night, cm/s) = -0.91 (sweeping velocity, cm/s) + 0.36 (swimming velocity, cm/s); n = 43, $r^2 = 0.9794$, SEE = 4.59

Screen passage velocity in the above equations was a function of swimming velocity, which again was estimated using the equations of Swanson et al. (2005).

> Swimming velocity (day, cm/s) = 11.24 + 0.24 (approach velocity, cm/s) + 0.09 (sweeping velocity, cm/s) + 0.37 (temperature, °C); n = 87, $r^2 = 0.3412$, SEE = 4.30
>
> Swimming velocity (night, cm/s) = 6.83 + 0.52 (approach velocity, cm/s) + 0.15 (sweeping velocity, cm/s); n = 87, $r^2 = 0.8534$, SEE = 2.13

6.A.2.3.1.3 Adult Delta Smelt (Screen Passage and Survival)

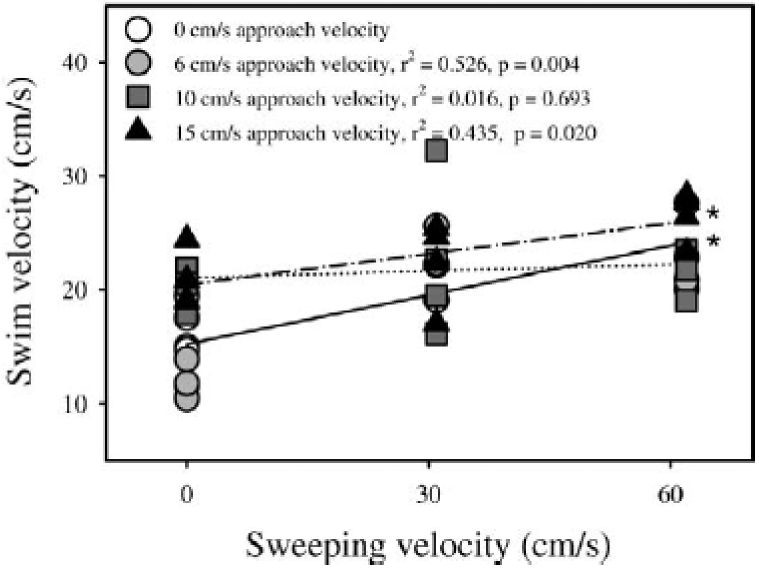
During the fall, the spatial distribution of the Delta Smelt population contracts due to seasonal increases in estuarine salinity (Feyrer et al. 2007). When it rains during the winter, the population expands its distribution in response to the increase in turbid fresh water (Sommer et al. 2011; Murphy and Hamilton 2013). This expansion is probably facilitated by numerous behaviors, but tidal surfing (changes in how the fish use channels when tides change) is one set of behavioral mechanisms that Delta Smelt can use to either stay in a desired location or to move rapidly

(Feyrer et al. 2013; Bennett and Burau 2015). As previously described in Section 6.A.2.1, *Migrating Adult Movement Upstream (DSM2-PTM)*, this effects analysis employed PTM using a simple tide surfing behavior originally described by Culberson et al. (2004) to evaluate the likelihood that adult Delta Smelt could tide surf to the proposed locations of the NDDs (see Section 6.A.2.1).

The results of the PTM analysis indicated that there was no measurable probability that tide surfing fish could ascend the Sacramento River even to Isleton, much less further upstream to the reach of river where the NDDs would be constructed. This makes intuitive sense for two reasons. First, the tidal energy extending up into Cache Slough is much greater than the tidal energy extending into the comparatively narrow mainstem channel. Second, both flood and ebb tide flows are usually moving downstream in the Sacramento River where the proposed NDDs would be built. Once the tides stop flowing in two directions, the standard tide surfing mechanisms would no longer work to move fish upstream. However, a few adult Delta Smelt do ascend the Sacramento River (Merz et al. 2011), in one robustly documented instance, even reaching Knight’s Landing, which is well beyond the reach of tidal influence (Vincik and Julienne 2012). The most parsimonious explanation for how Delta Smelt can accomplish this against strong water velocities is to do something they do less frequently further downstream – move toward the shoreline where water velocities are slower.

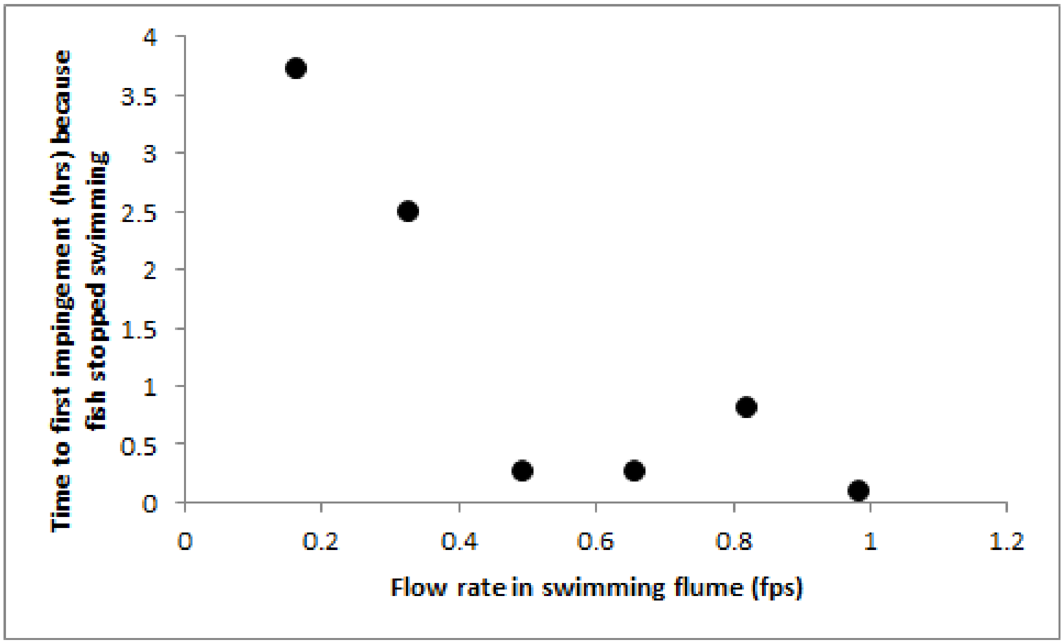
Once constructed, each of the NDDs will be a vertical wall of fish screens extending ~1,100-1,350 feet at a stretch along the east bank of the Sacramento River (see Chapter 3, Section 3.2.2.2, *Fish Screen Design*). If adult Delta Smelt attempt to move upstream along the east bank of the river, these areas will no longer have shoreline with relatively low velocity, requiring swimming against in-channel velocities if attempting to pass the screens. By virtue of small body size Delta Smelt are relatively “poor” swimmers (Swanson et al. 1998). In addition, they are non-continuous swimmers. This makes sense because they evolved in a high velocity tidal environment (as did their immediate ancestor, the surf smelt *H. pretiosus*) where it would be energetically wasteful for a small fish to swim against currents all the time.

Swanson et al. (1998) estimated that on average, the maximum sustainable swimming speed for Delta Smelt is 27.6±5.1 cm/s (0.91±0.17 ft/s), for about ten minutes. This estimate was not sensitive to fish length over the size range 30-70 mm (see Figure 1 of Swanson et al. 1998). Thus, for a Delta Smelt to swim upstream at all, the river velocity has to be less than their sustainable swimming speed. If the river velocity is higher than the sustainable swimming speed and Delta Smelt cannot escape the current, then they will be pushed back downstream. Young et al. (2010) found that sweeping velocities in the Fish Treadmill affected the swimming speed of adult Delta Smelt; when sweeping velocity was experimentally increased (analogous to river velocity), Delta Smelt increased their swimming speed (Young et al. 2010: Figure 2). However, the observed increases were very slight, and the mean swimming speed predictions from the equation produce even slower swimming speeds than the Swanson et al. (1998) results. Note the 1998 swimming speed estimate is very close to the maximum observed at the maximum sweeping velocity tested and therefore it provides an optimistic estimate of Delta Smelt’s swimming ability. If the average 2010 swimming speeds are substituted for the 1998 results, *then no adult Delta Smelt could ever pass the NDDs except when flows are too low to enable pumping*. Thus, it is acknowledged that calculations based on the 1998 swimming speed estimate will be inherently optimistic for three reasons. First, newer estimates suggest slower mean swimming speeds based on longer duration calculations (Young et al. 2010; Figure 2). Second, lacking information on how straight of a line Delta Smelt would swim in when trying to pass a long fish screen, it is necessary to make the assumption that they will swim in a perfectly straight line. Third, Delta Smelt are unlikely to swim continuously for lengthy periods of time when there is a current (Swanson et al. 1998; Figure 3), but for this analysis it was considered too speculative to try to adjust calculations based on such a nonlinear response developed under confined conditions to which the fish are not adapted. Thus, for the following analysis, the simplifying assumptions are made that the fish will swim past the fish screen in a straight line and that if they can swim the necessary distance in one hour or less that they will swim continuously except during the moments they are predicted to be impinged. The one-hour time step is reasonable because at the minimum channel velocity at which diversions were assumed to be allowable in the operations modeling (0.4 ft/s; see Appendix 5.A, Section 5.A.5.2.4.9, *North Delta Diversion Bypass Flows*, and Appendix 5.B, Section 5.B.2.3.5, *North Delta Diversion Operations*) Delta Smelt could theoretically swim upstream 1,110 feet in 0.60 hours and 1,350 feet in 0.74 hours (0.91 ft/s minus 0.4 ft/s = 0.51 ft/s "net" upstream swimming speed * 3,600 s/hr = 1,836 ft/hr). A similar calculation shows that Delta Smelt could possibly swim past a 1,350-foot-long fish screen in one hour when their net upstream swimming velocity was at least 0.375 ft/s. On the basis of the 0.91-ft/s maximum sustainable swimming speed, this would happen whenever Sacramento River velocity in front of the fish screens was less than 0.535 ft/s (or when Sacramento River flow was low enough that flood tide currents "reversed" the river flow and moved net currents in an upstream direction).



Source: Young et al. (2010: Figure 7).

Figure 6.A-3. Sweeping Velocity in the UC Davis Fish Treadmill Versus Swimming Velocity of Adult Delta Smelt During Two-Hour Experiments



Source: Swanson et al. (1998: Table 1).

Figure 6.A-4. Flow rates Experienced by Delta Smelt In A Swimming Flume Versus Time Until the Fish Were First Impinged Against the Back of the Flume Because They Had Stopped Swimming

The best available information on what Sacramento River velocities might be in front of the NDDs is from the velocity gauge in the river at Freeport (CDEC gauge FPT, sensor 21). These data were downloaded at an hourly time step for the months of December-June based on Delta Smelt collections in the area described in Appendix 6.A. The Freeport velocity data were available for 1990-2000. The hourly river velocities were converted into net upstream swimming velocities for adult Delta Smelt: 0.91 ft/s minus measured velocity, and the results were summarized using a histogram. This analysis was also repeated using only December-March data, which based on the fish salvage facilities in the south Delta, represents a time of year that most adult Delta Smelt “migration” occurs (Grimaldo et al. 2009).

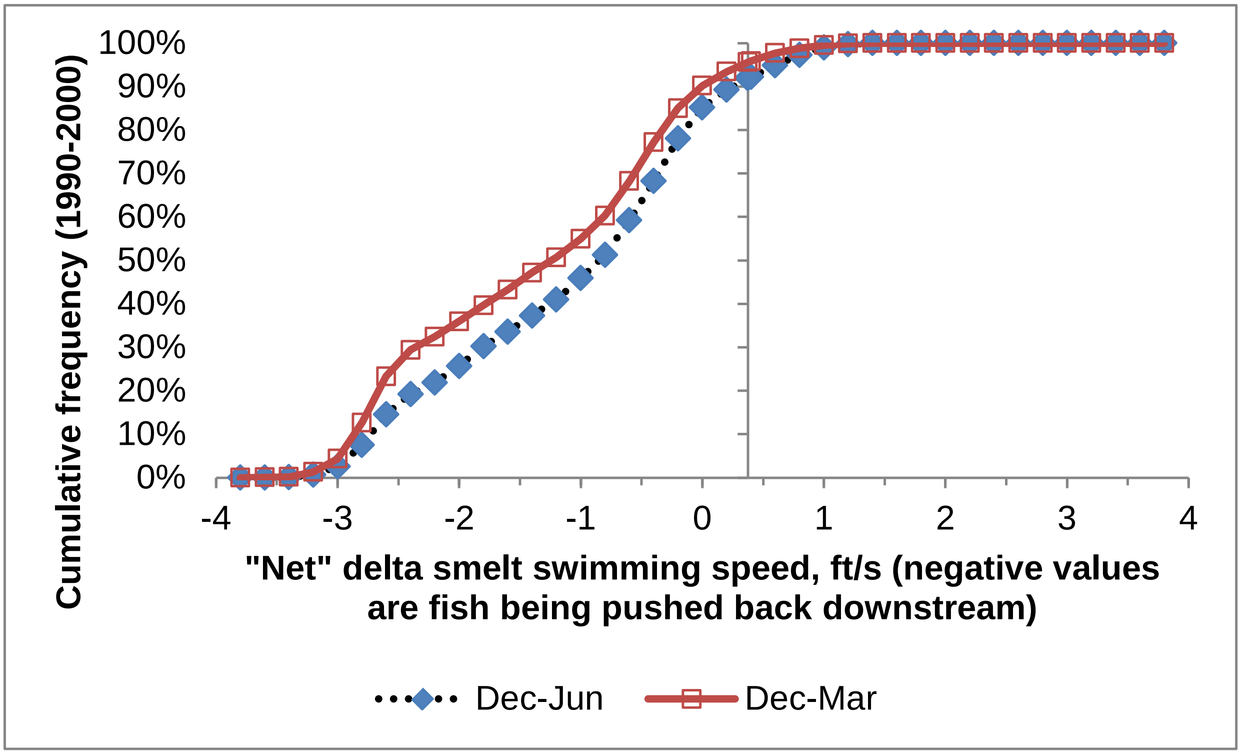


Figure 6.A-5. Cumulative Frequency Distributions of Estimated Swimming Velocities of Adult Delta Smelt in the Sacramento River (0.91 ft/s minus measured velocity at Freeport) for December-June, 1990-2000 (blue symbols with black line) and December-March, 1990-2000 (red line and symbols). Note that the y-axis crosses the x-axis at 0.375 ft/s, the velocity at which Delta Smelt could swim far enough in one hour to theoretically pass a 1,350-foot-long fish screen

Hourly river velocities slow enough that Delta Smelt could swim upstream more than 1,350 feet in an hour occurred with a frequency of 0.081 during December-June 1990-2000 and 0.044 during December-March 1990-2000 (Figure 6.A-5). This analysis was repeated using a swimming speed of 19 cm/s (0.62 ft/s), which was loosely derived from Young et al. (2010). The use of this slower swimming speed had the obvious effect of making estimates of successful fish passage even rarer; 0.042 and 0.018 for December-June and December-March, respectively (results not shown).

February 1 – 27, 1991 was a low-flow period in a drought year in which data were fairly complete and in-channel river velocities were frequently slow enough (based on the assumptions described above) to enable Delta Smelt to move upstream at rates exceeding 1,350 ft/hr. Therefore, this time period was used to develop estimates of survival rates of Delta Smelt passing the proposed fish screens using the daytime mortality equation provided by Swanson et al. (2005). To the extent that Freeport velocity represents a bypass flow velocity in front of the NDD fish screens, during February 1991, hourly river velocities were high enough to allow NDD pumping 72 percent of the time (based solely on the 0.4 ft/s velocity criterion assumed for modeling purposes, and not accounting for any other NDD operations considerations), but the percentage of time that pumping could occur *and* Delta Smelt could theoretically pass the screen was only 8.0 percent - comparable to the longer term fraction shown in Figure 6.A-5. The analysis of mortality was restricted to these 8.0 percent of observations because it was assumed that river velocities exceeding the maximum sustained swimming speed of Delta Smelt will prevent the fish from even trying to pass the screen, and that river velocities that Delta Smelt can only very slowly swim upstream against will likewise dissuade fish from attempting to pass the screen or cause 100 percent mortality of the individual fish that attempt it under those conditions. Note that these fates are accounted for by the large fractions of impassable velocities shown in Figure 6.A-5.

The linear regression equation describing the estimated mortality from the fish treadmill experiments (Swanson et al. 2005) was the same as the one used for the analysis of daytime mortality presented in Section 6.A.2.3.1.2, *Juvenile and Adult Delta Smelt (Percentage Mortality)*:

> 48-hour % mortality (day) = -26.59 + 171.90 (contact rate, contacts/fish/min) + 1.31 (temperature, °C) + 1.04(approach velocity, cm/s); n= 56, $r^2 = 0.4815$, SEE = 13.31

As previously noted, Swanson et al. (2005) also developed an equation for night time exposures that predicts a lower mortality rate. This equation was not used because several ambitious assumptions about swimming speed had already been made in the calculations and because data were lacking to indicate that Delta Smelt actively migrate at night. Freeport water temperature data (CDEC gauge FPT, sensor 25) for February 1 – 27, 2010-2015, were downloaded to generate a range of likely water temperatures during which Delta Smelt would be expected to ascend the Sacramento River.

As previously described, the screen contact rate is a linear regression function of the approach and sweeping velocities:

> Contact rate (contacts/fish/min) = 0.042 + 0.009 (approach velocity, cm/s) – 0.001 (sweeping velocity, cm/s); $r^2 = 0.421$

The Freeport velocity data were used to represent the sweeping velocity required for the calculation of mortality, and the approach velocity in both equations was assumed to be 0.2 ft/s (6.1 cm/s) if Freeport velocity equaled or exceeded 0.4 ft/s (12.2 cm/s) and zero otherwise, consistent with the modeling assumption that no pumping would be allowed when the bypass velocity criterion was not met.

The estimated probability that an individual Delta Smelt would successfully pass the downstream-most NDD screen was estimated as:

$P = U*S$

Where, P is the probability of successful passage, U is the probability water velocity was slow enough that an average Delta Smelt could swim at least 1,350 feet upstream in one hour or less (described above to range from 0.044 to 0.081), and S is the survival of Delta Smelt passing the screen in the event they could. Survival was derived from the predictions of the 48-hour mortality equation (Swanson et al.2005) presented above as 1-(mortality/100); variation in S was generated using variation in upstream swimming distances of Delta Smelt derived from variation in Freeport velocity (1990-2000) and using the six years of hourly water temperature data described above (2010-2015).

6.A.3 South Delta Exports

6.A.3.1 Percentage Loss Equations

The percentage of the Delta Smelt population lost to entrainment at the south Delta export facilities was estimated for the various modeling scenarios using similar regression equations to those used by the U.S. Fish and Wildlife Service (USFWS) (2008). The regression equations were based on the estimates of proportional entrainment by Kimmerer (2008), which were disputed and subsequently revised (Kimmerer 2011; Miller 2011). They are being revisited further in the Collaborative Science and Adaptive Management Program (CSAMP) process (see discussion below). Kimmerer's (2008) original estimates of entrainment loss had large confidence limits, which Kimmerer (2008:24) noted could be reduced by additional sampling. Since Kimmerer's (2008) paper was published, it has been recognized that turbidity plays a major role in the salvage of Delta Smelt, particularly in the adult stage (Grimaldo et al.2009). Thus, some of the uncertainty alluded to above is caused by the lack of turbidity as a predictor in Kimmerer's (2008) model. In addition, Miller (2011) assessed the explicit and implicit assumptions of Kimmerer's (2008) estimation methods and surmised that for estimates of adult proportional entrainment, there were eight assumptions of which three may have biased the estimates upward, one may have estimated the bias downward, and the remainder would not have resulted in bias. For larval-juvenile entrainment, Miller (2011) suggested that of 10 assumptions made by Kimmerer (2008), eight would have resulted in upward bias and two would not have resulted in bias. Miller (2011) suggested methodological adjustments for four of the assumptions that could have resulted in bias of adult and juvenile proportional entrainment estimates, but was not able to quantify adjustments for eight of the potential assumptions leading to (upward) bias. In response to the quantifiable biases suggested by Miller (2011), Kimmerer (2011) concurred with one (leading to a downward adjustment of his adult loss estimates by 24% [by multiplying by 0.76]; see detail below in Section 6.A.3.1.1, *Adults*) and rejected the others. A number of assumptions that may introduce upward bias remain unresolved and contribute to uncertainty in the estimates. At this time, there is no reliable way to forecast future turbidity, and therefore, the assumption is made that, on average, or across years, relative adult entrainment risk for comparison across model scenarios can be reasonably reflected using predictions of Old and Middle River (OMR) flow based on the USFWS (2008) equation. Similarly, it is assumed that the relative risk of larval-juvenile entrainment in the south Delta can be characterized by using predictions of X2 and OMR flow per equations similar to those developed by USFWS (2008). The equations and the adjustment are described further below.

Although much is known about the factors that affect entrainment of Delta Smelt, there remains uncertainty in a number of key aspects. Further investigation of the factors that influence entrainment is being undertaken during studies prompted by the CSAMP (Collaborative Adaptive Management Team [CAMT] 2014). The CSAMP was launched following a decision by the United States District Court for the Eastern District of California on April 9, 2013, issued in response to a motion to extend the court-ordered remand schedule for completing revisions to the NMFS (2009) and USFWS (2008) biological opinions (BiOps). Under the CSAMP, CAMT has the mission of working to develop a robust science and adaptive management program that will inform Central Valley Project (CVP) and State Water Project (SWP) operations, particularly with respect to Delta operations. Key questions and possible investigative approaches related to entrainment are summarized in Table 6.A-6. Knowledge gained from these investigations will inform future refinement of operations to protect Delta Smelt, which could then be implemented under the No Action Alternative (NAA) and the PA.

Table 6.A-5. Key Questions and Possible Investigative Approaches to Address Entrainment Management as Part of the CAMT OMR/Entrainment Work Plan

Key Questions	Possible Investigative Approaches
What factors affect adult Delta Smelt entrainment during and after winter movements to spawning areas? a. How should winter "first flush" be defined for the purposes of identifying entrainment risk and managing take of Delta Smelt at the south Delta facilities? b. What habitat conditions (e.g., first flush, turbidity, water source, food, time of year) lead to adult Delta Smelt entering and occupying the central and south Delta?	Summarization of environmental and fish distribution/abundance data (e.g., FMWT, SKT). Multivariate analyses and modeling (e.g., 3D particle tracking) to examine whether fall conditions affect winter distribution. Completion of First Flush Study analyses. The Delta Conditions Team (DCT) is currently developing a scope of work to use turbidity modeling to examine various "first flush" conditions, expected entrainment risks, and potential preventative actions that could be taken to reduce entrainment, consistent with key question (a). The DCT could also conduct analyses to address key question (b).
What are the effects of entrainment on the population? a. What is the magnitude (e.g., % of population) of adult and larval entrainment across different years and environmental conditions? b. How do different levels of entrainment for adults and larvae affect population dynamics, abundance, and viability?	a. Application of different models (e.g., individual based models, life history) to estimate proportional entrainment. A direct approach to addressing question (a) has been proposed by Kimmerer 2008, as modified in 2011. This or a derivative approach should be explored as a means to directly estimate the proportional entrainment that has occurred in recent years. Apply to as much of historical record as possible. b. Application of different models (e.g., IBM, life history, population viability analysis [PVA]) to simulate effects on population dynamics, abundance, and variability.
How many adult Delta Smelt and larval/post-larval Delta Smelt are entrained by the water projects?	Workshop or expert panel review. Testing of new field methodologies such as SmeltCAM. Gear efficiency and expanded trawling experiments. Evaluation of alternative models to estimate abundance, distribution and entrainment.
What conditions prior to movement to spawning areas affect adult Delta Smelt entrainment? Is there a relationship between Delta Smelt distribution and habitat conditions (e.g., turbidity, X2, temperature, food) during fall and subsequent distribution (and associated entrainment risk) in winter?	Summarization of environmental and fish distribution/abundance data (e.g., FMWT, SKT). Multivariate analyses and modeling (e.g., 3D particle tracking) to examine whether fall conditions affect winter distribution. Completion of first flush study analyses.

Key Questions	Possible Investigative Approaches
What factors affect larval and post-larval Delta Smelt entrainment? a. How does adult spawning distribution affect larval and post-larval entrainment? b. What conditions (e.g., first flush, spawning distribution, turbidity, water source, food, time of year) lead to larvae and post-larvae occupying the central and south Delta?	Summarization of environmental and fish distribution/abundance data. Statistical analysis and modeling (e.g. 3D PTM) of effects of adult distribution (e.g., SKT) on larval (e.g., 20 mm) distributions. Summarization of environmental and fish distribution/abundance data (e.g., 20 mm). Multivariate analyses/modeling to identify conditions promoting occupancy of central and south Delta.
What new information would inform future consideration of management actions to optimize water project operations while ensuring adequate entrainment protection for Delta Smelt? a. Can habitat conditions be managed during fall or early winter to prevent or mitigate significant entrainment events? b. Should habitat conditions (including OMR) be more aggressively managed in some circumstances as a preventative measure during the upstream movement period (e.g., following first flush) to reduce subsequent entrainment?	Synthesis of available information and study results by CAMT Entrainment Team, designated expert panel, or both. Consultation with regulatory agencies and operators about the feasibility of different actions.
Source: Collaborative Adaptive Management Team (2014).	

6.A.3.1.1 Adults

The percentage of the adult Delta Smelt population lost to entrainment at the south Delta export facilities was estimated using a similar approach to that employed by USFWS (2008)[2]. Estimates of annual percentage entrainment—as tabulated by Miller (2011: his Table 1), with downward adjustment by incorporating Kimmerer's (2011) 0.76 multiplier—were related to mean December-March Old and Middle river (OMR) flow (Smith, pers. comm.) using PROC GLM in SAS/STAT software, Version 9.4 of the SAS System for Windows.[3] The resulting GLM had $r^2 = 0.39$, and gave the following regression equation (with standard errors of coefficients in parentheses).

> percentage adult entrainment loss = 4.70299 (± 1.58901) – 0.000688 (± 0.000270)*December-March OMR Flow.

Predicted means and 95% prediction intervals of annual percentage adult entrainment loss for the NAA and PA scenarios were calculated using PROC PLM in SAS/STAT software. Estimates of negative entrainment—most notably for the lower limit of the 95% prediction intervals, which were negative in all years, for both scenarios—were changed to 0 before data summary.

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[2] The USFWS (2008) equation was not used directly because it was necessary to develop a similar regression incorporating uncertainty in parameter estimates, in order to follow the recommendation of the independent review panel report for the working draft BA to show prediction intervals (Simenstad et al. 2016).

[3] Copyright 2002-2010, SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA

It is acknowledged that the approach based solely on OMR flows does not fully encompass all factors related to entrainment loss, but that is primarily because doing so would render the estimates even less reliable. These factors would require forecasts of predictor variables that cannot be accurately forecasted (e.g., turbidity, Delta Smelt relative abundance). Estimates of percentage entrainment loss solely based on OMR flow would be overestimates if turbidity in the south Delta was not high enough to attract Delta Smelt into the area at the time of appreciably negative OMR flow or if abundance and distribution continue to be diminished. In addition, some uncertainty is introduced by using a regression that is based on point estimates of entrainment, which themselves have broad confidence intervals in some cases (Kimmerer 2008). Potential biases in the method are common to both scenarios examined in this effects analysis, although it is unknown the extent to which this affects the relative comparison of scenarios.

6.A.3.1.2 Larvae/Juveniles

For larval/juvenile Delta Smelt, regressions estimating percentage entrainment as a function of X2 and OMR flows was used to compare NAA and PA scenarios, following the approach adopted by USFWS (2008)[4]. The relevant portions of the development of the regression described by USFWS (2008: 220) are as follows:

> Kimmerer (2008) proposed a method for estimating the percentage of the larval-juvenile Delta Smelt population entrained at Banks and Jones each year. These estimates were based on a combination of larval distribution data from the 20 mm survey, estimates of net efficiency in this survey, estimates of larval mortality rates, estimates of spawn timing, particle tracking simulations from DWR's DSM2 PTM, and estimates of Banks and Jones salvage efficiency for larvae of various sizes. Kimmerer estimated larval-juvenile entrainment for 1995–2005. We used Kimmerer's entrainment estimates to develop multiple regression models to predict the proportion of the larval-juvenile Delta Smelt population entrained based on a combination of X2 and OMR. Using Kimmerer's method, larval-juvenile [entrainment] is predicted to be 0 during periods of very high outflow. For instance, Kimmerer predicted entrainment loss was 0% in 1995 and 1998. For simplicity, we estimated the relationship between X2, OMR, and larval-juvenile entrainment without 1995 and 1998 in the model because the relationship between these variables is linear when only years that had entrainment higher than 0 were modeled. [W]e developed two separate models, one for the March–June averaging period and one for the April–May averaging period. The reason for using two spring averaging periods was to demonstrate that the conclusions are robust with regard to choice of averaging period; the predicted entrainment is very similar…Because the equations were based only on data that had non-zero entrainment, they predict entrainment proportions are negative during periods of very high outflow. The negative entrainment predictions were changed to 0% before summary analysis.

The same approach was adopted for this effects analysis, using percentage entrainment estimates tabulated by Miller (2011: his Table 1; excluding water years 1995 and 1998), OMR (Smith pers. comm.), and X2 from DAYFLOW[5]. Following the approach of USFWS (2008), this effects analysis developed regressions using PROC GLM in SAS/STAT software based on OMR and

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[4] As previously noted for adult Delta Smelt, the USFWS (2008) equations were not used directly because it was necessary to develop a similar regression incorporating uncertainty in parameter estimates, in order to follow the recommendation of the independent review panel report for the working draft BA to show prediction intervals (Simenstad et al. 2016).

[5] DAYFLOW provides X2 estimates from water year 1997 onwards, so the DAYFLOW equation ($X2(t) = 10.16 + 0.945*X2(t-1) – 1.487\log(QOUT(t))$) was used to provide X2 for earlier years, based on a starting unpublished estimate of X2 (Mueller-Solger 2012).

X2 for both the March-June ($r^2 = 0.93$) and April-May ($r^2 = 0.89$) averaging periods. The resulting equations were as follows (with standard errors of coefficients in parentheses).

$$\text{percentage larval/juvenile entrainment loss} = -56.610125\ (\pm\ 12.425700) - 0.001982\ (\pm\ 0.000624)*\text{March-June OMR Flow} + 0.954589\ (\pm\ 0.205368)*\text{March-June X2}.$$

$$\text{percentage larval/juvenile entrainment loss} = -50.333484\ (\pm\ 15.735100) - 0.002736\ (\pm\ 0.001000)*\text{March-June OMR Flow} + 0.867364\ (\pm\ 0.254394)*\text{March-June X2}.$$

As noted for the adult regression analysis, some uncertainty is introduced by using a regression that is based on point estimates of entrainment, which themselves sometimes have broad confidence intervals (Kimmerer 2008). For comparison of NAA and PA scenarios, average OMR flows for the months of March–June and April–May were obtained from CALSIM modeling of the 1922–2003 water-year simulation period; these flows were averaged by water year. X2 was also obtained from CALSIM results. Because X2 output in CALSIM for a given month actually indicates X2 at the end of the previous month, the CALSIM output months for X2 averaged for the analysis in each water year were April–July and May–June, which were assumed to represent the March–June and April–May periods. The OMR and X2 data were used with PROC PLM in SAS/STAT software to produce predicted means and 95% prediction intervals of annual percentage larval/juvenile entrainment loss for the NAA and PA scenarios. Consistent with USFWS (2008: 220), estimates of negative entrainment were changed to 0 before data summary.

6.A.3.2 Larval Entrainment (DSM2-PTM)

The larval-juvenile Delta Smelt proportional loss equation for entrainment at the south Delta export facilities described above is concordant with predictions made using steady-state flows in an older version of DSM2 PTM (Kimmerer 2008). For the present effects analysis, the most recent version of DSM2 PTM was used in the effects analysis to estimate the proportional entrainment of Delta Smelt larvae by various water diversions in the Action Area (i.e., the south Delta export facilities, the NDD, and the NBA Barker Slough Pumping Plant). Further information is provided in Appendix 5.B, Section 5.B.3.3, *DSM2-PTM for Evaluating Larval Delta Smelt.* This second approach assumed that the susceptibility of Delta Smelt larvae can be represented by entrainment of passive particles, which USFWS considers likely based on existing literature (Kimmerer 2008, 2011). Results of the PTM simulations do not represent the actual entrainment of larval Delta Smelt that may have occurred in the past or would occur in the future, but rather should be viewed as a comparative indicator of the relative risk of larval entrainment under NAA and PA scenarios. For purposes of this effects analysis, those particles that were estimated to have entered the various water diversion locations included in the PTM outputs (e.g., south Delta export facilities, NDD, and NBA) are characterized as having been entrained. The latest version of DSM2-PTM allows agricultural diversions to be excluded as sources of entrainment (while still being included as water diversion sources): for this effects analysis, these agricultural diversions were excluded, given the relative coarseness of the assumptions related to specific locations of the agricultural diversions, the timing of water withdrawals by individual irrigators, and field observations that the density of young Delta Smelt entrained by these diversions is relatively low (Nobriga et al. 2004).

Delta smelt starting distributions used in the PTM larval entrainment analysis were based on the CDFW 20 mm larval survey and were developed in association with M. Nobriga (USFWS Bay-

Delta Office). This method paired observed Delta Smelt larval distributions from survey data with modeled hydraulic conditions from DSM2 PTM. Each pair was made by matching the observed Delta outflows of the first 20 mm survey that captured larval smelt (16 years of 20 mm surveys, 1995–2011) with the closest modeled mean monthly Delta outflow for the months of March to June in the 82 years of PTM simulations.

The 20 mm survey samples multiple stations throughout the Delta fortnightly. The average length of Delta Smelt caught during each survey was averaged across all stations (8–10 surveys per year) (Table 6.A-7). The survey with mean fish length closest to 13 mm was chosen to represent the starting distribution of larval smelt in the Delta for that particular year (Table 6.A-7). A length of 13 mm was chosen in order to represent a consistent period each year with respect to size/age of Delta Smelt larvae, while accounting for the mean size by survey across all years and the general pattern of more efficient capture with greater size. Catch efficiency changes rapidly for Delta Smelt larvae as they grow (see Figure 8 of Kimmerer 2008); the choice of 13 mm represents a compromise between larger larvae/early juveniles (e.g., ≥ 20 mm) that are captured more efficiently but which may have moved too far to accurately represent starting distribution and likely would be behaving less like passive particles, and smaller larvae (e.g., < 10 mm) that are not sampled efficiently enough to provide a reliable depiction of starting distribution. During the period included in the analysis (1995–2011), the fourth survey was selected most frequently (range between the first and fifth surveys).

Once a survey date was chosen for a given year, the actual Delta Smelt catch during this survey was examined by station number (Table 6.A-8). Stations downstream of the confluence of the Sacramento and San Joaquin River confluence (in Suisun Bay and Suisun Marsh) were eliminated, as particles originating in these areas would not be subject to entrainment in the Delta and the PTM is better suited for the channels of the Delta than for the open-estuary environment of Suisun Bay. Several stations in the Cache Slough area also were not included as they were introduced in 2008 and did not have data for the entire period from which starting distributions are calculated. A list of stations and counts of Delta Smelt are provided in Table 6.A-8, along with the fish count not used to calculate the starting distribution, as a percentage of total fish caught during a given survey. Note that the percentage of larvae collected downstream of the Sacramento–San Joaquin confluence varies from zero to almost 100%, depending on water year. For example, in 2002 (survey 4), with relatively low outflow of approximately 13,500 cubic feet per second (cfs), only 2.5% of larvae were downstream of the confluence (Table 6.A-8). In contrast, over 70% of larvae were downstream in 1998 (survey 4), with outflow of nearly 70,000 cfs (Figure 6.A-9). These percentages were used to adjust the percentage of particles (particles representing larvae) that would be considered susceptible to entrainment.

Delta smelt counts per station were then divided by the contributing area of a given station in acres (Table 6.A-9), to remove spatial disparities, and percentages of the total number of Delta Smelt caught were calculated for each of the main areas included in the analysis. The final annual starting distributions then were established by evenly distributing assigned percentages to each DSM2 PTM node (i.e., model particle insertion points) in a given area (Table 6.A-10).

Each of the 328 months included in the PTM (i.e., March-June in 82 years) was matched to the closest starting distribution based on the average monthly Delta outflow. Average monthly Delta outflow for the months modeled by PTM hydro periods were based on CALSIM (NAA scenario)

(Table 6.A-8). Average monthly Delta outflow during the selected 20 mm survey period was calculated from DAYFLOW. If the selected survey period spanned two months (usually April–May), the applied outflow was for the month when most of the sampling occurred. The correspondence between the modeled Delta outflow and the applied starting distribution outflow from the 20 mm survey was reasonable: the mean difference was 4% (median = 1%), with a range from -221% (modeled Delta outflow of over 290,000 cfs in March 1983 matched with historical outflow of 90,837 cfs during survey 1 of 1995) to +58% (modeled Delta outflow of 4,000 cfs in several months matched with historical outflow of 9,482 cfs during survey 4 of 2008). Analysis of the PTM outputs was then done by multiplying the percentage of particles entrained from each release location by the applicable starting distribution percentage summarized in Table 6.A-9. Results were summarized for 30-day particle tracking periods as the percentage of particles being entrained at the NDD, south Delta exports, or NBA; also summarized were the percentage of particles remaining in Delta channels and the percentage of particles having past Martinez. The total number of particles released at each location was 4,000. Note that a 30-day particle tracking period may result in relatively low fate resolution at low flows (Kimmerer and Nobriga 2008), but the relative differences between scenarios would be expected to be consistent, based on previous model comparisons of 30-day and 60-day fates.

Table 6.A-6. Delta Smelt Mean Length in 20 mm Larval Survey for Each Survey Period by Survey Year (1995–2011)

Year	Month of Selected Survey[1]	Mean Fish Length (mm) for Each Survey Period[2]								
		Survey 1	Survey 2	Survey 3	Survey 4	Survey 5	Survey 6	Survey 7	Survey 8	Survey 9
1995	April	**13.3**	19.2	19.9	19.0	21.1	21.0	21.2	24.2	–
1996	May	8.6	11.2	**14.5**	17.6	17.8	21.7	22.8	23.3	–
1997	May	7.8	9.8	12.2	**13.5**	17.2	23.5	24.9	25.4	25.5
1998	May	11.0	10.0	15.3	**14.2**	17.1	21.6	26.0	24.4	27.5
1999	April/May	10.2	**12.0**	15.8	20.3	19.1	18.9	21.4	23.2	–
2000	May	5.9	9.8	11.2	**12.5**	15.1	19.8	20.1	22.6	–
2001	May	7.5	8.6	10.6	11.5	**14.8**	21.2	23.6	25.6	–
2002	April/May	0.0	8.0	11.1	**13.9**	19.1	23.1	23.3	23.2	–
2003	May	6.3	10.2	10.8	**13.6**	16.4	19.7	20.4	20.3	–
2004	May	10.9	9.1	10.5	**16.8**	20.9	21.7	24.0	27.8	–
2005	April	6.7	11.0	11.7	**14.0**	14.9	20.1	22.2	24.8	20.8
2006	May	0.0	0.0	10.9	0.0	**13.8**	18.0	18.9	21.5	21.4
2007	April	5.6	6.3	9.5	**13.7**	12.3	22.0	21.6	25.0	27.7
2008	April/May	0.0	0.0	11.6	**14.1**	17.0	22.4	22.1	26.8	28.7
2009	April	0.0	0.0	9.4	**13.2**	10.9	18.0	23.6	21.8	23.5
2010	April	6.3	0.0	11.9	**13.4**	13.1	19.3	18.5	18.8	21.3
2011	April	6.0	5.0	8.5	**12.5**	16.7	15.8	16.7	19.2	20.8

[1] Month of survey period with mean Delta Smelt length approximately 13 mm.

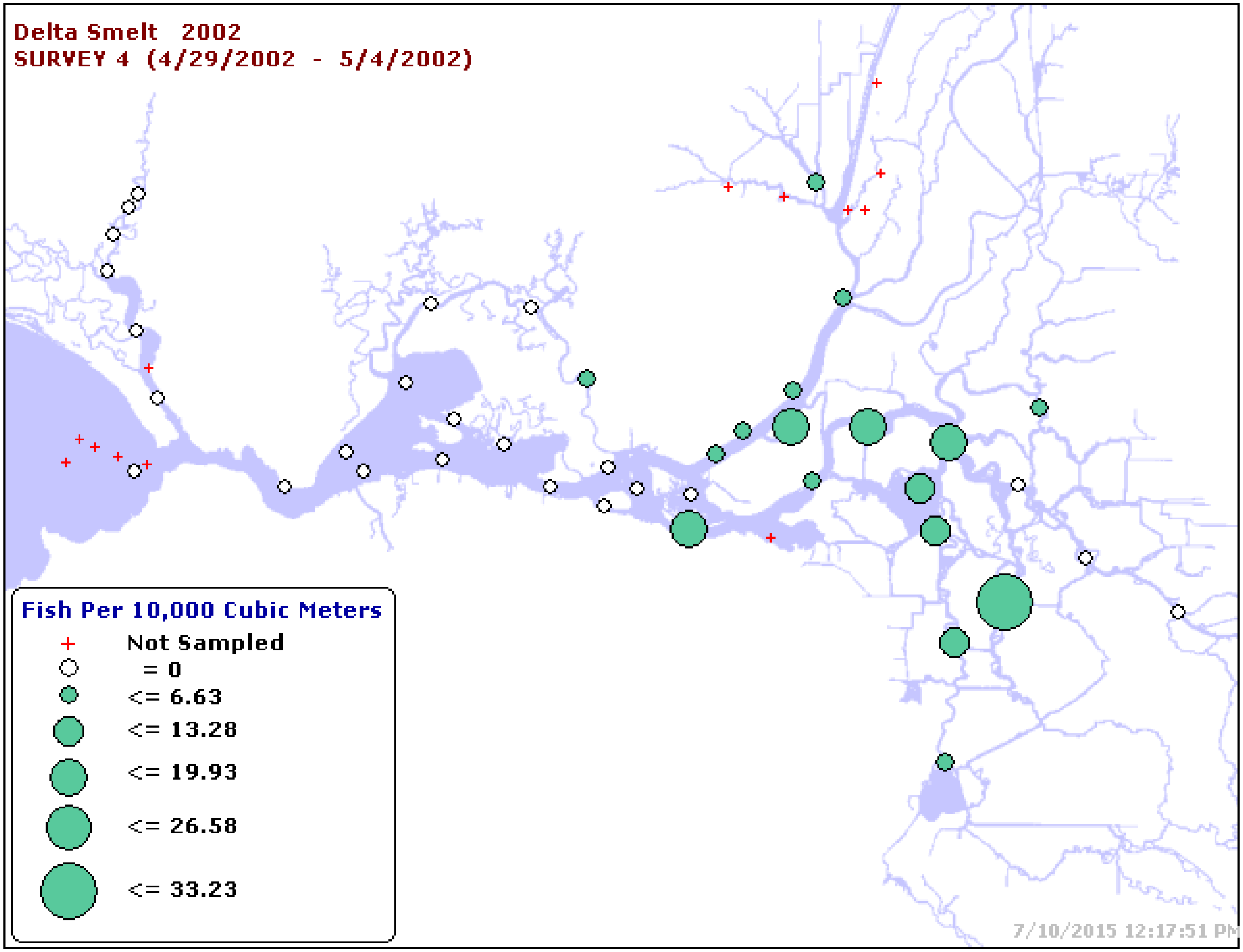
[2] Average length of Delta Smelt caught at all stations, by survey number. Survey chosen to provide starting distribution values are highlighted in **red bold** font.

Table 6.A-7. Distribution of Larval Delta Smelt (Number of Smelt) in Selected Survey Period (Survey Number)

Year	Selected Survey Number[1]	Average Monthly Outflow (cfs)[2]	Delta Smelt Count by Sampling Stations																			Number of Delta Smelt Caught at Other Stations		Percentage of Total Count Not Considered for Starting Distribution	
			West Delta/ Sacramento–San Joaquin Confluence				West Delta/Lower Sacramento River				Cache Slough and North Delta			West Delta/Lower San Joaquin River					South Delta		East Delta				
			508	513	520	801	704	705	706	707	711	716	719	804	809	812	815	901	902–915	918	919	Cache Slough Stations	Downstream of Confluence	Cache Slough Stations	Downstream of Confluence
1995	1	90,837	–	–	4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0	7	0.0	63.6
1996	3	46,021	51	110	65	41	11	4	4	–	–	–	–	8	20	8	3	5	0	1	1	0	567	0.0	63.1
1997	4	12,257	–	3	26	2	8	12	14	–	7	6	–	32	13	6	5	5	4	–	5	0	66	0.0	30.8
1998	4	67,612	1	–	1	–	–	–	2	–	–	–	–	12	–	–	–	–	–	–	–	0	43	0.0	72.9
1999	2	35,509	3	1	–	8	4	–	–	–	–	–	–	15	–	–	18	7	45	–	–	0	127	0.0	55.7
2000	4	22,057	1	18	9	18	–	1	1	–	1	3	–	8	–	1	1	–	18	21	1	0	46	0.0	31.1
2001	5	9,612	–	1	–	–	3	14	5	11	1	5	–	–	28	49	13	13	11	1	10	0	8	0.0	4.6
2002	4	13,483	–	–	–	–	–	5	1	–	1	1	–	4	1	3	5	2	14	1	1	0	1	0.0	2.5
2003	4	41,877	1	1	1	2	–	1	–	–	–	2	–	4	1	–	–	1	8	–	–	0	7	0.0	24.1
2004	4	12,354	–	7	–	13	1	8	3	2	–	2	–	5	87	6	26	4	3	2	–	0	20	0.0	10.6
2005	4	29,876	2	7	2	1	–	–	1	–	–	1	–	–	–	–	1	–	2	1	–	0	50	0.0	73.5
2006	5	82,004	–	–	–	–	–	1	–	–	1	3	–	1	–	–	1	–	–	–	–	0	242	0.0	97.2
2007	4	11,235	–	–	–	–	–	–	1	–	1	–	–	–	–	–		–	–	–	–	0	1	0.0	33.3
2008	4	9,482	–	–	–	1	1	–	–	–	–	–	2	1	–	1	2	–	3	–	–	10	0	47.6	0.0
2009	4	11,944	–	–	–	–	–	1	–	–	–	1	12	–	–	–	1	–	2	–	–	4	1	18.2	4.5
2010	4	25,102	–	2	1	1	–	–	1	–	–	2	38	1	–	–	1	–	1	–	–	16	4	23.5	5.9
2011	4	84,981	–	–	1	–	–	–	–	–	–	1	39	–	–	–	–	–	–	–	–	4	120	2.4	72.7

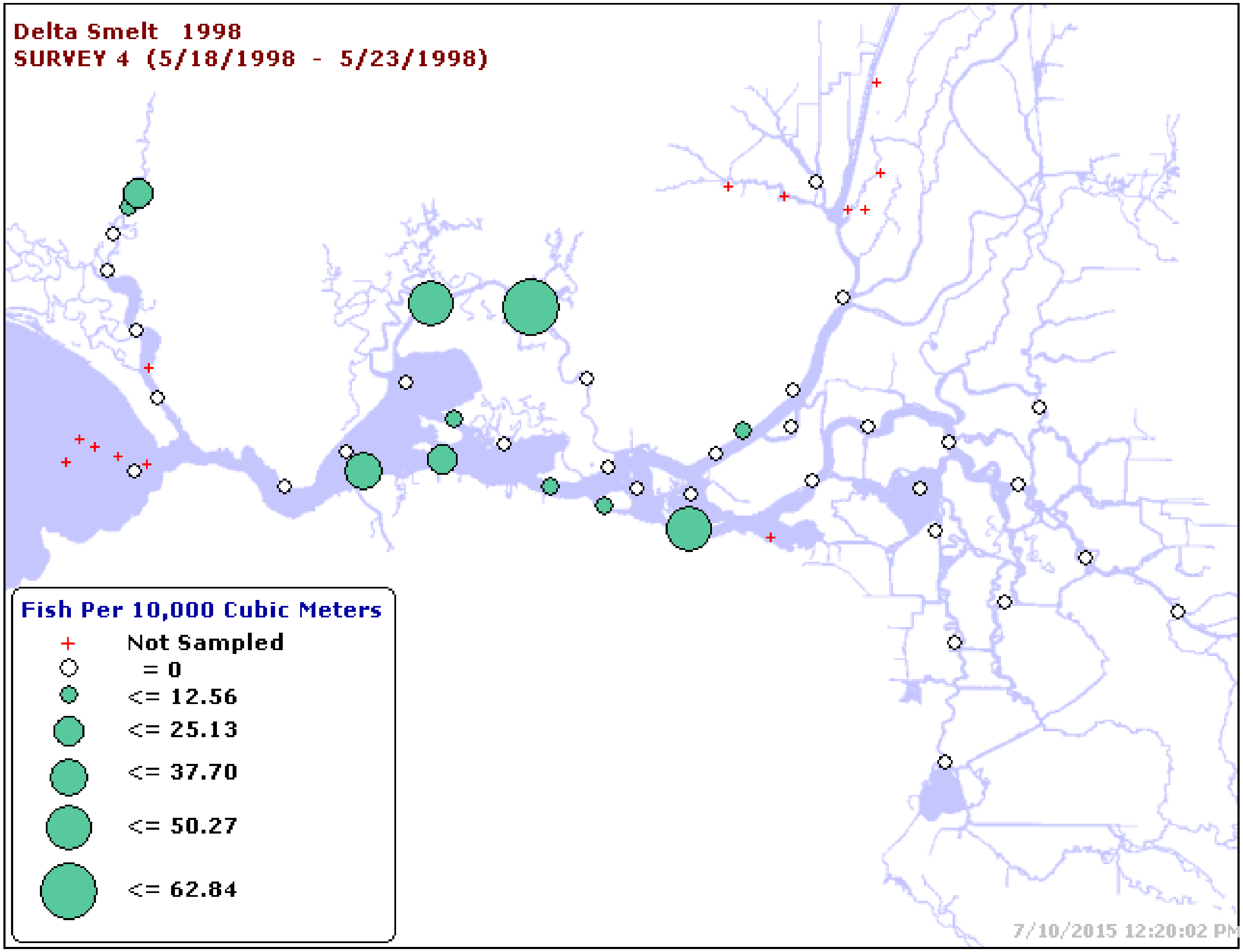
[1] The first survey of the year when mean Delta Smelt length was closest to 13 mm.

[2] Average monthly Delta outflow calculated from observed vales in DAYFLOW. If the selected 5-day survey period occurred in two months, the predominant month was chosen for the mean flow.



Source: http://www.dfg.ca.gov/delta/data/20mm/CPUE_map.asp. Accessed: July 10, 2015.

Figure 6.A-6. Density of Delta Smelt from 20 mm Survey 4, 2002



Source: http://www.dfg.ca.gov/delta/data/20mm/CPUE_map.asp. Accessed: July 10, 2015.

Figure 6.A-7.Density of Delta Smelt from 20 mm Survey 4, 1998

Table 6.A-8. Area of Water Represented by Each 20 mm Survey Station

Station	Area (acres)	Station	Area (acres)
508	2,296	812	1,767
513	1,703	815	4,023
520	438	901	3,822
801	2,226	902	1,744
704	605	906	1,780
705	277	910	1,925
706	931	912	1,225
707	1,859	914	1,554
711	1,994	915	1,146
716	3,110*	918	1,601
719	3,110*	919	2,043
804	1,195		
809	1,392		

Source: Saha 2008.
*Acreage for Station 716 was split between Stations 716 and 719.

Table 6.A-9. Percentage of Particles at PTM Insertion Location Used as Starting Distributions in the Delta Smelt Particle Tracking Analysis

Area	Average Monthly Outflow in cfs:	9,482	9,612	11,235	11,944	12,257	12,354	13,483	22,057	25,102	29,876	35,509	46,021	67,612	82,004	84,891	90,837
	Insertion Location	**Percentage of Particles**															
Sacramento –San Joaquin Confluence	Sacramento River at Sherman Lake	16.52	7.72	1.65	0	8.21	0	0.11	2.65	0	6.55	2.65	19.9	3.65	0	2.92	25.00
	Sacramento River at Port Chicago	16.52	7.72	1.65	0	8.21	0	0.11	2.65	0	6.55	2.65	19.9	3.65	0	2.92	25.00
	San Joaquin River downstream of Dutch Slough	16.52	7.72	1.65	0	8.21	0	0.11	2.65	0	6.55	2.65	19.9	3.65	0	2.92	25.00
	Sacramento River at Pittsburg	16.52	7.72	1.65	0	8.21	0	0.11	2.65	0	6.55	2.65	19.9	3.65	0	2.92	25.00
Lower Sacramento River	Threemile Slough	1.30	0.67	4.24	8.76	6.96	10.64	9.10	2.35	6.00	4.13	2.35	2.13	2.12	8.76	0	0
	Sacramento River at Rio Vista	1.30	0.67	4.24	8.76	6.96	10.64	9.10	2.35	6.00	4.13	2.35	2.13	2.12	8.76	0	0
	Sacramento River downstream of Decker Island	1.30	0.67	4.24	8.76	6.96	10.64	9.10	2.35	6.00	4.13	2.35	2.13	2.12	8.76	0	0
Cache Slough and North Delta	Miner Slough	0.32	0.35	0.06	5.86	1.26	1.05	0.40	0	9.11	0.60	0	0	0	5.86	9.82	0
	Sacramento Deep Water Ship Channel	0.32	0.35	0.06	5.86	1.26	1.05	0.40	0	9.11	0.60	0	0	0	5.86	9.82	0
	Cache Slough at Shag Slough	0.32	0.35	0.06	5.86	1.26	1.05	0.40	0	9.11	0.60	0	0	0	5.86	9.82	0
	Cache Slough at Liberty Island	0.32	0.35	0.06	5.86	1.26	1.05	0.40	0	9.11	0.60	0	0	0	5.86	9.82	0
	Lindsey Slough at Barker Slough	0.32	0.35	0.06	5.86	1.26	1.05	0.40	0	9.11	0.60	0	0	0	5.86	9.82	0
	Sacramento River at Sacramento	0.32	0.35	0.06	5.86	1.26	1.05	0.40	0	9.11	0.60	0	0	0	5.86	9.82	0
	Sacramento River at Sutter Slough	0.32	0.35	0.06	5.86	1.26	1.05	0.40	0	9.11	0.60	0	0	0	5.86	9.82	0
	Sacramento River at Ryde	0.32	0.35	0.06	5.86	1.26	1.05	0.40	0	9.11	0.60	0	0	0	5.86	9.82	0
	Sacramento River near Cache Slough confluence	0.32	0.35	0.06	5.86	1.26	1.05	0.40	0	9.11	0.60	0	0	0	5.86	9.82	0

	Average Monthly Outflow in cfs:	**9,482**	**9,612**	**11,235**	**11,944**	**12,257**	**12,354**	**13,483**	**22,057**	**25,102**	**29,876**	**35,509**	**46,021**	**67,612**	**82,004**	**84,891**	**90,837**
Area	**Insertion Location**	**Percentage of Particles**															
West Delta/ San Joaquin River	San Joaquin River at Potato Slough	0.80	2.86	25.12	7.00	10.87	11.13	19.73	17.80	0	13.16	17.80	4.24	26.34	7.00	0	0
	San Joaquin River at Twitchell Island	0.80	2.86	25.12	7.00	10.87	11.13	19.73	17.80	0	13.16	17.80	4.24	26.34	7.00	0	0
	San Joaquin River near Jersey Point	0.80	2.86	25.12	7.00	10.87	11.13	19.73	17.80	0	13.16	17.80	4.24	26.34	7.00	0	0
Central/ South Delta	San Joaquin River downstream of Rough and Ready Island	2.47	5.50	0.47	0	0.07	2.34	0.50	2.89	0	1.66	2.89	0.10	0	0	0	0
	San Joaquin River at Buckley Cove	2.47	5.50	0.47	0	0.07	2.34	0.50	2.89	0	1.66	2.89	0.10	0	0	0	0
	San Joaquin River near Medford Island	2.47	5.50	0.47	0	0.07	2.34	0.50	2.89	0	1.66	2.89	0.10	0	0	0	0
	Old River near Victoria Canal	2.47	5.50	0.47	0	0.07	2.34	0.50	2.89	0	1.66	2.89	0.10	0	0	0	0
	Old River at Railroad Cut	2.47	5.50	0.47	0	0.07	2.34	0.50	2.89	0	1.66	2.89	0.10	0	0	0	0
	Old River near Quimby Island	2.47	5.50	0.47	0	0.07	2.34	0.50	2.89	0	1.66	2.89	0.10	0	0	0	0
	Middle River at Victoria Canal	2.47	5.50	0.47	0	0.07	2.34	0.50	2.89	0	1.66	2.89	0.10	0	0	0	0
	Middle River u/s of Mildred Island	2.47	5.50	0.47	0	0.07	2.34	0.50	2.89	0	1.66	2.89	0.10	0	0	0	0
	Grant Line Canal	2.47	5.50	0.47	0	0.07	2.34	0.50	2.89	0	1.66	2.89	0.10	0	0	0	0
	Frank’s Tract East	2.47	5.50	0.47	0	0.07	2.34	0.50	2.89	0	1.66	2.89	0.10	0	0	0	0
East Delta	Little Potato Slough	0	0.08	0	0	0.26	0.30	0.74	0.00	0	0	0	0.03	0	0	0	0
	Mokelumne River downstream of Cosumnes confluence	0	0.08	0	0	0.26	0.30	0.74	0.00	0	0	0	0.03	0	0	0	0
	South Fork Mokelumne	0	0.08	0	0	0.26	0.30	0.74	0.00	0	0	0	0.03	0	0	0	0
	Mokelumne River downstream of Georgiana confluence	0	0.08	0	0	0.26	0.30	0.74	0.00	0	0	0	0.03	0	0	0	0
	North Fork Mokelumne	0	0.08	0	0	0.26	0.30	0.74	0	0	0	0	0.03	0	0	0	0
	Georgiana Slough	0	0.08	0	0	0.26	0.30	0.74	0	0	0	0	0.03	0	0	0	0

The 20 mm survey does not sample far enough upstream to inform the risk of entrainment at the proposed NDD, although Delta Smelt do occur in that reach based on other surveys (see discussion in Chapter 6, Section 6.1.3.2, *North Delta Exports*). As shown in Table 6.A-10, the single particle release location upstream of the NDD (Sacramento River at Sacramento) was included in the Cache Slough and north Delta grouping of release locations. Given that the density of Delta Smelt in the vicinity of and upstream of the NDD would be expected to be lower than the other stations in these release locations, but the particles were assumed to be equally distributed among these stations, this may generate an overestimate of the percentage of particles entrained by the NDD.

6.A.4 Habitat Effects

6.A.4.1 Abiotic Habitat Suitability (Feyrer et al. 2011)

Potential differences between PA and NAA in the extent of abiotic habitat for Delta Smelt in the fall (September–December, the older juvenile rearing and maturation period) as a function of changes in outflow (X2) were assessed using a technique based on the method of Feyrer et al. (2011).

Feyrer et al. (2011) demonstrated that X2 in the fall correlates nonlinearly with an index of Delta Smelt abiotic habitat (see Figure 3 of Feyrer et al. 2011). Note that the underlying data used in the analysis by Feyrer et al. (2011) did not include sampling stations in the Cache Slough area north of Rio Vista. As such, their model may have underestimated the frequency that Delta Smelt will use the turbid, very low-salinity water. Investigations in recent years have suggested that Delta Smelt occur year-round in the Cache Slough area, including Cache Slough, Liberty Island, and the Sacramento Deep Water Ship Channel; however, numbers have often been considerably lower in the warmer summer and fall months than during the cooler winter and spring months (Baxter et al. 2010; Sommer et al. 2011). The Delta Smelt fall abiotic habitat index is the surface area of water in the regions indicated by Figure 3 of Feyrer et al. (2011) weighted by the probability of presence of Delta Smelt based on water clarity (Secchi depth) and salinity (specific conductance) in the water. Feyrer et al.'s (2011) method found these two variables to be significant predictors of Delta Smelt presence in the fall and also concluded that water temperature was not a meaningful predictor of Delta Smelt presence in the fall, although it has been shown to be important during summer months when water temperatures are higher (Nobriga et al. 2008).

The low salinity zone, the extent of which correlates positively with X2 and therefore with the abiotic habitat index of Feyrer et al. (2011), largely overlaps the distribution of other essential physical resources and key biotic resources that are necessary to support Delta Smelt but that are not explicitly represented in the abiotic habitat index, and the higher the outflow, the more habitat and habitat variability there is for Delta Smelt to exploit. The abiotic habitat index is based on the probability of presence of Delta Smelt given certain water clarity and salinity and does not explicitly account for other abiotic (e.g., water velocity, depth) and biotic (e.g., food density) factors that may interact with water clarity and salinity to influence the probability of occurrence. However, Delta outflow and its effects on X2 are habitat elements that the projects can directly influence, whereas the other habitat features are not.

Various peer-reviewed studies have statistically examined linkages between fall abiotic habitat (often indexed by X2) and indices of Delta Smelt abundance or survival. Feyrer et al. (2007) found that Delta Smelt abundance in summer was positively related to prior fall abundance, and negatively related to prior fall salinity and water clarity. Mac Nally et al. (2010) found no evidence for a relationship between fall X2 and Delta Smelt fall abundance. Miller et al. (2012) found that neither fall X2 nor the volume of suitable fall habitat (with suitability based on salinity, water clarity, and temperature) were able to explain additional variability in trends in Delta Smelt fall-to-fall survival, beyond direct factors included in a best regression model.

As previously noted in the description of analyses related to south Delta entrainment, the CAMT has the mission of working to develop a robust science and adaptive management program through the CSAMP that will inform both the implementation of the current BiOps and the development of revised BiOps. This adaptive management team has formulated a workplan that identifies a number of key questions and possible investigative approaches to the issue of fall outflow management (Table 6.A-11; Collaborative Adaptive Management Team 2014); the investigations resulting from this work would directly inform fall outflow management under both the NAA and the PA. Such work is important to address scientific uncertainty and debate regarding the importance of fall abiotic habitat for Delta Smelt, and the methods used to analyze it. Regarding the Feyrer et al. (2011) method, the overall relationship between X2 and the Delta Smelt fall abiotic habitat index is the result of two linked statistical analyses, each of which has uncertainty that is compounded when the analyses are combined. The National Research Council (2010) has expressed concern about the effects of compounding uncertainty in linked statistical analyses such as Feyrer et al.'s (2011) analysis and its implication for quantitative conclusions. Additionally, they noted that the "weak statistical relationship between the location of X2 and the size of smelt populations makes the justification for this action [the prescribed locations for X2 in the Delta in wet and above-normal years] difficult to understand. In addition, although the position of X2 is correlated with the distribution of salinity and turbidity regimes (Feyrer et al. 2007), the relationship of that distribution and smelt abundance indices is unclear" (National Research Council 2010: 5).

Table 6.A-10. Key Questions and Possible Investigative Approaches to Address Fall Outflow Management as Part of the Collaborative Adaptive Management Team Fall Outflow Workplan

Key Questions	Possible Investigative Approaches
Are there biases in the IEP survey data? How should the survey data be utilized if biases do exist?	Convene a workshop to discuss possible survey problems and identify opportunities to address in 2014 with existing data. Consider ongoing work and approaches of Emilio Laca. Many of these issues have been proposed by FWS to be addressed through a package of gear efficiency and smelt distribution studies; however, that package includes extensive field work, and some elements have timelines extending beyond the remand period.
Under what circumstances does survival in the fall affect subsequent winter abundance?	Quantitatively determine the contribution of Delta Smelt survivorship in the fall to inter-annual population variability. Review available lifecycle models for applicability.
Under what circumstances do environmental conditions in the fall season contribute to determining the subsequent abundance of Delta Smelt?	Investigate the relationship between fall outflow and the relative change in Delta Smelt abundance using univariate and multivariate and available historic data. Related to work undertaken in the Management, Analysis, and Synthesis Team (MAST) report, which examined pairs of dry and wet years in 2005/6 and 2010/11. Also explore effects occurring through other avenues (e.g. growth or fecundity).
How much variability in tidal, daily, weekly, and monthly fluctuations in fall X2 is attributable to water project operations?	Hydrological modeling tools to determine the prospective locations of X2 in the fall under circumstances with and without project operations. An analysis of historical data will also be carried out to examine outflow during periods when the projects were required to meet specific outflow requirements, to evaluate the degree of control that has been possible at various time scales. See work addressing this issue by: Grossinger, Hutton, and a paper by Cloern and Jassby (2012)
Under what circumstances is survival of Delta Smelt through the fall related to survival or growth rates in previous life stages?	Compare Delta Smelt survival during the fall to both survival in prior seasons and to fork length at the end of the summer/start of the fall. New data are being collected as part of the Fall Outflow Adaptive Management Plan (FOAMP). Consider individual-based modeling (IBM).
Does outflow during the fall have significant effects on habitat attributes that may limit the survival and growth of Delta Smelt during the fall?	There may be competing approaches that will be simultaneously pursued. One is to develop graphs and conduct univariate and multivariate analyses involving survival ratios and growth rates. Test whether month-to-month declines in abundance or growth during the fall is greater when X2 is located further east. See also the analytical approach in MAST report, work by Kimmerer, Burnham & Manly.
Can an index based on multiple habitat attributes provide a better surrogate for Delta Smelt habitat than one based only on salinity and turbidity?	Review approaches in existing literature. There may be competing approaches that will be simultaneously pursued, depending on expert advice. One possible approach is to develop suitability index curves and combine geometrically to create a habitat quality index. Utilize data from areas where Delta Smelt are frequently observed to assess habitat quality. See work by Burnham, Manly, and Guay.
Under what conditions (e.g., distribution of the population, prey density, contaminants) do fall operations have significant effects on survival?	Utilizing relationships identified in the above studies, simulate how changes in project operations may influence survival of Delta Smelt during the fall.

Source: Collaborative Adaptive Management Team (2014)

6.A.4.1.1.1 Development of the Original X2–Fall Abiotic Habitat Index

The methods for developing the abiotic habitat index and its relationship to X2 are described in more detail by Feyrer et al. (2011). The description below is adapted from their account.

FMWT survey data were used to develop the index. The FMWT samples approximately 100 stations across the estuary each month from September to December (Stevens and Miller 1983). A subset of 73 of the 100 stations was used for analyses to avoid including stations where sampling had not occurred consistently or where Delta Smelt were rare. Each station was sampled once per month, each of the four months, from 1967 to 2008 with a single 10-minute tow. The only exceptions were that sampling was not conducted in 1974 and 1979, and in 1976 was conducted only in October and November. Measurements of the water quality variables normally are taken coincident with each sample. In total, there were nearly 14,000 individual samples with complete data for analysis spanning 42 years.

Generalized additive modeling (GAM) was used to estimate the probability of occurrence of Delta Smelt at a trawl station in a given month and year based on water temperature (°C), water clarity (Secchi depth, meters), and specific conductance, a surrogate for salinity (microSiemens per centimeter [µs/cm]). The probability of occurrence (i.e., presence-absence data) was used as the dependent variable rather than a measure of abundance (e.g., catch per trawl) to minimize the possible influence of outliers and bias associated with long-term abundance declines. This approach is supported by recent simulations, based on assumed underlying statistical distributions of fish catch, that suggest habitat curves based on presence-absence are conservative relative to catch per trawl because high frequencies of occurrence could be associated with both high and moderate catch per trawl (Kimmerer et al. 2009).

Model fits were evaluated in terms of the reduction in deviance (a measure of the explanatory power of the model, similar to variance in other modeling techniques such as analysis of variance) attributable to each of the abiotic factors, relative to a null model. The final model included Secchi depth and specific conductance but did not include water temperature, as it did not give an appreciable reduction in deviance or suggest a pattern consistent with a priori expectations. The final model accounted for 26% of the deviance. There are a number of reasons why the deviance reduction is this low, including species decline that affects the probability of catching a fish, zooplankton declines, and insufficient habitat parameters available in the FMWT data set. Of these, zooplankton decline may be particularly important (Miller et al. 2012; Rose et al. 2013a, 2013b). Nonetheless, the model is able to quantify how the basic extent of usable habitat has varied through time. These concepts were recognized prior to the analyses done by Feyrer et al. (2007, 2011), Nobriga et al. (2008), and Kimmerer et al. (2009), but they have been described in more qualitative ways (Moyle et al. 1992; Bennett 2005) or with a focus on striped bass (Turner and Chadwick 1972) or the low-salinity zone ecosystem (Jassby et al. 1995).

The Delta Smelt fall abiotic habitat index was calculated as follows:

$$H_y = \sum_{S=1}^{73} \left[A_s \frac{1}{4} \sum_{m=Sep}^{Dec} \hat{\pi}_{y,m,s} \right]$$

(Equation 1)

Where H_y is the fall abiotic habitat index, A_s is the surface area of station s and $\hat{\pi}_{y,m,s}$ is the GAM estimate of the probability of occurrence.

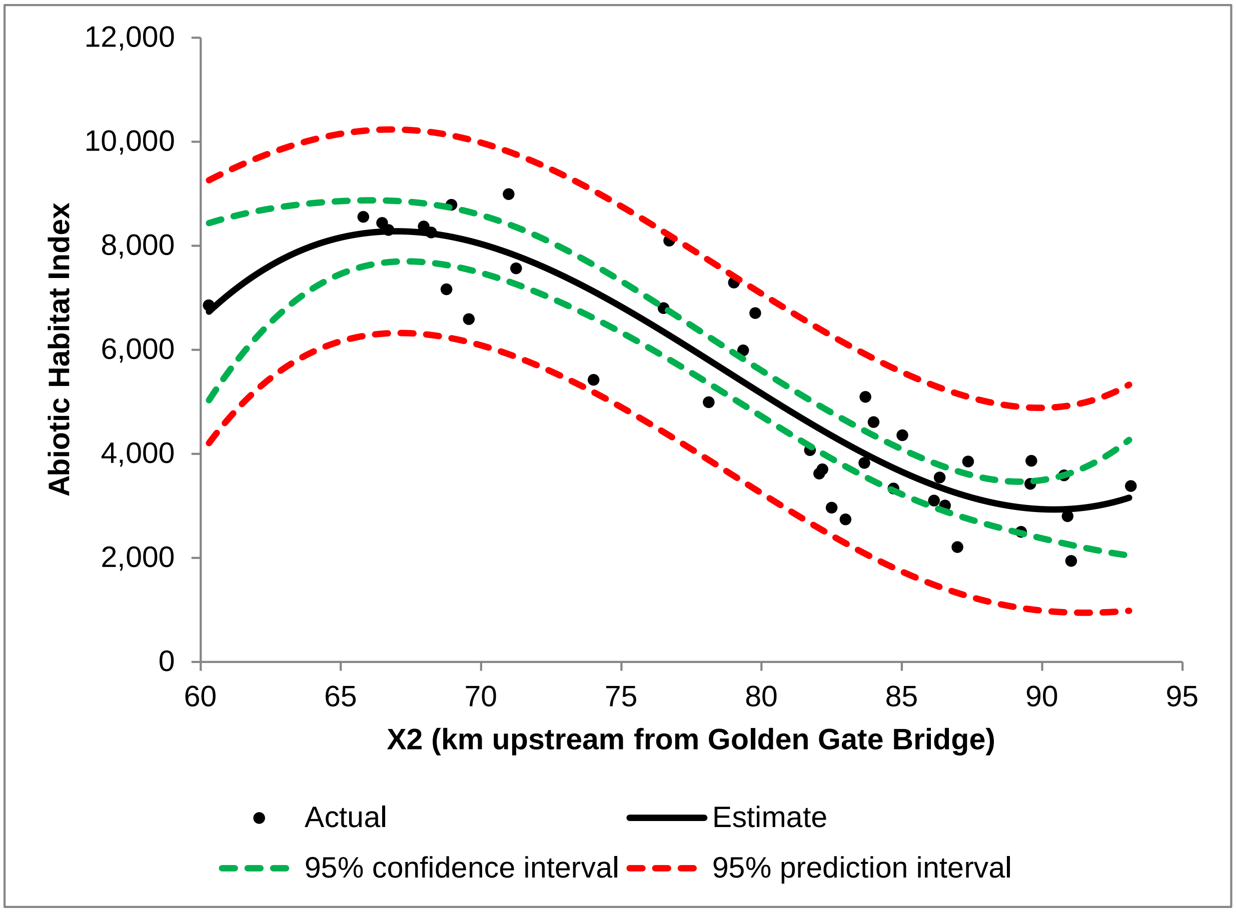
Station surface areas of each station were obtained from CDFW and originally were reported by Feyrer et al. (2007). CDFW generated surface area estimates using GIS that ranged from 90 to 1,251 hectares per station for the 73 stations. Summation of the probability of occurrence–weighted surface areas provided an index that accounts for both the quantity and value (in terms of probability of occurrence) of abiotic habitat for Delta Smelt.

Feyrer et al. (2011) developed a data-driven relationship (using locally weighted regression-scatterplot smoothing, i.e., LOWESS regression) between the habitat index and mean September to December X2, which explained 85% of the variation in the estimates of abiotic habitat (i.e., $r^2 = 0.85$). The data were averaged over the 4-month fall period to minimize the influence of sampling error that could occur if the data were summarized over shorter temporal scales. For instance, shorter averaging periods might be less reliable because samples are taken irrespective of tidal conditions across a geographic region with large tidal excursions, and because abundance estimates, and by extension distribution, can be highly variable among months (Newman 2008).

6.A.4.1.1.2 Use of the Delta Smelt Fall Abiotic Habitat Index in the Effects Analysis

Similar to the approach adopted by USFWS (2008: Figure E-20), a polynomial regression was developed using PROC GLM of SAS/STAT software to estimate the fall abiotic habitat index as a function of X2, using mean September-December habitat indices and X2 values covering 1967-2008 (Feyrer, pers. comm.). The resulting regression had $r^2 = 0.84$ (similar to the variation explained by the Feyrer et al. 2011 LOWESS regression) and the following equation (with standard errors of coefficients in parentheses), with its fit illustrated in Figure 6.A-10.

Abiotic habitat index = -371807.002122 (± 99728.528070) + 15071.698799 (± 3896.357220)*September-December X2 – 195.866498 (± 50.422170)*[September-December X2]^2 + 0.829638 (± 0.216200)*[September-December X2]^3.



Source: Developed by ICF, from data provided by Feyrer (pers. comm.)

Figure 6.A-8. Polynomial Relationship of Mean September-December Abiotic Habitat Index of Delta Smelt as a Function of X2, 1967-2008

For each year of the CALSIM period (water years 1922–2002[6]), the mean X2 was calculated for September through December and predicted means and 95% prediction intervals of the abiotic habitat index for the NAA and PA scenarios were estimated using PROC PLM in SAS/STAT software. .

6.A.4.2 Food Web Material Entrainment by the NDD

As described in Chapter 6, *Effects Analysis for Delta Smelt and Terrestrial Species*, by removing water from the Sacramento River, the NDD will also remove small planktonic organisms that otherwise would enter the Delta where they could contribute to the food web that supports Delta Smelt. This section describes the methods used to estimate this loss in relation to the overall quantity of these organisms in the Delta, with the results being reported in Chapter 6.

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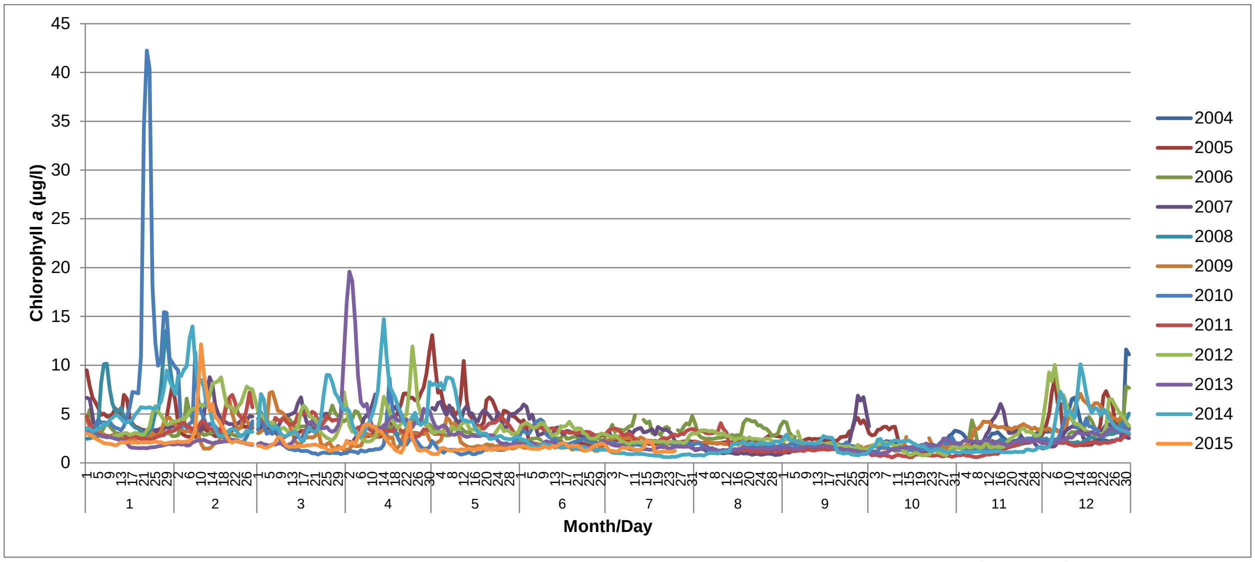
[6] Water year 2003 was omitted because only September data were available.

The indicator of food web material entrainment used in this BA was phytoplankton carbon. This choice was based on data availability and the likelihood that phytoplankton cells would be relatively uniformly distributed in the water column so that their removal from the river could be reasonably represented using DSM2-HYDRO outputs. Fluorescence data from a continuous recorder operated by DWR were assembled for various stations in the Delta. These data are calibrated to represent the concentration (µg/l) of chlorophyll *a* in the water column. Data from the Sacramento River at the town of Hood were used to estimate the rate of removal of phytoplankton carbon that otherwise would continue to be transported farther into the Delta. The 15-minute data were available from October 4, 2004, to July 27, 2015; daily means were calculated to simplify subsequent calculations (Figure 6.A-11).



Source: Gardner Jones, DWR (personal communication). Note: Chlorophyll *a* values are estimated by calibration from raw fluorescence data.

Figure 6.A-9. Daily Mean Chlorophyll *a* in the Sacramento River at Hood

The estimated chlorophyll *a* concentrations (µg/l) were converted to phytoplankton carbon using a standard ratio of 35 (Cloern et al. 1995, as cited by Jassby et al. 2002). Thus, there were 11 to 12 estimates of daily mean phytoplankton carbon concentrations for each calendar day of the year. The 11 to 12 estimates of mean phytoplankton carbon data were matched by day of the year to daily mean DSM2-HYDRO flow data for 1922–2003 to illustrate potential variability in NDD phytoplankton carbon entrainment across years. Sacramento River flow into the Delta (cubic feet per second, converted to metric units) was represented by RSAC155 (Freeport), and flow below the NDD was represented by 418_MID; RSAC155 minus 418_MID represented NDD export rate. Daily load (metric tons/day) of phytoplankton carbon entrained by the NDD was estimated for each day of the 1922–2003 DSM2-HYDRO simulation by multiplying NDD export flow by the corresponding daily mean concentration of phytoplankton carbon for 2004–2015. The resulting matrix of entrained phytoplankton carbon load (metric tons/day) was summarized into percentiles by month.

The estimates of phytoplankton carbon load entrained by the NDD were placed into the context of first-order estimates of the total biomass of phytoplankton carbon simultaneously present in the Delta by multiplying an estimated mean concentration of phytoplankton carbon in the Delta by a static average volume of the Delta (i.e., it was considered too speculative to try to adjust the volume of the Delta based on tidal cycles and flow variation). Fluorescence data—for Antioch from September 25, 2004, to July 27, 2015, were again converted to density of chlorophyll using the method described above for Hood. The Antioch data were assumed to provide a conservatively low chlorophyll *a* density compared to other available locations because of its proximity to areas that are intensively grazed by the overbite clam, so that the actual proportional entrainment is likely less than predicted using this method. The volume of the Delta upstream of Chipps Island— minus the Sacramento River upstream of Sutter Slough, in order to exclude the area approximately including and upstream of the NDD—is approximately 690,000 acre-feet, based on the Delta channel volumes that are used in the DSM2 model (see Table 5.2-1 in Section 5.2 of Jones & Stokes 2005). The total Delta-wide phytoplankton carbon biomass was estimated for each month of each year (2004 to 2015). From these data, the 5th, 50th (median), and 95th percentiles of the NDD entrained phytoplankton carbon estimates were calculated to characterize the variability in the data. Note that this method does not account for in-situ production that would replace some portion of the entrained phytoplankton, as well as less entrainment by the south Delta export facilities under the PA; these factors are discussed qualitatively in Chapter 6.

6.A.4.3 *Microcystis* (DSM2-PTM Residence Time)

As described in Chapter 6, *Effects Analysis for Delta Smelt and Terrestrial Species*, water residence time is likely to be an important factor affecting the maintenance of *Microcystis* blooms in the Delta. This section describes the methods of a residence time analysis based on DSM2-PTM. The biological context for these results is discussed in Chapter 6. Further information regarding the methods are provided in Appendix 5.B, Section 5.B.3.5, *DSM2-PTM for Evaluating Delta Residence Times*. As described in Chapter 6, *Microcystis* blooms are likely driven by other factors that are not included in this analysis. Note that an analysis based on flow (Lehman et al. 2013), as opposed to residence time, is also included in Chapter 6.

It was necessary to choose a subset of years for the analysis of residence time because it was not feasible to conduct the analyses for the full 82-year time series (1922–2003) that had been simulated with DSM2-HYDRO. To this end, the mean July to November Delta exports, outflow, and inflow across all 82 years were computed for the NAA scenario. The 82 years were sorted into five export bins, and several years were selected within each bin after examining plots of inflow versus outflow to represent the range of flow conditions. A total of 25 years was chosen, and the DSM2-PTM simulations that were run were based on the DSM2-HYDRO simulations for these years.

For each of the 25 years included in the analysis, 90-day DSM2-PTM runs were undertaken beginning the first day in each month, from July to November. There were a total of 125 runs for both scenarios (NAA and PA) (i.e., 25 years × 5 months). Particles were inserted at locations that were grouped based on subregions used in the Delta Smelt Life Cycle Model (Newman et al. in prep.) (Figure 6.A-12 and Figure 6.A-13; Table 6.A-13). Four thousand particles were inserted per subregion, and were evenly divided between the insertion locations within each subregion. The predicted particle fates were used to estimate residence time under each of these 125 sets of conditions.

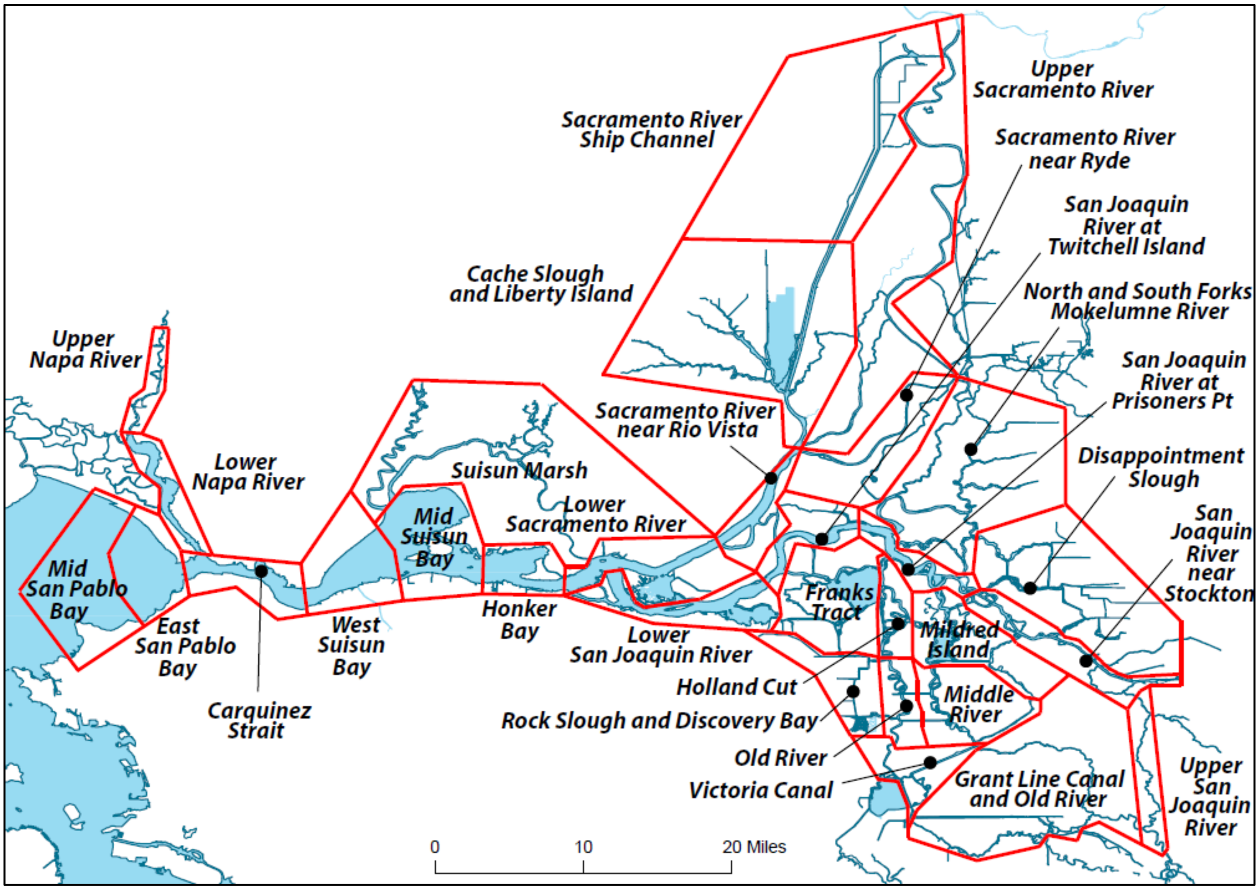


Figure 6.A-10. Subregions Used in the Analysis of Residence Time Based on DSM2-PTM

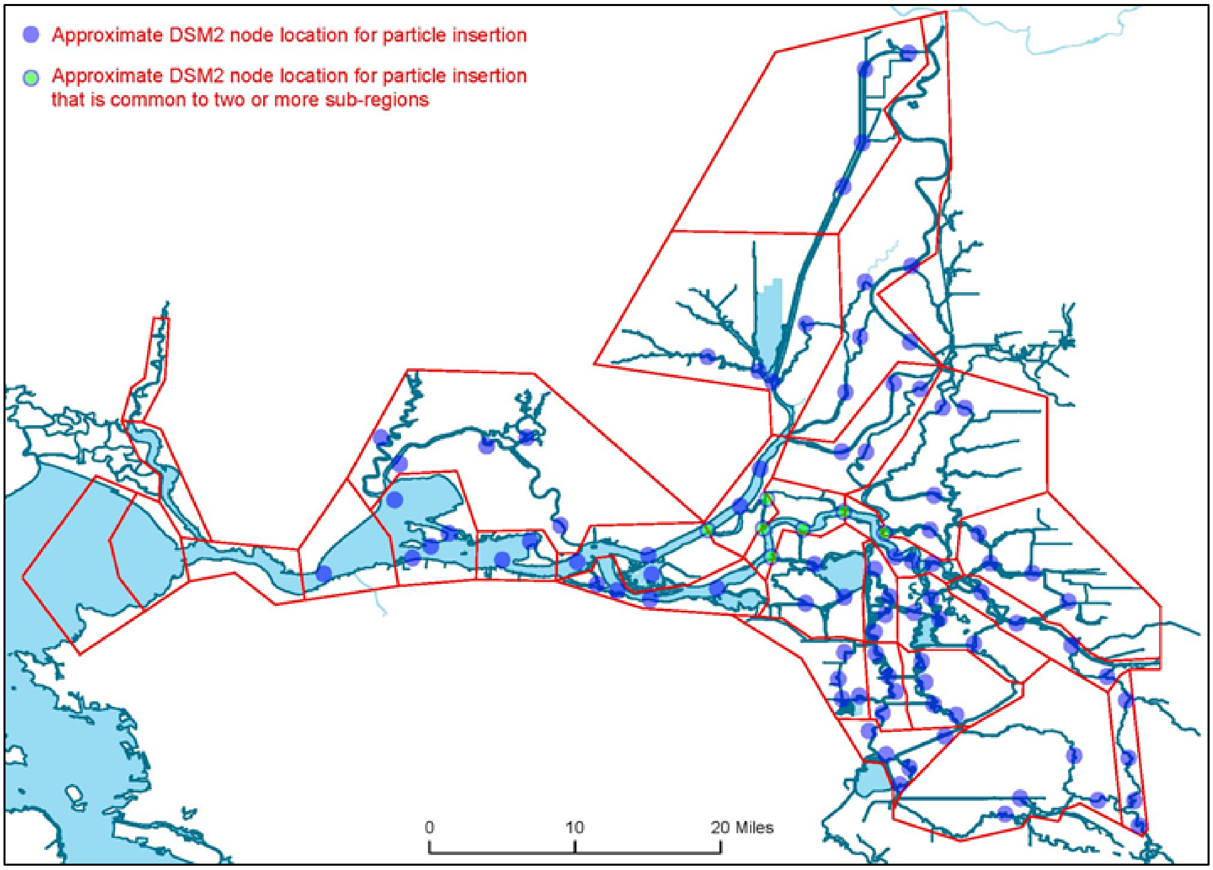


Figure 6.A-11. Particle Insertion Locations within the Subregions Used in the Analysis of Residence Time Based on DSM2-PTM

Table 6.A-11. DSM2-PTM Insertion Locations (Nodes) within the Subregions Used in the Analysis of Residence Time Based on DSM2-PTM.

Subregion	DSM2 Particle Insertion Nodes
Upper Sacramento River	338, 341, 300, 303, 305
Sacramento River Ship channel	309, 310, 311, 312
Cache Slough and Liberty Island	307, 316, 322, 325
Sacramento River near Ryde	344, 288, 348, 293
North and South Forks Mokelumne River*	281, 261, 269, 251, 39
Sacramento River near Rio Vista*	351, 352, 240, 43, 353
Lower Sacramento River*	353, 354, 459, 465
Upper San Joaquin River	7, 9, 11, 13
Grant Line Canal and Old River	50, 106, 171, 60
Victoria Canal	188, 185, 72, 79, 75
Rock Slough and Discovery Bay	197, 198, 200, 202
Old River	81, 84, 86, 92
Middle River	115, 117, 120, 124
Mildred Island	142, 130, 207, 133
San Joaquin River near Stockton	16, 22, 25, 30
Disappointment Slough	241, 242, 243, 248
San Joaquin River at Prisoners Pt*	34, 35, 37, 39, 41
Holland Cut	94, 98, 100, 101
Franks Tract*	225, 216, 222, 42, 44
San Joaquin River at Twitchell Island*	41, 42, 43, 44, 240
Lower San Joaquin River	45, 46, 47, 463
Honker Bay	357, 328
Suisun Marsh	406, 418, 422, 375, 428
Mid Suisun Bay	238, 329, 358, 365
West Suisun Bay	360
Note: * Subregions that share DSM2 particle insertion nodes with one or more sub-regions.	

The number of particles in the subregion was outputted from the PTM every hour over the 90-day simulation periods. Residence time (in hours) was calculated as the time since the start of the simulation *i* weighted by the number of particles remaining in the subregion at time *i*:

$$Residence\ time\ (hours) = \frac{\sum_{i=1}^{90*24}(No.of\ particles\ in\ the\ subregion)_i * i}{\sum_{i=1}^{90*24}(No.of\ particles\ in\ the\ subregion)_i}$$

Residence time in hours was converted to residence time in days for reporting purposes. The results are presented in tabular format in Chapter 6, *Effects Analysis for Delta Smelt and Terrestrial Species* by subregion and based on the 5th, 25th, 50th (median), 75th, and 95th percentiles of the 25 simulated years for each month for the NAA and PA scenarios, with differences and percentage differences between scenarios for each percentile.

6.A.4.4 Selenium

Waterborne selenium concentrations and Delta Smelt tissue selenium concentrations were estimated for the NAA and PA. DSM2 volumetric fingerprint estimates (see Section 5.B.2.2.2.2 *Delta Sourcewater Fingerprinting* in Appendix 5.B, *DSM2 Modeling and Results*) plus additional modeling and analyses were used to predict changes to waterborne and Delta Smelt tissue selenium concentrations resulting from changes in water operations under the NAA and PA.

6.A.4.4.1 Selenium Concentrations in Water

Monthly-averaged DSM2 volumetric fingerprinting output for 1922-2003 was compiled for five locations, representative of fractional contributions of water of differing selenium concentrations: San Joaquin River at Prisoners Point, Cache Slough at Ryer Island, Sacramento River at Emmaton, San Joaquin River at Antioch, and Suisun Bay at Mallard Island. Each of the six source-water inputs below was assigned a selenium load based on historical data (Table 6.A-12).

Table 6.A-12. Delta water source inputs and associated selenium concentrations.

Source	Representation	Geometric mean Se concentration (µg/L)	Data source
Delta agriculture	Agricultural drainage inflow	0.11	Lucas and Stewart (2007)
Sacramento River at Freeport	Inflow from the Sacramento River	0.09	USGS (2014)
San Joaquin River at Mallard Island	Inflow from Calaveras, Cosumnes, Mokelumne	0.10	None (estimate)
Martinez/Suisun Bay	Inflow from Suisun Bay	0.10	SFEI (2014)
San Joaquin River at Vernalis	Inflow from the San Joaquin River	0.83	SWAMP (2009)
Sacramento River at Knights Landing	Inflow from Yolo Bypass	0.23	DWR (2009)

The geometric mean selenium concentrations for each of the six source water inputs were then multiplied by the fraction of that source water at each of the five DSM2 output locations to estimate monthly-averaged water selenium concentration for 82 years for both the NAA and the PA (Equation 1).

Equation 1: $C_{watermonthly} = [(I_1*C_1) + (I_2*C_2) + (I_3*C_3) + (I_4*C_4) + (I_5*C_5) + (I_6*C_6)]/100$

Where:

$C_{watermonthly}$ = monthly mean selenium concentration in water (µg/L);

$I_{1\text{-}6}$ = modeled monthly inflow from each of the six sources of water to the Delta for each DSM2 output output locations (percentage);

$C_{1\text{-}6}$ = selenium concentration in water (µg/L) from each of the six inflow sources to the Delta.

Delta Smelt whole-body selenium tissue concentrations were estimated using a bioaccumulation model developed for the Bay-Delta (Presser and Luoma 2013).

Equation 2: $C_{particulate} = C_{watermonthly} * K_d$

Where:

$C_{particulate}$ = selenium concentration in particulate material in (µg/kg, dry weight);

$C_{watermonthly}$ = selenium concentration in the water column (µg/L);

K_d = selenium particulate to water ratio.

Total selenium water concentrations obtained from Equation 1 were converted to bioavailable particulate selenium using Equation 2. Particulate selenium includes selenium in detritus and phytoplankton. K_d values for the estuary vary by flow, location and season, and can range from approximately 500-30,000. Two K_d values, 3000 and 6000, were selected based on the observed means in Suisun Bay and the Delta to represent the range of particulate selenium conditions in Delta Smelt habitat (Presser and Luoma 2013: 14).

6.A.4.4.2 Selenium Concentrations in Biota

The concentrations of selenium accumulated into Delta Smelt tissue were estimated using $C_{particulate}$ calculated from Equation 2 and two trophic transfer factors (TTF) that represent a simplified food web linkage for Delta Smelt (Equation 3). Selenium accumulation from particulate matter ($C_{particulate}$) into prey items was represented by a TTF value for copepods (1.35; Presser and Luoma 2013: 18). A second TTF value (1.1) represented the bioaccumulation of selenium from copepods into Delta Smelt tissue, consistent with the value assumed for fish by Presser and Luoma (2013: 25). Delta Smelt selenium tissue concentrations were estimated using the following equation:

Equation 3: $C_{smelt} = C_{particulate} * TTF_{copepod} * TTF_{fish}$

Where:

C_{smelt} = selenium concentration in particulate material in (µg/kg, dry weight);

$C_{particulate}$ = particulate selenium concentration in the water column (µg/L);

$TTF_{copepod}$= trophic transfer factor in copepods;

TTF_{smelt} = trophic transfer factor in fish.

6.A.4.4.3 Evaluation of Tissue Concentrations

Whole-body tissue concentrations were then compared to known effects thresholds available in scientific literature. Selenium effects thresholds for whole-body tissue concentrations are not available for Delta Smelt, or any closely related or trophically similar fish species. Whole-body tissue effect thresholds were available for Sacramento Splittail (*Pogonichthys macrolepidotus*) deformities and Rainbow Trout (*Oncorhynchus mykiss*) growth. Delta Smelt and Splittail co-evolved, and co-occur, in the Delta ecosystem. Although trophically different, Splittail EC_{10} was selected to be nearer in relevance to Delta Smelt than Rainbow Trout for purposes of comparison. The EC_{10} for Splittail, 7.2 µg/g, was the whole-body concentration that resulted in deformities in 10% of a juvenile test population fed a selenium-spiked diet, based on a conversion from 7.90 µg/g (95% confidence interval: 4.99–9.45 µg/g) muscle concentration (Rigby et al. 2010). Note that the analysis does not consider quantitatively incorporate uncertainty in the estimate of the EC_{10} (e.g., by consideration of confidence intervals around the 7.2-µg/g threshold, or in the values of K_d), although there is qualitative discussion. Scatter and box plots were produced to summarize Delta Smelt tissue concentration data.

6.A.4.4.4 Modeling Assumptions

The analysis of potential selenium effects to Delta Smelt makes the following assumptions:

- DSM2 accurately represents future hydrodynamic conditions in the Delta.
- Selenium loading is linearly proportional to source water volume.
- Historical geometric mean selenium concentrations do not vary greatly with flow or season and are similar to inputs that will occur in the near-term future.
- Concentrations of selenium in phytoplankton can be estimated by K_d.
- Transfer of selenium from one trophic level to the next can be sufficiently represented by a constant (TTF).
- The EC_{10} derived for Sacramento Splittail (Rigby et al. 2010) is approximately the same for Delta Smelt.
- Whole-body tissue concentrations modeling at the 5 sites investigated presume that Delta Smelt and its prey occupy that site long enough to accumulate the environmental selenium present.

6.A.5 References

6.A.5.1 Printed References

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