Appendix A
Stanislaus River Survival Model

Refer to the Microsoft Excel-based spreadsheet to utilize this model.

Appendix B
Environmental Objectives for Achieving the Stanislaus River Biological Objectives

Appendix B, Table B-1
Adult Upstream Migration Environmental Objectives

Desired Habitat Parameter	Physical Parameter	Units	Metric	Fall-run Chinook			Spring-run Chinook			*O. mykiss*		
				Supportive	**Stressful**	**Detrimental**	**Supportive**	**Stressful**	**Detrimental**	**Supportive**	**Stressful**	**Detrimental**
Water Quality	Temperature [1,2,3]	°C (°F)	Daily Average	8 to 14 (46.4 to 57.2)	14 to 19 (57.2 to 66.2)	> 19 (66.2)	8 to 14 (46.4 to 57.2)	14 to 19 (57.2 to 66.2)	> 19 (66.2)	Less direct evidence; assume similar to Chinook salmon		
Water Quality	Temperature [1,2,3]	°C (°F)	7DADM	9.5 to 15.5 (49.1 to 59.9)	15.5 to 20.5 (59.9 to 68.9)	> 20.5 (68.9)	9.5 to 15.5 (49.1 to 59.9)	15.5 to 20.5 (59.9 to 68.9)	> 20.5 (68.9)	Less direct evidence; assume similar to Chinook salmon		
Water Quality	Temperature [1,2,3]	°C (°F)	Weekly Average			> 18 (64.4)			> 18 (64.4)	Less direct evidence; assume similar to Chinook salmon		
Water Quality	Temperature [1,2,3]	°C (°F)	Instantaneous			> 22 (71.6)			> 22 (71.6)	Less direct evidence; assume similar to Chinook salmon		
Water Quality	Dissolved Oxygen [4,5,6,7,8]	mg/L	Daily Minimum	> 8	6 to 8	< 6	> 8	6 to 8	< 6	Less direct evidence; assume similar to Chinook salmon		
Water Quantity/ Physical Habitat	Channel – Depth[9]	meter (m) (foot [ft])		1. Shallowest riffle: at least 10% of the entire length of a transect (perpendicular to the flow) in the shallowest riffle in the migratory corridor (critical riffle) must be contiguous for a depth no less than 0.3 m (at least 1 ft) and at least 25% of the entire transect must be greater than or equal to 0.3 m (1 ft; CDFW 2013). 2. Frequency of shallow riffles: 90% of the riffles in the migratory corridor must satisfy the requirements of the critical riffle for depths greater than or equal to 0.46 m (1.5 ft) instead of greater than or equal to 0.3 m (1 ft).			1. Shallowest riffle: at least 10% of the entire length of a transect (perpendicular to the flow) in the shallowest riffle in the migratory corridor (critical riffle) must be contiguous for a depth no less than 0.3 m (at least 1 ft) and at least 25% of the entire transect must be greater than or equal to 0.3 m (1 ft; CDFW 2013). 2. Frequency of shallow riffles: 90% of the riffles in the migratory corridor must satisfy the requirements of the critical riffle for depths greater than or equal to 0.46 m (1.5 ft) instead of greater than or equal to 0.3 m (1 ft).			1.Shallowest riffle: at least 10% of the entire length of a transect (perpendicular to the flow) in the shallowest riffle in the migratory corridor (critical riffle) must be contiguous for a depth no less than 0.3 m (at least 1 ft) and at least 25% of the entire transect must be greater than or equal to 0.23 m (0.77 ft; (CDFW 2013). 2. Frequency of shallow riffles: 90% of the riffles in the migratory corridor must satisfy the requirements of the critical riffle for depths greater than or equal to 0.35 m (1.15 ft).		
Water Quality	Pesticides (including Copper)	Risk – Frequency of Benchmark Exceedances	Frequency of Exceedances	≤ 0.017	0.018 to 0.303	≥ 0.304	≤ 0.017	0.018 to 0.303	≥ 0.304	≤ 0.017	0.018 to 0.303	≥ 0.304
Water Quantity	Flow – Attraction	To be determined		**Basin-wide Environmental Objective needed**			**Basin-wide Environmental Objective needed**			**Basin-wide Environmental Objective needed**		
Water Quantity	Flow – Base	To be determined		At least the minimum necessary to provide target levels for each of the other water quality and physical habitat parameters identified here.			At least the minimum necessary to provide target levels for each of the other water quality and physical habitat parameters identified here.			At least the minimum necessary to provide target levels for each of the other water quality and physical habitat parameters identified here.		
Physical Habitat	Connectivity/ Unimpaired Passage / Window	Hours of Delay		0 □	< 24	> 24	0 □	< 24	> 24	0 □	< 24	> 24

Appendix B, Table B-1
Adult Upstream Migration Environmental Objectives

Desired Habitat Parameter	Physical Parameter	Units	Metric	Fall-run Chinook			Spring-run Chinook			*O. mykiss*		
				Supportive	Stressful	Detrimental	Supportive	Stressful	Detrimental	Supportive	Stressful	Detrimental
Physical Habitat	Structure – Hydraulic Refuge and Predation Cover	Suitable Area/River Mile		Basin-wide Environmental Objective needed: Hydraulic refuge/Predation Cover will be a function of returns expected from all rivers in the basin.			Basin-wide Environmental Objective needed: Hydraulic refuge/Predation Cover will be a function of returns expected from all rivers in the basin.			Basin-wide Environmental Objective needed: Hydraulic refuge/Predation Cover will be a function of returns expected from all rivers in the basin.		

Appendix B, Table B-1
Adult Upstream Migration Environmental Objectives

Notes:

[1] Chinook supportive: Weekly average: 8 - 12°C (Raleigh et al. 1986) to avoid egg impacts, daily average <17°C (USEPA 2003)

[2] Chinook stressful: Weekly average 14 - 17°C - disease rate elevated risk (USEPA 2001 and Richter and Kolmes 2005); Daily average 17 - 18°C (McCullough as cited in USEPA 2001); Instantaneous average 19°C (Williams 2006; Richter and Kolmes 2005)

[3] Chinook migration blocked/lethal: Instantaneous average 20 - 22°C (See Hicks 2000, as cited by Richter and Kolmes 2005; USEPA 1999, 2001, 2003)

[4] Detrimental/avoidance: <6 mg/L (WDOE 2002)

[5] Detrimental/distress: 6.0 mg/L (Davis 1975 and WDOE 2002)

[6] Stressful/poor: <6.5 mg/L (USEPA 1986; WDOE Water Quality Standards; and Canadian Council of Ministers of the Environment 1999)

[7] Stressful [<8 mg/L]: ≥7 mg/L for all waterbodies other than bays and reservoirs (SWRCB 2001 Water Quality Control Plan, North Coast region TABLE 3-1. 10% reduction in swimming speed at 7mg/L [vs saturation]; See Davis 1963 as cited by WDOE 2002 and Dahlberg 1968 as cited by British Columbia, Ministry of the Environment)

[8] Supportive: >8 mg/L USEPA 1986 (no production impairment); 8-9 mg/L WDOE 2002 (swimming of fitness of salmonids maximized). 9 mg/L (at <10°C) or 13 mg/L (at >10°C) optimal (Raleigh et. al. 1986).

[9] DFG 2013.

°C = degrees Celsius

7DADM = 7-day average of the daily maximum

cfs = cubic feet per second

ft = feet

mg/L = milligram per liter

SJR = San Joaquin River

">" = greater than

"<" = less than

"≤" = less than or equal to

"≥" = greater than or equal to

References:

Canadian Council of Ministers of the Environment 1999. Canadian Environmental Quality Guidelines.

Dahlberg 1968, as cited in British Columbia, Ministry of the Environment, Environmental Protection Division; available at: http://www.elp.gov.bc.ca/wat/wq/BCguidelines/do/do-03.htm.

Davis, J.C. 1975. Minimal dissolved oxygen requirements of aquatic life with emphasis on Canadian species: a review. *Journal of Fisheries Research Board Canada* 32(12):2295-2332.

Davis 1963, as cited in WDOE 2002a. Available at: http://www.sjrdotmdl.org/concept_model/bio- effects_model/documents/Hicks2000.pdf)

DFG, 2013. *Standard Operating Procedure for Critical Riffle Analysis for Fish Passage in California* , DFG-IFP-001, October 2012, updated February 2013. Prepared by: Melinda E. Woodard, Quality Assurance Research Group, Moss Landing Marine Laboratories.

Hicks 2000, as cited in Richter, A., and S.A. Kolmes, 2005. Maximum Temperature Limits for Chinook, Coho, and Chum Salmon, and Steelhead Trout in the Pacific Northwest. *Reviews in Fisheries Science* 13-23-49.

Raleigh, R.F., W.J. Miller, and P.C. Nelson, 1986. *Habitat suitability index model and flow suitability curves: Chinook salmon* . National Ecology Center, Division of Wildlife and Contaminant Research, U.S. Fish and Wildlife Service, Biological Report 82 (10.122).

Richter, A., and S.A. Kolmes, 2005. Maximum Temperature Limits for Chinook, Coho, and Chum Salmon, and Steelhead Trout in the Pacific Northwest. *Reviews in Fisheries Science* 13:23-49.

SWRCB 2001.

USEPA (US. Environmental Protection Agency), 1986. *Ambient Water Quality Criteria for Dissolved Oxygen* . Office of Water. EPA 440/5-86-003. Available from: http://www.epa.gov/cgi-bin/claritgw?op-Display&document=clserv:OAR:0579;&rank=4&template=epa --

USEPA, 1999. *A review and synthesis of effects of alterations to the water temperature regime on freshwater life stages of salmonids, with special reference to Chinook salmon* . U.S. Environmental Protection Agency, Region 10.

USEPA, 2001. *Salmonid Behavior and Water Temperature* . Issue Paper 1, Prepared as Part of EPA Region 10 Temperature Water Quality Criteria Guidance Development Project, by S.T. Sauter, J. McMillan, and J. Dunham. EPA-910-D-01-001. EPA Region 10.

USEPA, 2003. *EPA Region 10 guidance for Pacific Northwest state and tribal temperature water quality standards* . EPA 910-B-03-002. Environmental Protection Agency, Seattle, Washington.

USEPA, 2014. *External Peer Review Draft Aquatic Life Ambient Water Quality Criterion for Selenium - Freshwater 2014* . U.S. Environmental Protection Agency. Washington D.C. May

WDOE, 2002. Available at: http://www.sjrdotmdl.org/concept_model/bio-effects_model/documents/Hicks2000.pdf

WDOE Water Quality Standards available at: https://fortress.wa.gov/ecy/publications/publications/0010071.pdf & http://www.ecy.wa.gov/programs/wq/swqs/criteria-freshwater/wac173201a_200-do.html

Williams, J.G., 2006. Central Valley Salmon: A Perspective on Chinook and Steelhead in the Central Valley of California. *San Francisco Estuary and Watershed Science* 4:416.

Appendix B, Table B-2
Adult Holding Environmental Objectives

Desired Habitat Parameter	Physical Parameter	Units	Metric	Goodwin Dam to Knights Ferry Reach[1]		
				Spring-Run Chinook salmon and *O. mykiss*		
				Supportive	Stressful	Detrimental
Water Quality	Temperature	°C(°F)	Daily Average	< 13 (55.4)	13 to 17 (55.4 to 62.6)	18 to 20 (64.4 to 68)
Water Quality	Temperature	°C(°F)	7DADM	< 14.5 (58.1)	14.5 to 18.5 (58.1 to 65.3)	
Water Quality	Temperature	°C(°F)	Prolonged Exposure			17 to 18 (62.6 to 64.4)
Water Quality	Dissolved Oxygen	mg/L	Daily Minimum	> 8	6 to 8	< 6
Physical Habitat	Water Depth	m (ft)	Minimum	≥ 1.5 (4.9)		
Physical Habitat	Velocity	m/s (ft/s)	Maximum	< 0.37 (1.2)		
Water Quality	Pesticides, including Copper	Risk - Frequency of Benchmark Exceedances	Frequency of Exceedances	≤ 0.017	0.018 to 0.303	≥ 0.304
Other Non-Physical Parameters	Predation (Anglers/Poachers)	% Mortality		0		

Notes:

[1] Geographic range guidance provided to indicate those reaches where inherent characteristics of the system (e.g., geologic, topographic, and geomorphic) suggest that a particular type of habitat may be created in service of the overall need to increase spatial habitat extent. The reach is defined as broadly as possible to allow for maximum flexibility in the attainment of Environmental Objectives given the inherent constraints of the system. The location of sufficient area of holding habitat required to meet Environmental Objectives determines the number of river miles in which high-quality holding habitat must occur. For example, no holding habitat is expected or needed downstream of Knights Ferry, and this guidance does not require that such habitat be created as far downstream as Knights Ferry.

7DADM = 7-day average of the daily maximum

ft/s = feet per second

mg/L = milligrams per liter

m/s = meters per second

≤ = less than or equal to

≥ = greater than or equal to

> = greater than

< = less than

References available in report for:

Moyle et al. 1995 (depths); Moyle 2003b (velocity); USEPA 2003 (temperature)

Appendix B, Table B-3
Spawning Habitat Environmental Objectives

Desired Habitat Parameter	Physical Parameter	Units	Metric	Fall-run Chinook salmon			Spring-run Chinook salmon			*O. mykiss*		
				Supportive	Stressful	Detrimental	Supportive	Stressful	Detrimental	Supportive	Stressful	Detrimental
Water Quality	Temperature[1, 2]	°C (°F)	Daily Average	6 to12 (42.8 to 53.6)	4 to 6 (39.2 to 42.8) 12 to 13.3 (53.6 to 55.9)	> 13.3 (55.9)	6 to 12 (42.8 to 53.6)	4 to 6 (39.2 to 42.8) 12 to 13.3 (53.6 to 55.9)	> 13.3 (55.9)	7 to 10 (44.6 to 50)	4 to 6.9 (39.2 to 44.4) and 10 to 13.5 (50 to 56.3)	> 13.5 (56.3)
O. mykiss(Bovee 1978 as cited in McEwan and Jackson 1996)[3]	Temperature[1, 2]	°C (°F)	7DADM	< 12.5 (54.5)	12.5 to 13.8 (54.5 to 56.8)	> 13.8 (56.8)	< 12.5 to 13 (54.5 to 55.4)	12.5 to 13.8 (54.5 to 56.8)	> 13.8 (56.8)	10.5 (50.9)	10.5 to 14 (50.9 to 57.2)	> 14.0 (57.2)
Water Quality	Dissolved Oxygen	mg/L	Daily Minimum	> 8	6 to 8	< 6	> 8	6 to 8	< 6	> 8	6 to 8	< 6
Physical Habitat	Depth	m (ft)		0.3 to 0.76 (1 to 2.5) (HSI > 0.6)	0.15 to 0.3 (0.5 to 1) and 0.76 to 3.05 (2.5 to 10)	< 0.15 (0.5) or > 3.05 (10)	0.3 to 0.76 (1 to 2.5) (HSI > 0.6)	0.15 to 0.3 (0.5 to 1) and 0.76 to 3.05 (2.5 to 10)	< 0.15 (0.5) or > 3.05 (10)	0.15 to 0.61 (0.5 to 2)	0.08 to 0.15 (0.26 to 0.5) and 0.61 to 1(2 to 3.3)	< 0.08 (0.26) or > 1 (3.3)
Physical Habitat	Velocity[3]	m/s (ft/s)		0.3 to 1.2 (1 to 4)	0.12 to 0.3 (0.4 to 1) and 1.2 to 1.5 (4 to 5)	< 0.12 (0.4) or > 1.5 (5)	0.3 to 1.2 (1 to 4)	0.12 to 0.3 (0.4 to 1) and 1.2 to 1.5 (4 to 5)	< 0.12 (0.4) or > 1.5 (5)	0.5 to 1.1 (1.6 to 3.6)	0.32 to 0.4 (1.1 to 1.3)	< 0.3 (< 0.98) or > 1.2 (4)
Water Quality	Pesticides, including Copper[4]	% days in a month	Risk - Frequency of Benchmark Exceedances	≤ 1.7%	1.8% to 30.3%	≥ 30.4%	≤ 1.7%	1.8% to 30.3%	≥ 30.4%	≤ 1.7%	1.8% to 30.3%	≥ 30.4%
Physical Habitat	Spawning Area - Sediment Size Distribution[5]	Gravel Size: D_{50} mm (in)	Majority Composition	55 to 25 (2.17 to 0.98)	80 to 56 (3.15 to 2.20) and 24 to 10 (0. 94 to 0.39)	Not spawning habitat < 9 (0.35) or > 81 (3.19)	55 to 25 (2.17 to 0.98)	80 to 56 (3.15 to 2.20) and 24 to 10 (0. 94 to 0.39)	Not spawning habitat < 9 (0.35) or > 81 (3.19)	30 to 15 (1.18 to 0.59)	50 to 30 (1.97 to 1.18) and 15 to 10 (0.59 to 0.39)	Not spawning habitat < 9 (0.35 in) or > 51 (2)
Physical Habitat	Spawning Area - Extent[6]	Acres	Entire Spawning Area	14.7			14.7			2.7		
Physical Habitat	Spawning Area - Habitat Heterogeneity			Geomorphic processes should be operating naturally so that there is a natural alternation of pools and riffles.			Geomorphic processes should be operating naturally so that there is a natural alternation of pools and riffles.			Spawning areas need to be adjacent to deep pools and cover.		
Physical Habitat	Spawning Area - Distribution			Fall-run Chinook salmon spawning area must be segregated from spring-run Chinook salmon spawning area temporally, spatially, or both.								
Other Non-Physical Parameters	Predation (Anglers/Poachers)[7]			0			0			0		

Appendix B, Table B-3
Spawning Habitat Environmental Objectives

Notes:

[1] Chinook Supportive: USEPA (2003) found that 4 to 12°C result in good egg survival and that a narrower range (6 to 10°C) is optimal. USFWS (1999 cited by Myrick and Cech 2004) concluded that temperature-related egg mortality in Chinook salmon increased at temperatures above 13.3°C (56°F). Myrick and Cech (2004) found that temperatures between 6 and 12°C were optimal for Central Valley Chinook salmon.

[2] Myrick and Cech (2004), Richter and Kolmes (2005); see also McEwan and Jackson (1996)

[3] *O. mykiss:* Bovee 1978 as cited in McEwan and Jackson 1996

[4] Hoogeweg et al. 2011

[5] 0.5 in. to 3 in. diameter (Orcutt et al. 1968); D_{50} of redds from smaller steelhead (65 - 68 cm) was about 0.5 in. to 1.5 in. (Kondolf and Wolman 1993). Orcutt et al. 1968, Kondolf and Wolman 1993: See calculation in notes for combination of anadromous/resident spawning

[6] 5 to 7 square yards/redd (Orcutt et al. 1968)

[7] Target of zero poaching; eventual target (successful restoration) would be increased fishing mortality as the population recovers and fishing pressure increases.

7DADM = 7-day average of the daily maximum

cm = centimeter

ft/s = feet per second

HSI = habitat suitability index

in = inch

m/s = meter per second

mg/L = milligram per liter

mm = millimeter

">" = greater than

"<" = less than

"≤" = less than or equal to

"≥" = greater than or equal to

References:

Bovee, K.D., 1978. *Probability of use criteria for the family salmonidae* . Instream Flow Information Paper No. 4, FWS/OBS-78/07. U.S. Fish and Wildlife Service, Division of Biological Services, Western Energy and Land Use Team. Washington, D.C.

Hoogeweg, C.G., W.M. Williams, R. Breuer, D. Denton, B. Rook, and C. Watry, 2011. *Spatial and Temporal Quantification of Pesticide Loadings to the Sacramento River, San Joaquin River, and Bay-Delta to Guide Risk Assessment for Sensitive Species* . CALFED Science Grant #1055, 293 p.

Kondolf, G.M., and M.G. Wolman, 1993. The sizes of salmonid spawning gravels. *Water Resources Research* 29:2275-2285.

Myrick, C.A., and J.J. Cech, 2004. Temperature effects on juvenile anadromous salmonids in California's central valley: what don't we know? *Reviews in Fish Biology and Fisheries* 14:113-123.

McEwan, D., and T.A. Jackson, 1996. *Steelhead restoration and management plan for California* . Management Report. California Department of Fish and Game, Inland Fisheries Division, Sacramento.

Orcutt, D.R., B.R. Pulliam, and A. Arp, 1968. Characteristics of steelhead trout redds in Idaho streams. *Transactions of the American Fisheries Society* 97:42-45.

Richter, A., and S.A. Kolmes, 2005. Maximum Temperature Limits for Chinook, Coho, and Chum Salmon, and Steelhead Trout in the Pacific Northwest. *Reviews in Fisheries Science* 13-23-49.

USEPA, 2003. *EPA Region 10 guidance for Pacific Northwest state and tribal temperature water quality standards* . EPA 910-B-03-002. Environmental Protection Agency, Seattle, Washington.

Williams, J.G., 2006. *Central Valley Salmon: A Perspective on Chinook and Steelhead in the Central Valley of California.* San Francisco Estuary and Watershed Science Vol. 4 (3). Available from: http://repositories.cdlib.org/jmie/sfews/vol4/iss3/art2

Appendix B, Table B-4
Egg Development Environmental Objectives

Desired Habitat Parameter	Physical Parameter	Units	Metric	Goodwin Dam to Riverbank [1]			Upstream to Knights Ferry [1]			Goodwin Dam to Oakdale [1]		
				Fall-run Chinook			Spring-run Chinook			*O. mykiss*		
				Supportive	**Stressful**	**Detrimental**	**Supportive**	**Stressful**	**Detrimental**	**Supportive**	**Stressful**	**Detrimental**
Water Quality	Temperature	°C (°F)	Daily Average	6 to 12 (42.8 to 53.6)	4 to 6 (39.2 to 42.8) 12 to 13.3 (53.6 to 55.9)	> 13.3 (55.9)	6 to 12 (42.8 to 53.6)	4 to 6 (39.2 to 42.8) 12 to 13.3 (53.6 to 55.9)	> 13.3 (55.9)	7 to 10 (44.6 to 50)	4 to 6.9 (39.2 to 44.4) 10 to 13.5 (50 to 56.3)	> 13.5 (56.3)
Water Quality	Temperature	°C (°F)	7DADM	< 12.5 (54.5)	12.5 to 13.8 (54.5 to 56.8)	> 13.8 (56.8)	< 12.5 (54.5)	12.5 to 13.8 (54.5 to 56.8)	> 13.8 (56.8)	< 10.5 (50.9)	10.5 to 14.0 (50.9 to 57.2)	> 14.0 (57.2)
Water Quality	Dissolved Oxygen	mg/L	Daily Minimum	> 8	6 to 8	< 6	> 8	6 to 8	< 6	> 8	6 to 8	< 6
Physical Habitat	Water Depth	m (ft)		0.3 to 0.76 (1 to 2.5) (HSI > 0.6)	0.15 to 0.3 (0.5 to 1) and 0.76 to 3.05 (2.5 to 10)	< 0.15 (0.5) or > 3.05 (10)	0.3 to 0.76 (1 to 2.5) (HSI > 0.6)	0.15 to 0.3 (0.5 to 1) and 0.76 to 3.05 (2.5 to 10)	< 0.15 (0.5) or > 3.05 (10)	0.15 to 0.61 (0.5 to 2)	0.08 to 0.15 (0.26 to 0.5) and 0.61 to 1(2 to 3.3)	< 0.08 (0.26) or > 1 (3.3)
Physical Habitat	Velocity	m/s (ft/s)		0.3 to 1.2 (1 to 4)	0.12 to 0.3 (0.4 to 1) and 1.2 to 1.5 (4 to 5)	< 0.12 (0.4) or > 1.5 (5)	0.3 to 1.2 (1 to 4)	0.12 to 0.3 (0.4 to 1) and 1.2 to 1.5 (4 to 5)	< 0.12 (0.4) or > 1.5 (5)	0.5 to 1.1 (1.6 to 3.6)	0.32 to 0.4 (1.1 to 1.3)	< 0.3 (< 0.98) or > 1.2 (3.9)
Water Quality	Pesticides, including Copper	Risk – Frequency of Benchmark Exceedances	Frequency of Exceedances	≤ 0.017	0.018 to 0.303	≥ 0.304	≤ 0.017	0.018 to 0.303	≥ 0.304	≤ 0.017	0.018 to 0.303	≥ 0.304
Water Quality	Other Contaminants – Selenium	mg/kg (d.w., tissue) µg/L (water)	Maximum Concentration	15.1 mg/kg (egg/ovary) 3.1 µg/L (water, lotic)			15.1 mg/kg (egg/ovary) 3.1 µg/L (water, lotic)			15.1 mg/kg (egg/ovary) 3.1 µg/L (water, lotic)		
Water Quality	Other Contaminants – Mercury	mg/kg (w.w., tissue, eggs/larvae)	Maximum Concentration	< 0.02	0.02 to 0.1	> 0.1	< 0.02	0.02 to 0.1	> 0.1	< 0.02	0.02 to 0.1	> 0.1
Physical Habitat	Spawning Area – Gravel Quality – Fine Sediment	Percent (%) of fines		< 5 smaller than 4.8 mm (0.189 in)	5 to 15 finer than 4.8 mm (0.189 in) or 5 to 10 finer than 0.85 mm (0.033 in)	> 15 smaller than 4.8 mm (0.189 in) or > 10 smaller than 0.85 mm (0.033 in)	< 5 smaller than 4.8 mm (0.189 in)	5 to 15 finer than 4.8 mm (0.189 in) or 5 to 10 finer than 0.85 mm (0.033 in)	> 15 smaller than 4.8 mm (0.189 in) or > 10 smaller than 0.85 mm (0.033 in)	< 5 smaller than 4.8 mm (0.189 in)	5 to 15 finer than 4.8 mm (0.189 in) or 5 to 10 finer than 0.85 mm (0.033 in)	> 15 smaller than 4.8 mm (0.189 in) or > 10 smaller than 0.85 mm (0.033 in)

[1] Geographic range guidance provided to indicate those reaches where inherent characteristics of the system (e.g. geologic, topographic, and geomorphic) suggest that a particular type of habitat may be created in service of the overall need to increase spatial habitat extent. The reach is defined as broadly as possible to allow for maximum flexibility in the attainment of environmental objectives given the inherent constraints of the system. The location of sufficient acreage of spawning habitat required to meet Environmental Objectives determines the number of river miles in which high-quality spawning habitat must occur. Environmental objectives for egg development begin as soon as spawning has occurred through the full time period needed for development.

Appendix B, Table B-4
Egg Development Environmental Objectives

Notes:

^{0}C = degrees Celsius

µg/L = microgram per liter

7DADM = 7-day average of the daily maximum

d.w. = dry weight

ft/s = feet per second

HSI = habitat suitability index

in = inch

m/s = meter per second

mg/L = milligram per liter

ppm = parts per million

w.w. = wet weight

">" = greater than

"<" = less than

"≤" = less than or equal to

"≤" = greater than or equal to

References:

Beckvar, N., T. Dillon, and l. Read, 2005. Approaches for linking whole-body fish tissue residues of mercury or DDT to biological effects thresholds. *Environmental Toxicology and Chemistry* 24:2094-2105.

Bell, M.C., 1986. *Fisheries Handbook of Engineering Requirements and Biological Criteria* , edited by U.S. Army Corps of Engineers, Portland, Oregon, p. 320. Washington, D.C.

Dillon, T. N. Beckvar, and J. Kern, 2010. Residue-based mercury dose-response in fish: An analysis using lethality-equivalent test endpoints. *Environmental Toxicology and Chemistry* 11:2559-2565.

Hoogeweg, C.G., W.M. Williams, R. Breuer, D. Denton, B. Rook, and C. Watry, 2011. *Spatial and Temporal Quantification of Pesticide Loadings to the Sacramento River, San Joaquin River, and Bay-Delta to Guide Risk Assessment for Sensitive Species* . CALFED Science Grant #1055, 293 p.

Gard, M., 2001. *Identification of the instream flow requirements for anadromous fish in the streams within the Central Valley of California* . Annual Progress Report. Fiscal Year 2001. U.S. Fish and Wildlife Service. Sacramento Fish and Wildlife Office.

McCullough, D. A., S. Spalding, D. Sturdevant, and M. Hicks, 2001. *Summary of Technical Literature Examining the Physiological Effects of Temperature on Salmonids - Issue Paper 5* . Report No. EPA-910-D-01-005. U.S. Environmental Protection Agency.

Myrick, C.A., and J.J. Cech, Jr., 2001. *Temperature effects on Chinook salmon and steelhead: a review focusing on California's Central Valley populations* . Bay-Delta Modeling Forum Technical Publication 01-1.

Richter, A., and S.A. Kolmes, 2005. Maximum Temperature Limits for Chinook, Coho, and Chum Salmon, and Steelhead Trout in the Pacific Northwest. *Reviews in Fisheries Science* 13:23-49.

USEPA (U.S. Environmental Protection Agency), 2003. *EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards.* EPA 910-B-03-002. Region 10 Office of Water, Seattle, Washington.

Appendix B, Table B-5a
Juvenile Rearing Environmental Objectives (Floodplain, Long Inundation)

Desired Habitat Parameter	Physical Parameter	Units	Metric	Below Ripon								
				Fall-run Chinook			Spring-run Chinook			*O. mykiss*		
				Supportive	Stressful	Detrimental	Supportive	Stressful	Detrimental	Supportive	Stressful	Detrimental
Water Quality	Temperature	°C (°F)	7DADM	10 to 18 (50 to 64.4)	18 to 25 (64.4 to 77)	> 25 (77)	10 to 18 (50 to 64.4)	18 to 25 (64.4 to 77)	> 25 (77)	10 to 18 (50 to 64.4)	18 to 25 (64.4 to 77)	> 25 (77)
Water Quality	Dissolved Oxygen	mg/L	Daily Minimum	> 8[1]	6 to 8	< 6	> 8[1]	6 to 8	< 6	> 8[1]	6 to 8	< 6
Water Quantity	Water Depth	m (ft)	Averaged Spatially	0.15 to 1.22 (0.5 to 4)	1.23 to 2.13 (4 to 7)		0.15 to 1.22 (0.5 to 4)	1.23 to 2.13 (4 to 7)		0.15 to 1.22 (0.5 to 4)	1.23 to 2.13 (4 to 7)	
Water Quantity	Velocity	m/s (ft/s)		0 to 0.9 (0 to 3)	> 0.9 (3)		0 to 0.9 (0 to 3)	> 0.9 (3)		0 to 0.9 (0 to 3)	> 0.9 (3)	
Water Quality	Pesticides, including Copper[2]	Risk – Frequency of Benchmark Exceedances	Frequency of Exceedances	≤0.017	0.018 to 0.303	≥ 0.304	≤0.017	0.018 to 0.303	≥ 0.304	≤0.017	0.018 to 0.303	≥ 0.304
Water Quality	Other Contaminants – Selenium	mg/kg (d.w., tissue) µg/L (water)	Maximum Concentration	8.5 mg/kg (whole body) 11.3 mg/kg (muscle) 3.1 µg/L (water, lotic)			8.5 mg/kg (whole body) 11.3 mg/kg (muscle) 3.1 µg/L (water, lotic)			8.5 mg/kg (whole body) 11.3 mg/kg (muscle) 3.1 µg/L (water, lotic)		
Water Quality	Other Contaminants – Mercury	mg/kg (w.w., tissue, whole body, juvenile)	Maximum Concentration	< 0.2	0.2 to 1.0	> 1.0	< 0.2	0.2 to 1.0	> 1.0	< 0.2	0.2 to 1.0	> 1.0
Physical Habitat	Inundation	Wetted Acre-Days	Duration	10 to 21			10 to 21			10 to 21		
Physical Habitat	Inundation	events/year	Recurrence Interval (RI)	≥ 1 in 3 years; (minimum of 1 week drawdown to distinguish discrete event)			≥ 1 in 3 years; (minimum of 1 week drawdown to distinguish discrete event)			≥ 1 in 3 years; (minimum of 1 week drawdown to distinguish discrete event)		
Landform and Cover	Cover	% suitable; HSI score		Presence and diversity of suitable cover type(s); Average HSI score ≥ 0.5			Presence and diversity of suitable cover type(s); Average HSI score ≥ 0.5			Presence and diversity of suitable cover type(s); Average HSI score ≥ 0.5		
Landform and Cover	Substrate	grain size; % fines		> X% fines			> X% fines			> X% fines		

Appendix B, Table B-5a
Juvenile Rearing Environmental Objectives (Floodplain, Long Inundation)

Desired Habitat Parameter	Physical Parameter	Units	Metric	Below Ripon								
				Fall-run Chinook			Spring-run Chinook			*O. mykiss*		
				Supportive	Stressful	Detrimental	Supportive	Stressful	Detrimental	Supportive	Stressful	Detrimental
Landform and Cover	Spatial Extent and Distribution			Ripon To Caswell: ≥ X% Caswell to Confluence: ≥ X%			Ripon To Caswell: ≥ X% Caswell to Confluence: ≥ X%			Ripon To Caswell: ≥ X% Caswell to Confluence: ≥ X%		

Notes:

[1] Bell 1986

[2] Hoogeweg et al. 2011

^{0}C = degrees Celsius

^{0}F = degrees Fahrenheit

7DADM = 7-day average of the daily maximum

ft = feet

ft/s = feet per second

HSI = habitat suitability index

m = meter

in = inch

m/s = meter per second

mg/L = milligram per liter

ppm = parts per million

">" = greater than

"<" = less than

"≤" = less than or equal to

"≥" = greater than or equal to

w.w. = wet weight

d.w. = dry weight

µg/L = microgram per liter

References:

Bell, M.C., 1986. *Fisheries Handbook of Engineering Requirements and Biological Criteria* , edited by U.S. Army Corps of Engineers, Portland, Oregon, p. 320.

Hoogeweg, C.G., W.M. Williams, R. Breuer, D. Denton, B. Rook, and C. Watry, 2011. *Spatial and Temporal Quantification of Pesticide Loadings to the Sacramento River, San Joaquin River, and Bay-Delta to Guide Risk Assessment for Sensitive Species* . CALFED Science Grant #1055.

Sources:

Aceituno, M.E., 1990. *Habitat preference criteria for Chinook salmon of the Stanislaus River, California* . U.S. Department of the Interior Fish & Wildlife Service, Sacramento, California.

USEPA (U.S. Environmental Protection Agency), 2003. *EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards* . EPA 910-B-03-002. Region 10 Office of Water, Seattle, Washington.

Gard, M. 2001. Identification of the instream flow requirements for anadromous fish in the streams within the Central Valley of California

Jeffres, C., 2014. Unpublished Data.

Katz, J., 2013. Unpublished Data.

McCullough, D. A., S. Spalding, D. Sturdevant, and M. Hicks, 2001. *Summary of Technical Literature Examining the Physiological Effects of Temperature on Salmonids.* Issue Paper 5. Report No. EPA-910-D-01-005. U.S. Environmental Protection Agency.

Myrick, C.A., and J.J. Cech, Jr., 2004. Temperature effects on juvenile anadromous salmonids in California's central valley: what don't we know? *Reviews in Fish Biology and Fisheries* 14:113-123.

Myrick, C.A., and J.J. Cech, Jr., 2001. *Temperature effects on Chinook salmon and steelhead: a review focusing on California's Central Valley populations.* Bay-Delta Modeling Forum Technical Publication 01-1.

Richter, A., and S.A. Kolmes, 2005. Maximum Temperature Limits for Chinook, Coho, and Chum Salmon, and Steelhead Trout in the Pacific Northwest. *Reviews in Fisheries Science* 13:23-49.

SJRRP (San Joaquin River Restoration Program), 2012. *Minimum Floodplain Habitat Area for Spring and Fall-Run Chinook Salmon* . November 2012.

Appendix B, Table B-5b
Juvenile Rearing Environmental Objectives (Off-Channel, Short Inundation)

Desired Habitat Parameter	Physical Parameter	Units	Metric	Above Ripon								
				Fall-run Chinook			Spring-run Chinook			*O. mykiss*		
				Supportive	Stressful	Detrimental	Supportive	Stressful	Detrimental	Supportive	Stressful	Detrimental
Water Quality	Temperature	°C (°F)	7DADM	10 to 18 (50 to 64.4)	18 to 20 (64.4 to 68)	> 20 (68)	10 to 18 (50 to 64.4)	18 to 20 (64.4 to 68)	> 20 (68)	10 to 18 (50 to 64.4)	18 to 20 (64.4 to 68)	> 20 (68)
Water Quality	Dissolved Oxygen	ppm	Daily Minimum	> 8[1]	6 to 8	< 6	> 8[1]	6 to 8	< 6	> 8[1]	6 to 8	< 6
Water Quantity	Water Depth	m (ft)	Averaged Spatially	0.15 to 1.22 (0.5 to 4)	1.23 to 2.13 (4 to 7)		0.15 to 1.22 (0.5 to 4)	1.23 to 2.13 (4 to 7)		0.15 to 1.22 (0.5 to 4)	1.23 to 2.13 (4 to 7)	
Water Quantity	Velocity	m/s (ft/s)		0 to 0.9 (0 to 3)	> 0.9 (3)		0 to 0.9 (0 to 3)	> 0.9 (3)		0 to 0.9 (0 to 3)	> 0.9 (3)	
Water Quality	Pesticides, including Copper[2]	Risk – Frequency of Benchmark Exceedances	Frequency of Exceedances	≤ 0.017	0.018 to 0.303	≥ 0.304	≤ 0.017	0.018 to 0.303	≥ 0.304	≤ 0.017	0.018 to 0.303	≥ 0.304
Water Quality	Other Contaminants – Selenium	mg/kg (d.w., tissue) µg/L (water)	Maximum Concentration	8.5 mg/kg (whole body) 11.3 mg/kg (muscle) 3.1 µg/L (water, lotic)			8.5 mg/kg (whole body) 11.3 mg/kg (muscle) 3.1 µg/L (water, lotic)			8.5 mg/kg (whole body) 11.3 mg/kg (muscle) 3.1 µg/L (water, lotic)		
Water Quality	Other Contaminants – Mercury	mg/kg (w.w., tissue, whole body, juvenile)	Maximum Concentration	< 0.2	0.2 to 1.0	> 1.0	< 0.2	0.2 to 1.0	> 1.0	< 0.2	0.2 to 1.0	> 1.0
Physical Habitat	Inundation	Wetted Acre-Days	Duration	1 to 9			1 to 9			1 to 9		
Physical Habitat	Inundation	Events/Year	Recurrence Interval (RI)	≥ 2 in 3 years; (minimum of 1 week drawdown to distinguish discrete event); >1 event per year in years when innundation occurs			≥ 2 in 3 years; (minimum of 1 week drawdown to distinguish discrete event); >1 event per year in years when innundation occurs			≥ 2 in 3 years; (minimum of 1 week drawdown to distinguish discrete event); >1 event per year in years when innundation occurs		
Landform and Cover	Cover	% Suitable; HSI Score		Presence and diversity of suitable cover type(s); Average HSI score greater ≥ 0.5 (see table)			Presence and diversity of suitable cover type(s); Average HSI score greater ≥ 0.5 (see table)			Presence and diversity of suitable cover type(s); Average HSI score greater ≥ 0.5 (see table)		
Landform and Cover	Substrate	grain size; % fines		Greater than X% cobble/ gravel Less than X% fines			Greater than X% cobble/ gravel Less than X% fines			Greater than X% cobble/ gravel Less than X% fines		

Appendix B, Table B-5b
Juvenile Rearing Environmental Objectives (Off-Channel, Short Inundation)

				Above Ripon								
				Fall-run Chinook			Spring-run Chinook			*O. mykiss*		
Desired Habitat Parameter	**Physical Parameter**	**Units**	**Metric**	**Supportive**	**Stressful**	**Detrimental**	**Supportive**	**Stressful**	**Detrimental**	**Supportive**	**Stressful**	**Detrimental**
Landform and Cover	Spatial Extent and Distribution			Upstream of Goodwin: ≥ X% Goodwin to Knights Ferry: ≥ X% Knights Ferry to Oakdale: ≥ X% Oakdale to Riverbank: ≥ X% Riverbank to Ripon: ≥ X%			Upstream of Goodwin: ≥ X% Goodwin to Knights Ferry: ≥ X% Knights Ferry to Oakdale: ≥ X% Oakdale to Riverbank: ≥ X% Riverbank to Ripon: ≥ X%			Upstream of Goodwin: ≥ X% Goodwin to Knights Ferry: ≥ X% Knights Ferry to Oakdale: ≥ X% Oakdale to Riverbank: ≥ X% Riverbank to Ripon: ≥ X%		

Notes:
[1] Bell 1986
°C = degrees Celsius
°F = degrees Fahrenheit
7DADM = 7-day average of the daily maximum
ft = feet
ft/s = feet per second
HSI = habitat suitability index
m = meter
in = inch
m/s = meter per second
mg/L = milligram per liter
ppm = parts per million
">" = greater than
"<" = less than
"≤" = less than or equal to
"≥" = greater than or equal to
w.w. = wet weight
d.w. = dry weight
μg/L = microgram per liter

References:
Bell, M.C., 1986. *Fisheries Handbook of Engineering Requirements and Biological Criteria*, edited by U.S. Army Corps of Engineers, Portland, Oregon, p. 320.
Sources:
Aceituno, M.E., 1990. Habitat preference criteria for Chinook salmon of the Stanislaus River, California. U.S. Department of the Interior Fish & Wildlife Service, Sacramento, California.
USEPA (U.S. Environmental Protection Agency), 2003. *EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards*. EPA 910-B-03-002. Region 10 Office of Water, Seattle, Washington.
Gard, M., 2001. Identification of the instream flow requirements for anadromous fish in the streams within the Central Valley of California
Jeffres, C., 2014. Unpublished Data.
Katz, J., 2013. Unpublished Data.
McCullough, D. A., S. Spalding, D. Sturdevant, and M. Hicks, 2001. *Summary of Technical Literature Examining the Physiological Effects of Temperature on Salmonids.* Issue Paper 5. Report No. EPA-910-D-01-005. U.S. Environmental Protection Agency.
Myrick, C.A., and J.J. Cech, Jr., 2004. Temperature effects on juvenile anadromous salmonids in California's central valley: what don't we know? *Reviews in Fish Biology and Fisheries* 14:113-123.
Myrick, C.A., and J.J. Cech, Jr., 2001. *Temperature effects on Chinook salmon and steelhead: a review focusing on California's Central Valley populations.* Bay-Delta Modeling Forum Technical Publication 01-1.
Richter, A., and S.A. Kolmes, 2005. Maximum Temperature Limits for Chinook, Coho, and Chum Salmon, and Steelhead Trout in the Pacific Northwest. *Reviews in Fisheries Science* 13:23-49.
SJRRP (San Joaquin River Restoration Program), 2012. *Minimum Floodplain Habitat Area for Spring and Fall-Run Chinook Salmon*. November 2012.

Appendix B, Table B-5c
Juvenile Rearing Environmental Objectives (Channel)

Desired Habitat Parameter	Physical Parameter	Units	Metric	Entire River to Confluence								
				Fall-run Chinook			Spring-run Chinook			*O. mykiss*		
				Supportive	Stressful	Detrimental	Supportive	Stressful	Detrimental	Supportive	Stressful	Detrimental
Water Quality	Temperature	^{o}C (^{o}F)	7DADM	6 to 16 (42.8 to 60.8)	17 to 20 (62.6 to 68)	> 20 (68)	6 to 16 (42.8 to 60.8)	17 to 20 (62.6 to 68)	> 20 (68)	6 to 16 (42.8 to 60.8)	17 to 20 (62.6 to 68)	> 20 (68)
Water Quantity	Flow Variability			TBD (X to X applicable during X time of year)			TBD (X to X applicable during X time of year)			TBD (X to X applicable during X time of year)		
Water Quality	Pesticides, including Copper[2]	Risk - Frequency of Benchmark Exceedances	Frequency of Exceedances	≤ 0.017	0.018 to 0.303	≥ 0.304	≤ 0.017	0.018 to 0.303	≥ 0.304	≤ 0.017	0.018 to 0.303	≥ 0.304
Water Quality	Other Contaminants - Selenium	mg/kg (d.w., tissue) µg/L (water)	Maximum Concentration	8.5 mg/kg (whole body) 11.3 mg/kg (muscle) 3.1 µg/L (water, lotic)			8.5 mg/kg (whole body) 11.3 mg/kg (muscle) 3.1 µg/L (water, lotic)			8.5 mg/kg (whole body) 11.3 mg/kg (muscle) 3.1 µg/L (water, lotic)		
Water Quality	Other Contaminants - Mercury	mg/kg (w.w., tissue, whole body, juvenile)	Maximum Concentration	< 0.2	0.2 to 1.0	> 1.0	< 0.2	0.2 to 1.0	> 1.0	< 0.2	0.2 to 1.0	> 1.0
Landform and Cover	Substrate	Grain Size; % Suitable		> X% cobble/gravel < X% fines			> X% cobble/gravel < X% fines			> X% cobble/gravel < X% fines		

Notes:

^{0}C = degrees Celsius

^{0}F = degrees Fahrenheit

7DADM = 7-day average of the daily maximum

ppm = parts per million

">" = greater than

"<" = less than

"≤" = less than or equal to

"≥" = greater than or equal to

w.w. = wet weight

d.w. = dry weight

µg/L = microgram per liter

Sources:

Aceituno, M.E., 1990. Habitat preference criteria for Chinook salmon of the Stanislaus River, California. U.S. Department of the Interior Fish & Wildlife Service, Sacramento, California.

USEPA (U.S. Environmental Protection Agency), 2003. *EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards* . EPA 910-B-03-002. Region 10 Office of Water, Seattle, Washington.

Gard, M., 2001. Identification of the instream flow requirements for anadromous fish in the streams within the Central Valley of California

Jeffres, C., 2014. Unpublished Data.

Katz, J,. 2013. Unpublished Data.

McCullough, D. A., S. Spalding, D. Sturdevant, and M. Hicks, 2001. *Summary of Technical Literature Examining the Physiological Effects of Temperature on Salmonids.* Issue Paper 5. Report No. EPA-910-D-01-005. U.S. Environmental Protection Agency.

Myrick, C.A., and J.J. Cech, Jr., 2004. Temperature effects on juvenile anadromous salmonids in California's central valley: what don't we know? *Reviews in Fish Biology and Fisheries* 14:113-123.

Myrick, C.A., and J.J. Cech, Jr., 2001. *Temperature effects on Chinook salmon and steelhead: a review focusing on California's Central Valley populations.* Bay-Delta Modeling Forum Technical Publication 01-1.

Richter, A., and S.A. Kolmes, 2005. Maximum Temperature Limits for Chinook, Coho, and Chum Salmon, and Steelhead Trout in the Pacific Northwest. *Reviews in Fisheries Science* 13:23-49.

SJRRP (San Joaquin River Restoration Program), 2012. *Minimum Floodplain Habitat Area for Spring and Fall-Run Chinook Salmon* . November 2012.

Appendix B, Table B-5d
Juvenile Migration (Smoltification) Environmental Objectives (Channel)

Desired Habitat Parameter	Physical Parameter	Units	Metric	Entire River to Confluence								
				Fall-run Chinook			Spring-run Chinook			*O. mykiss*		
				Supportive	Stressful	Detrimental	Supportive	Stressful	Detrimental	Supportive	Stressful	Detrimental
Water Quality	Temperature	^{o}C (^{o}F)	7DADM	6 to 16 (42.8 to 60.8)			6 to 16 (42.8 to 60.8)			12.5 (54.5)		> 12.5 (54.5)
Water Quality	Temperature	^{o}C (^{o}F)	Weekly Average							< 11 (51.8)		> 11 (51.8)

Notes:

^{o}C = degrees Celsius

^{o}F = degrees Fahrenheit

7DADM = 7-day average of the daily maximum

">" = greater than

"<" = less than

Sources:

Aceituno, M.E., 1990. *Habitat preference criteria for Chinook salmon of the Stanislaus River, California* . U.S. Department of the Interior Fish & Wildlife Service, Sacramento, California.

USEPA (U.S. Environmental Protection Agency), 2003. *EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards* . EPA 910-B-03-002. Region 10 Office of Water, Seattle, Washington.

Gard,M., 2001. Identification of the instream flow requirements for anadromous fish in the streams within the Central Valley of California

Jeffres, C., 2014. Unpublished Data.

Katz, J., 2013. Unpublished Data.

McCullough, D. A., S. Spalding, D. Sturdevant, and M. Hicks, 2001. *Summary of Technical Literature Examining the Physiological Effects of Temperature on Salmonids.* Issue Paper 5. Report No. EPA-910-D-01-005. U.S. Environmental Protection Agency.

Myrick, C.A., and J.J. Cech, Jr., 2004. Temperature effects on juvenile anadromous salmonids in California's central valley: what don't we know? *Reviews in Fish Biology and Fisheries* 14:113-123.

Myrick, C.A., and J.J. Cech, Jr., 2001. *Temperature effects on Chinook salmon and steelhead: a review focusing on California's Central Valley populations.* Bay-Delta Modeling Forum Technical Publication 01-1.

Richter, A., and S.A. Kolmes, 2005. Maximum Temperature Limits for Chinook, Coho, and Chum Salmon, and Steelhead Trout in the Pacific Northwest. *Reviews in Fisheries Science* 13:23-49.

SJRRP (San Joaquin River Restoration Program), 2012. *Minimum Floodplain Habitat Area for Spring and Fall-Run Chinook Salmon* . November 2012.

Appendix C
Environmental Objectives That Apply Across All Species and Life History Stages

TABLE OF CONTENTS

TABLES

FIGURES

ABBREVIATIONS

µg/g	micrograms per gram
µg/L	micrograms per liter
7DADM	7-day average of daily maximum temperature
ATP	adenosine triphosphate
Basin Plan	Sacramento and San Joaquin River Basins Water Quality Control Plan
CFR	Code of Federal Regulations
ChE	cholinesterase
CTR	California Toxics Rule
CVRWQCB	Central Valley Regional Water Quality Control Board
Delta	Sacramento-San Joaquin Delta
DO	dissolved oxygen
ELS	early-life stage
IULT	Incipient Upper Lethal Temperatures
LC_{50}	lethal concentration 50%
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
ng/L	nanograms per liter
OPP	Office of Pesticide Programs
SEP	Scientific Evaluation Process
steelhead	California Central Valley steelhead
TMDL	total maximum daily load
t-TEL	tissue threshold-effect level
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
WDOE	Washington State Department of Ecology

1 Environmental Objectives and Supporting Rationale for Variables that Apply Across All Species and Life History Stages

To facilitate an integrated understanding of temperature, dissolved oxygen (DO), and contaminants, which are critical to all life history stages, the following sections summarize the temperature, DO, and contaminants dynamics and physiological responses broken down in the life history stage specific sections.

1.1 Temperature Objectives

1.1.1 Rationale

Salmonid growth and egg development rates, life history stage duration, and metabolic efficiency are directly influenced by water temperature (Quinn 2005). Temperature also has indirect effects on growth rate and egg development rates and success through its interaction with DO concentrations and pathogen activity. Water temperatures and developmental rates are tightly and positively correlated (Healey 1991; Quinn 2005); however, beyond certain thresholds, temperature correlates negatively with efficient use of food resources and proper enzymatic functioning. For example, eggs and alevins incubated at temperatures just below their lethal limit produce smaller juveniles than they would at supportive temperatures.

Temperature effects on timing of juvenile emergence and juvenile size at emergence have large impacts on the early life history and success of developing salmonids. Numerous studies document these sublethal effects in different life history stages (Healey 1991; Quinn 2005); however, their importance in the overall population dynamics of Chinook salmon (*Oncorhynchus tshawytscha*) populations is not often considered by water and fishery managers.

High water temperatures are a widespread and frequent challenge for several life history stages of Central Valley Chinook salmon and *O. mykiss*, whereas negative impacts of temperatures near or below low temperature thresholds are uncommon. Several authors have hypothesized that Central Valley populations of Chinook salmon and California Central Valley steelhead (steelhead) may tolerate warmer temperatures than other populations (Myrick and Cech 2004). However, in the San Joaquin Basin's Tuolumne River, there is limited evidence to support this hypothesis in *O. mykiss* populations (Farrell et al. 2015), and in general, published data do not consistently support the hypothesis.

Temperature-related mortality and habitat-limitation may become more detrimental for Central Valley salmonids in the future because of global climate change. This makes restoration of salmonid populations in the San Joaquin Valley particularly important as the river and its tributaries drain the

highest elevation basins in the lower 48 United States—these watersheds are expected to maintain snowpack (the source of reservoir coldwater pools) further into the future than are watersheds in the northern Central Valley (DWR 2010). San Joaquin Valley Chinook salmon are at the southern edge of their range, and access to the coldest waters in this watershed are currently blocked by impassable dams. The dams form reservoirs where water gains heat during the spring and summer before it is released downstream into salmon redd and rearing habitats. Water management strategies that provide sufficient supplies of cold water for egg development and rearing salmonids are constrained by increasing human demands on water stored in reservoirs and projections of increasing temperatures in the Central Valley (CDFG 2004a, 2004b; Lindley et al. 2007). Potential approaches to preserving and expanding redd and rearing habitat for salmonids in the Central Valley include the following:

- Reservoir management practices that increase coldwater supplies (e.g., Nickel et al. 2004)
- Measures that limit temperature increases of flowing waters (e.g., planting of riparian forests that shade waterways)
- Restoration of migratory access to colder habitats (NMFS 2009a, 2014)

In the Central Valley, human ability to actively manage temperatures through reservoir releases diminishes with distance from the reservoir during the late-spring through the mid fall period. Certain riparian and aquatic habitats can limit seasonal temperature gain as water flows to the estuary. Some areas that may have once been used for rearing by juvenile salmonids may no longer be suitable for those functions (even if habitats were restored) because water temperatures have or are expected to increase in those regions as a result of global climate change. Thus, decisions about how and whether to restore salmon rearing habitats at lower elevation are intimately tied to an understanding of thermal limitations of the parr and smolt life history stages.

1.1.2 Approach

The Scientific Evaluation Process (SEP) Group identified temperature objectives as ranges for the following conditions:

- Supportive (little to no negative effects)
- Stressful (demonstrably negative, though perhaps not directly lethal)
- Detrimental for various salmonid life history stages and transitions

In the case of juvenile salmon, temperature objectives were expressed as habitat-specific ranges within a life history stage that reflect the impact of food availability on temperature response norms. Special attention was given to the metamorphosis of parr to smolt (smoltification), as this transformation is sensitive to elevated temperatures among salmonids.

Estimates of the supportive, stressful, and detrimental temperature limits for various life history stages of Chinook salmon and *O. mykiss* are myriad and variable. Within a species, different life history stages have different temperature response curves. Within life history stages, variance in estimates of temperature thresholds may result from a combination of factors, including the following:

- Natural genetic and phenotypic variation among individuals studied
- Genetic differences among populations studied
- Experimental methods and protocols employed by the researchers
- The manner in which experimental data were interpreted and presented in published papers

The SEP Group relied primarily on U.S. Environmental Protection Agency (USEPA; 2003) guidance for temperature effects on Pacific salmon and supplemented that information when newer information and Central Valley-specific studies were available. Except where otherwise noted, temperatures reported in this document reflect ranges derived from experiments where temperature was held constant throughout an experimental period (i.e., there was no diurnal variation). USEPA (2003) notes that daily average temperatures in the field do not translate directly to static temperatures in a laboratory. For example, diurnal variation in temperatures exposes fish to higher, and potentially injurious, conditions in the field that are not reflected in a laboratory where temperatures are held constant. Thus, USEPA (2003) recommends use of a 7-day average of daily maximum temperature (7DADM) metric for evaluating temperature impacts on salmonid life history stages. Where temperatures in the field exceed those that are supportive, USEPA (2003) proposes the following simple conversion of observed (or modeled) temperatures to values that can be compared to static temperatures used in laboratory experiments:

> When the mean temperature is above the optimal [supportive] growth temperature, the "midpoint" temperature between the mean and the maximum is the "equivalent" constant temperature. This "equivalent" constant temperature then can be directly compared to laboratory studies done at constant temperatures. (p. 19)

In the Stanislaus River, the difference between daily maximum and daily mean temperatures stays roughly constant across seasons, but the temperature difference increases with distance downstream from the dam. The difference between the daily maximum and daily mean temperatures at the Goodwin Dam gage is approximately 1°C (1.8°F). This difference is approximately 3°C (5.4°F) farther downstream at the Orange Blossom Bridge gage (J.D. Wikert, personal communication 2014). Thus, the SEP Group added approximately 0.5°C (0.9°F) to egg development and early life stage (ELS) constant temperature thresholds and approximately 1.5°C (2.7°F) to rearing and migration temperature thresholds to provide a 7DADM expression of temperature requirements.

1.1.3 Objectives

1.1.3.1 Chinook Salmon

Life history stage-specific temperature thresholds were assumed to be the same for spring-run and fall-run Chinook salmon.

1.1.3.1.1 Spawning and Egg Development

Adult spawning Chinook salmon temperature needs are generally similar to their eggs. Considerations specific to spawning habitat include temperature triggers for spawning and potential thermal stress, which could lead to high rates of prespawn mortality and egg retention. In general, the temperature criteria for eggs are protective of the spawning phase and subsequent egg development phase.

Salmonid eggs and larvae require cold water to successfully complete egg development. With the construction of impassable dams, coldwater storage in reservoirs is necessary to provide sufficient coldwater releases to protect developing eggs for Chinook salmon spawning in the San Joaquin Valley. The restricted supply of cold water from storage limits successful spawning habitat for Chinook salmon populations in the Central Valley in general, and the San Joaquin River Basin in particular.

The impact of water temperatures on developing embryos is not well understood. Because the temperature tolerances of fertilized eggs are much lower than those that adult salmon tolerate, there is concern that developing reproductive tissues exposed to high temperatures may be less viable than those that are formed under cooler temperatures. USEPA (2003) indicates that eggs in holding females exposed to constant temperatures greater than 13°C (55.4°F) suffer reduced viability. Berman (USEPA 1999) found that offspring of adult Chinook salmon that had been held for 2 weeks at temperatures between 17.5°C and 19°C (63.5°F to 66.2°F) had higher pre-hatch mortality and developmental abnormality rates and lower weight than a control group.

USEPA (2003) found that constant temperatures between 4°C and 12°C (39.2°F and 53.6°F) result in good egg survival, and a narrower range, i.e., 6°C to 10°C (42.8°F to 50°F), is supportive. A 7DADM of less than 13°C (55.4°F) is recommended (Table C-1). In a review, the U.S. Fish and Wildlife Service (USFWS; 1999, cited by Myrick and Cech 2004) concluded that temperature-related egg mortality in Chinook salmon increased at temperatures above 13.3°C (55.9°F); this is the limit applied in most regulatory settings (NMFS 2009a; State Water Resources Control Board Order 90-05). Myrick and Cech (2004) conducted a review of studies on different populations of Chinook salmon from within and outside the Central Valley; their findings indicated that temperatures between 6°C and 12°C (42.8°F and 53.6°F) were supportive for Central Valley Chinook salmon. Table C-1 identifies the

supportive, stressful, and detrimental temperature conditions for Chinook salmon spawning and egg development.

Table C-1
Temperature Objectives for Chinook Salmon Spawning and Egg Development

Spatial Extent (Habitat Type)	Temporal Extent	Condition	Range (Metric)
Gravel	Fall-run: Late October to March Spring-run: Late August to March	Supportive	6°C to 12°C (42.8°F to 53.6°F) (Daily Average)
			< 12.5°C to 13°C (54.5°F to 55.4°F) (7DADM)
		Stressful	4°C to 6 °C (Daily Average)
			12°C to 13.3°C (53.6°F to 55.9°) (Daily Average)
			12.5°C to 13.8°C (54.5°F to 56.8°F) (7DADM)
		Detrimental	> 13.3°C (55.9°F) (Daily Average)
			> 13.8°C (56.8°F) (7DADM)

Notes:
> = greater than
< = less than

1.1.3.1.2 Juvenile Rearing and Migration

Temperatures that cause mortality among Pacific salmon depend, to some extent, on acclimation temperatures—higher acclimation temperatures produce higher Incipient Upper Lethal Temperatures (IULT; Myrick and Cech 2004). Various sources indicate an IULT for Chinook salmon in the range of 24°C to 25°C (75.2°F to 77°F; Myrick and Cech 2004). Baker et al. (1995) found that Central Valley Chinook salmon had an IULT between approximately 22°C and 24°C (71.6°F to 75.2°F).

Negative sublethal effects (i.e., effects that may increase susceptibility to other mortality mechanisms) begin to occur at temperatures lower than the IULT. In the laboratory, when fish have access to full rations, juvenile salmonid growth increases as temperature increases up to the physiological limits of a fish. However, when food supplies are limited (as it often is under normal conditions in the field) supportive and stressful growth and mortality occur at lower temperatures. For example, Mesa et al. (2002) detected increased levels of heat shock proteins (an indicator of stress) after several hours of exposure to 20°C (68°F) for Columbia River fall-run Chinook salmon. Among juvenile fall-run Chinook salmon from California's Central Valley population, Marine and Cech (2004) found decreased growth, reduced smoltification success, and impaired ability to avoid predation at temperatures above 20°C (68°F). They also reported that fish reared at temperatures from 17°C to 20°C (62.6°F to 68°F) experienced increased predation relative to fish raised at 13°C to 16°C (55.4°F to 60.8°F), though they found no difference in growth rate among fish reared in these two temperature ranges. The finding of decreased performance at temperatures above 17°C (62.6°F) is consistent with several studies that suggest, when food supplies are not superabundant,

supportive growth and survival among Chinook salmon occurs at temperatures somewhat lower than 17°C (62.6°F). USEPA (2003) identifies constant temperatures of 10°C to 17°C (50°F to 62.6°F) and a 7DADM less than 18°C (64.4°F) as being supportive conditions for juvenile Chinook salmon when food supplies are limiting. USEPA (2003) recommends 16°C (60.8°F) 7DADM as a maximum criterion to ensure the following:

- Protect juvenile salmon and trout from lethal temperatures
- Provide supportive conditions for juvenile growth under limited food supplies during summer's maximum temperatures and supportive temperatures for other times of the growth season
- Avoid temperatures where juvenile salmon and trout are at a competitive disadvantage with other fish
- Protect against temperature-induced elevated disease rates
- Provide research-backed temperatures that juvenile salmon and trout prefer and are found in high densities

Based on this recommendation, 16°C (60.8°F) 7DADM or less has been established as the supportive water temperature for juvenile rearing and migration in the river channel.

Rearing juvenile Chinook salmon's ability to tolerate temperatures depends to a great extent on food availability. USEPA (2003) states that when food supplies are unlimited, temperatures from 13°C to 20°C (55.4°F to 68°F; constant) may be supportive. Recent studies of Central Valley Chinook salmon rearing on inundated floodplains reveal excellent survival and growth rates at even higher temperatures. Growth and survival have been recorded at temperatures as high as approximately 25°C (77°F; Katz unpublished data; Jeffres unpublished data). The increased tolerance for high temperatures in these fish is believed to be related to the relatively high abundance of high quality food available to Chinook salmon rearing on floodplains. The results of this study suggest that, when food is not limiting, Chinook salmon can tolerate and even thrive in the wild at temperatures approaching the physiological limits observed in the laboratory (i.e., IULT). As a result, the SEP Group assumed that, following successful restoration of floodplain habitats (and during periods when juvenile Chinook salmon occupy inundated floodplains), rearing juvenile Chinook salmon could survive temperatures approaching 25°C (77°F). For example, both spring-run and fall-run Chinook salmon could survive temperatures approaching 25°C (77°F) for limited periods of time based on their life history timing and productivity objectives. Based on these distinctions, temperatures greater than 25°C were established as detrimental for salmon rearing on long-inundation floodplains only. However, the SEP Group also recognizes that exposure to such warm water temperatures greatly increases disease risk, and stress from other water quality factors (e.g., DO or contaminants) likely reduces thermal tolerance. When Chinook salmon are not in habitats that support superabundant

food resources (e.g., in mainstem channel habitats), lower temperatures are required to avoid negative sublethal effects.

Elevated water temperatures can inhibit smoltification in salmonids. Chinook salmon can smolt at temperatures ranging from 6°C to 20°C (42.8°F to 68°F; Myrick and Cech 2004). However, salmon that smolt at higher temperatures (greater than 16°C [60.8°F]) tend to display impaired smoltification patterns and reduced saltwater survival (Myrick and Cech 2004). Marine and Cech (2004) found that Central Valley Chinook salmon rearing in temperatures greater than or equal to 20°C (68°F) suffered altered smolt physiology. Other studies from within this ecosystem suggest that negative effects of temperature on smoltification may occur at temperatures less than 20°C (68°F). Richter and Kolmes (2005) cite two studies that indicated negative impacts on Chinook salmon smoltification success at temperatures greater than 17°C (62.6°F). Further, USEPA (2003) indicates that smoltification impairment may occur at temperatures between 12°C and 15°C (53.6°F to 59°F).

Table C-2 identifies the supportive, stressful, and detrimental temperature conditions for juvenile Chinook salmon rearing and migration.

Table C-2
Temperature Objectives for Juvenile (Fry, Parr, and Smolt) Chinook Salmon Rearing and Migration

Spatial Extent (Habitat Type)	Temporal Extent	Condition[1]	Range (Metric)
Channel	Fall-run: Last week of January to the second week of June Spring-run: First week of January to the second week of June	Supportive	6°C to 16°C (42.8°F to 60.8°F) (7DADM)
		Stressful	17°C to 20°C (62.6°F to 68°F) (7DADM)
		Detrimental	> 20°C (68°F) (7DADM)
Off-Channel – (Short Inundation)		Supportive	10°C to 18°C (50°F to 64.4°F) (7DADM)
		Stressful	18°C to 20°C (64.4°F to 68°F) (7DADM)
		Detrimental	> 20°C (68°F) (7DADM)
Inundated Floodplain – (Long Inundation)		Supportive	10°C to 18°C (50°F to 64.4°F) (7DADM)
		Stressful	18°C to 25°C (7DADM)
		Detrimental	> 20°C (68°F) (7DADM)

Note:

1. These temperatures apply along the juvenile migratory corridor. Because water temperatures are expected to increase as water travels downstream during warmer months, temperatures measured or modeled upstream that are at or near the limit of a given range would be expected to exceed that range further downstream. Thus, temperatures at the high end of the stressful range that are measured or modeled in upstream locations indicate potentially detrimental temperature conditions farther downstream, including into the San Joaquin mainstem.

1.1.3.1.3 Adult Migration

High water temperatures can lead to direct mortality and indirect loss of fitness for migrating salmon. The IULT may be as low as 21°C to 22°C (69.8°F to 71.6°F) for both adult Chinook salmon and steelhead during migration (USEPA 1999, 2003; Richter and Kolmes 2005). Swimming performance is reduced at temperatures greater than 20°C (68°F) (USEPA 2003). High water temperatures also facilitate infection among migrating adult salmonids (Noga 1996). USEPA (2003) identifies an elevated risk of infection at temperatures above 13°C (55.4°F) and a high risk of infection at temperatures greater than 18°C (64.4°F).

Water temperatures below the IULT may also impede spawning migration. Higher temperatures may produce acute distress. Prolonged exposure to temperatures greater than 17°C (62.6°F) reduces fitness during migration due to cumulative stresses (USEPA 2003). In fact, McCullough et al. (2001), writes the following:

> Migration blockages, susceptibility to disease, impaired maturation process, increases to stress parameters, reduced efficiency of energy use, and reduced swimming performance were all cited [by MacDonald in press] as potentially serious hazards as daily mean temperatures exceed 62.6°F (17°C). (p. 9).

Williams (2006) reported that salmon returning to the Stanislaus River in 2003 endured water temperatures greater than 21°C (69.8°F) on their migration; however, there is no indication that these fish spawned successfully or that they produced viable offspring. Williams (2006) also reported that migrating Sacramento River fall-run Chinook adult salmon appeared to avoid temperatures greater than approximately 19°C (66.2°F), an observation consistent with reports for Chinook salmon from other watersheds (Richter and Kolmes 2005). Many sources recommend maintaining temperatures less than 20°C to 21°C (68°F to 69.8°F) to prevent direct impairment of Chinook salmon migrations (USEPA 1999, 2003; Richter and Kolmes 2005).

Table C-3 identifies the range in temperatures associated with supportive, stressful, and detrimental conditions for Chinook salmon adult migration and holding.

Table C-3
Temperature Objectives for Chinook Salmon Adult Migration and Holding

Spatial Extent (Habitat Type)	Temporal Extent	Condition	Range (Metric)
Main Channel	Fall-run: Late September to December Spring-run: March to July (Migration); March to September (Holding)	Supportive	Holding: 8°C to 13°C (46.4°F to 55.4°F) (Daily Average) Migration: 8°C to 14°C (46.4°F to 57.2°F) (Daily Average)
			Holding: 9.5°C to 14.5°C (49.1°F to 58.1°F) (7DADM) Migration: 9.5°C to 15.5°C (49.1°F to 59.9°F) (7DADM)
		Stressful	Holding: >13°C to 19°C (>55.4°F to 66.2°F) (Daily Average) Migration: >14°C to 19°C (>57.2°F to 66.2°F) (Daily Average)
			Holding: >14.5°C to 20.5°C (>58.1°F to 68.9°F) (7DADM) Migration: >15.5°C to 20.5°C (>59.9°F to 68.9°F) (7DADM)
		Detrimental	> 18°C (64.4°F) (weekly mean)
			> 19°C (66.2°F) (Daily Average)
			> 20.5°C (68.9°F) (7DADM)
			> 22°C (71.6°F) (instantaneous)

1.1.3.2 *O. mykiss*

1.1.3.2.1 Spawning and Egg Development

As with Chinook salmon, adult spawning *O. mykiss* temperature needs are generally similar to their eggs' temperature needs. Considerations specific to spawning habitat include temperature triggers for spawning and potential thermal stress that could lead to high rates of prespawn mortality and egg retention. In general, the temperature criteria for eggs are protective of spawning and the subsequent egg development phase.

Oncorhynchus mykiss eggs and larvae require cold water to successfully complete egg development. With the construction of impassable dams, *O. mykiss* eggs developing in the San Joaquin Valley became dependent on coldwater releases from reservoirs. The accessible supply of coldwater storage limits successful spawning habitat for *O. mykiss* populations in the southern Central Valley. There is a lack of peer-reviewed studies on the temperature tolerances of Central Valley *O. mykiss* eggs, and additional study of temperature impacts on this species' eggs is needed (Myrick and Cech 2004). Supportive egg development temperatures for *O. mykiss* occur in a narrower range than egg development temperatures for Chinook salmon. Indeed, Myrick and Cech (2004) warn against managing water temperatures for the upper end of the Chinook salmon thermal tolerance range in waterways and during periods when *O. mykiss* eggs are also developing because developing *O. mykiss* eggs cannot tolerate such high temperatures. Richter and Kolmes (2005) conclude that egg mortality increases as egg development temperatures exceed 10°C (50°F), and substantial mortality

may occur when temperatures exceed 13.5°C to 14.5°C (56.3°F to 58.1°F). Based on hatchery operations in the Central Valley, supportive egg development temperatures appear to be in the 7°C to 10°C (44.6°F to 50°F) range (Myrick and Cech 2004). California's steelhead management plan (McEwan and Jackson 1996) suggests a slightly higher temperature range (from 9°C to 11°C [48.2°F to 51.8°F]).

Table C-4 identifies supportive, stressful, and detrimental temperature conditions for *O. mykiss* spawning and egg development.

Table C-4
Temperature Objectives for *O. mykiss* Spawning

Spatial Extent (Habitat Type)	Temporal Extent	Condition	Range (Metric)
Gravel	December to June	Supportive	7°C to 10°C (44.6°F to 50°F) (Daily Average)
			10.5°C (50.9°F) (7DADM)
		Stressful	4°C to 6.9°C (39.2°F to 44.4°F) (Daily average)
			10°C to 13.5°C (50°F to 56.3°F) (Daily Average)
			10.5°C to 14.0°C (50.9°F to 57.2°F) (7DADM)
		Detrimental	> 13.5°C (56.3°F) (Daily Average)
			> 14.0°C (57.2°F) (7DADM)

1.1.3.2.2 Juvenile Rearing and Migration

Laboratory studies show that incipient lethal temperatures for juvenile *O. mykiss* occur in a range between 27.5°C and 29.6°C (81.5°F to 85.3°F), depending on acclimation temperatures (Myrick and Cech 2005). Supportive temperatures for *O. mykiss* juvenile growth occur between 15°C and 19°C (59°F and 66.2°F; Moyle 2002; Richter and Kolmes 2005).

Temperature also mediates the impact of competition between species. For example, *O. mykiss* juveniles suffer adverse impacts of competition with Sacramento pikeminnow (*Ptychocheilus grandis*) at temperatures greater than 20°C (68°F), though no competitive impact is detectable at lower temperatures (Reese and Harvey 2002).

Table C-5 identifies supportive, stressful, and detrimental temperature conditions for *O. mykiss* juvenile rearing.

Table C-5
Temperature Objectives for *O. mykiss* Juvenile Rearing

Spatial Extent (Habitat Type)	Temporal Extent	Condition[1]	Range (Metric)
Mainstem	January to December (i.e., year-round)	Supportive	15°C to 19°C (59°F to 66.2°F) (Daily Average)
			16.5°C to 21.5°C (61.7°F to 70.7°F) (7DADM)
		Stressful	20°C to 25°C (68°F to 77°F) (Daily Average)
			21.5°C to 26.5°C (70.7°F to 79.7°F) (7DADM)
		Detrimental	> 25°C (77°F) (Daily Average)
			26.5°C (79.7°F) (7DADM)
			> 27.5°C (81.5°F) (Instantaneous)

Note:

1. These temperatures apply all along the juvenile migratory corridor. Because water temperatures are expected to increase as water travels downstream during warmer months, temperatures measured or modeled upstream that are at or near the limit of a given range would be expected to exceed that range farther downstream. Thus, temperatures at the high end of the stressful range that are measured or modeled in upstream locations indicate potentially detrimental temperature conditions farther downstream, including into the San Joaquin mainstem.

Steelhead may be particularly sensitive to high temperatures during the smoltification process. USEPA (2003) indicates that temperatures greater than 12°C (53.6°F) inhibit steelhead metamorphosis into smolts. Richter and Kolmes (2005) and USEPA (1999) cite studies that present a range of temperatures between 11°C and 14°C (51.8°F and 57.2°F) that may inhibit steelhead smoltification. Myrick and Cech (2005) caution that smolting steelhead in the Central Valley must experience temperatures less than 11°C (51.8°F) to successfully complete this metamorphosis. The critical temperature at which smoltification becomes inhibited may vary from run to run (Richter and Kolmes 2005).

Table C-6 identifies the supportive, stressful, and detrimental temperature conditions for juvenile steelhead smoltification.

Table C-6
Temperature Objectives for Steelhead Juvenile Migration (Smoltification)

Spatial Extent (Habitat Type)	Temporal Extent	Condition	Range (Metric)
Main Channel	December to March	Supportive	11°C (51.8°F) (Weekly Average)
			12.5°C (54.5°F) (7DADM)
		Detrimental	> 11°C (51.8°F) (Weekly Average; i.e., detrimental if necessary temperature is not achieved during appropriate annual window)
			> 12.5°C (54.5°F) (7DADM)

1.1.3.2.3 Adult Migration and Holding

The IULT may be as low as 22°C (71.6°F) for migrating steelhead (USEPA 1999; Richter and Kolmes 2005). Although steelhead have been known to migrate in most months of the year, they are mostly present from mid fall to early spring (Hallock et al. 1961; Harvey 1995; McEwan 2001) when temperatures are generally well below the lethal threshold. For purposes of this document, the SEP Group has assumed that temperatures that are acceptable to migrating Chinook salmon adults are also acceptable to migrating steelhead adults.

Table C-7 provides the supportive, stressful, and detrimental temperature conditions for adult steelhead migration.

Table C-7
Temperature Objectives for Steelhead Migration, Holding, and Post-Spawning Adults (Kelts)

Spatial Extent (Habitat Type)	Temporal Extent	Condition	Range (Metric)
Main Channel	Mid-September to Mid-May	Supportive	8°C to 13°C (46.4°F to 55.4°F) (Daily Average)
			9.5°C to 14.5°C (49.1°F to 58.1°F) (7DADM)
		Stressful	>13°C to 19°C (>55.4°F to 66.2°F) (Daily Average)
			>14.5°C to 20.5°C (>58.1°F to 68.9°F) (7DADM)
		Detrimental	> 18°C (64.4°F) (Weekly average)
			> 19°C (66.2°F) (Daily Average)
			20.5°C (68.9°F) (7DADM)
			> 22°C (71.6°F) (Instantaneous)

1.2 Dissolved Oxygen Objectives

1.2.1 Rationale

Adequate concentrations of DO in water are critical for salmon and *O. mykiss* survival. In freshwater streams, hypoxia can impact the growth and development of salmon and *O. mykiss* eggs, alevins, and fry as well as the swimming, feeding, and reproductive ability of juveniles and adults. If salmonids are exposed to hypoxic conditions for too long, mortality can result (Carter 2005). Without achieving some combination of the supportive (or sub-supportive) environmental objectives for DO described below, the biological objectives for Chinook salmon and *O. mykiss* will not be met.

1.2.2 Approach

The SEP Group relied on DO criteria established by USEPA (1986), the Central Valley Regional Water Quality Control Board (CVRWQCB; 2018), and relevant technical literature (WDOE 2002) to identify DO objectives that are supportive (no negative effects), stressful (observably negative, though not

significantly harmful), and detrimental (clearly harmful) ranges for various salmonid life history stages and transitions. The approach the SEP Group used to translate available information on impairment levels into supportive, stressful, and detrimental objectives is shown in Table C-8.

Table C-8
Recommended Coldwater Species Dissolved Oxygen Levels for Spawning, Egg Development, and Larval Life History Stages

Level of Impairment to Embryo and Larvae Stages	Water Column Minimum Average Concentration	Intra-gravel Minimum Average Concentration	Supportive, Stressful, or Detrimental[1]
No production impairment	11 mg/L	8 mg/L	Supportive
Slight production impairment	10 mg/L	7 mg/L	Stressful
Slight production impairment	9 mg/L	6 mg/L	Stressful
Moderate production impairment	8 mg/L	5 mg/L	Detrimental
Severe production impairment	7 mg/L	4 mg/L	Detrimental
Limit to avoid acute mortality	6 mg/L	3 mg/L	Detrimental

Notes:

1. Relationship of recommended DO levels to supportive, stressful, and detrimental levels identified by the SEP Group

Table adapted from USEPA 1986
mg/L: milligrams per liter

The criteria established by USEPA (1986) and CVRWQCB (2018) put coldwater species in one category; separate criteria for Chinook salmon and *O. mykiss* were not provided. This blanket approach of protecting salmon and *O. mykiss* with one set of DO criteria is supported by the available literature; as such, the SEP Group followed that approach. While it is not necessary to have species-specific DO objectives, life history stage-specific objectives are needed because DO requirements for eggs and larvae differ from DO requirements for juveniles and adults.

The following summaries of egg mortality through hatching, egg development growth rates, juvenile rearing and migration, and adult migration and holding provide life history stage-specific rationale for the DO objectives presented in Section 1.2.3.

1.2.2.1 Egg Mortality through Hatching

At favorable egg development temperatures, mortality rates should be expected to remain less than 1% at a concentration of 9 milligrams per liter (mg/L) or greater, less than 2% at a concentration of 7 mg/L, and between 2 and 6% at a concentration of 6 mg/L (WDOE 2002). While mean oxygen concentrations over the development period below 6 mg/L are sometimes associated with significant increases in mortality rates, the overall pattern is for mortality rates and the occurrence of abnormalities to remain low (less than 7%) at concentrations above 4 mg/L.

Survival rates at oxygen concentrations below 4 mg/L are highly variable. While mortality rates were low (4% to 7%) in some studies, they ranged from 25% to 100% in other studies (WDOE 2002). All tests with oxygen concentrations below 1.7 mg/L resulted in 100% mortality. While mortality rates related to low oxygen concentrations remain relatively low at favorable egg development temperatures (averages below 11°C [51.8°F]), these rates increase substantially at temperatures that are warmer. For instance, in warmer water (13.4°C [56.1°F]), a decrease from 11 to 10 mg/L is associated with a 4% reduction in survival through hatching. A decrease to 7 mg/L is associated with a 19% reduction in survival (WDOE 2002).

In laboratory studies the developing alevins did not need to push their way up through gravel substrate as would wild fish. The studies described above focused on survival through hatching and did not consider this substantial final act for emerging through redds. Optimal fitness will likely be required for optimal emergence in the natural environment, and the metabolic requirements to emerge would be expected to be substantial. Thus, higher oxygen levels may be needed to fully protect emergence in addition to supporting hatching alone.

1.2.2.2 Egg Development Growth Rates

A decrease in the mean oxygen concentration during the egg development period appears to directly reduce the size of newly hatched salmonids. However, at favorable egg development temperatures, the level of this size reduction should remain slight (2%) with mean oxygen concentrations of 10.5 mg/L or more; the size reduction remains below 5% at concentrations of 10 mg/L or more. At 9 mg/L, the size of hatched fry would be reduced approximately 8%. Mean concentrations of 7 mg/L and 6 mg/L would be expected to cause 18% and 25% reductions in size, respectively (WDOE 2002).

1.2.2.3 Juvenile Rearing and Migration

Salmonids may be able to survive when DO concentrations are low (less than 5 mg/L), but growth, food conversion efficiency, and swimming performance will be adversely affected (Bjornn and Reiser 1991). Davis (1975) reviewed numerous studies and reported no impairment to rearing salmonids if DO concentrations averaged 9 mg/L. At oxygen levels of 6.5 mg/L, "the average member of the community will exhibit symptoms of oxygen distress," and at 4 mg/L, a large portion of salmonids may be affected (Davis 1975). The Washington State Department of Ecology (WDOE; 2002) concluded that a monthly or weekly average concentration of 9 mg/L, and a monthly average of the daily minimum concentrations, should be at or above 8 to 8.5 mg/L to have a negligible effect (i.e., 5% or less) on growth and support healthy growth rates. According to USEPA (1986), the reductions in growth rates seen above 6 mg/L are not usually statistically significant due to the variability inherent in growth studies, while reductions in growth at DO levels below 4 mg/L are considered severe. WDOE (2002) advised that DO levels below 5 to 6 mg/L should be considered a potential

barrier to the movement and habitat selection of juvenile salmonids. Given WDOE's (2002) recommendation, DO levels below 6 mg/L have been established as detrimental for juvenile salmon.

1.2.2.4 Adult Migration and Holding

WDOE (2002) reported that DO concentrations above 8 to 9 mg/L are needed for maximum swimming performance and concentrations below 5 to 6 mg/L elicited avoidance. Hallock et al. (1970) found that adult Chinook salmon migrating up the San Joaquin River avoided DO concentrations below 5 mg/L. DO concentrations above 8 mg/L were assumed by the SEP to represent supportive conditions, and concentrations below 6 mg/L were detrimental. DO concentrations between 6 and 8 mg/L were identified as stressful for migrating and holding adults.

1.2.3 Objectives

DO objectives are provided in Tables C-9 and C-10 using the following life history stage groupings:

- Spawning adults, eggs, and larvae
- Rearing and emigrating fry and juveniles and immigrating and holding adults

These groupings are consistent with USEPA and CVRWQCB DO criteria and the supporting technical literature. Anadromous salmonid eggs and larvae are more sensitive to low DO concentrations than rearing juveniles and adults that are immigrating or holding.

Table C-9
Dissolved Oxygen Objectives for Chinook Salmon and *O. mykiss* Spawning and Egg Development

Spatial Extent (Habitat Type)	Temporal Extent	Condition	Range (Metric)
Gravel (measurement must occur in gravel, not water column)	Fall-run: Late October to March	Supportive	> 8 mg/L (Daily Minimum)
		Stressful	6 to 8 mg/L (Daily Minimum)
	Spring-run: Late August to March	Detrimental	< 6 mg/L (Daily Minimum)
	O. mykiss: December to June		

Table C-10
Dissolved Oxygen Objectives for Chinook Salmon and *O. mykiss* Fry and Juveniles and Migrating and Holding Adults

Spatial Extent (Habitat Type)	Temporal Extent	Condition	Range (Metric)
River Channel or Floodplain (water column measurement)	Fall-run: Last week of January to second week of June (fry and juveniles) Late September to December (migration and holding)	Supportive	> 8 mg/L (Daily Minimum)
		Stressful	6 to 8 mg/L (Daily Minimum)
	Spring-run: January to December (i.e., year-round; fry and juveniles) March to July (migration) March to September (holding)	Detrimental	< 6 mg/L (Daily Minimum)
	O. mykiss: January to December (i.e., year-round; fry and juveniles) Mid-September to mid-May (migration and holding)		

1.3 Contaminant Objectives

1.3.1 Rationale

Since the early 1990s, the Stanislaus River between Goodwin Dam and Caswell State Park has been identified as impaired on the USEPA Clean Water Act Section 303(d) list for not meeting water quality standards. The following pollutants (or stressors) were identified as causes: diazinon, chlorpyriphos, Class A pesticides (e.g., organochlorines, DDT, and legacy pesticides), unknown toxicity, mercury, and temperature (USEPA 2011). In addition, mercury, selenium, and nutrients were identified as impairing beneficial uses in the San Joaquin River, the Sacramento-San Joaquin Delta (Delta), and San Francisco Bay, which are downstream salmonid rearing and migratory habitats (SWRCB 2010; USEPA 2011). Beneficial uses that are not being supported include the following:

- Cold freshwater habitat
- Migration
- Spawning, reproduction, and early development
- Warm freshwater habitat

Ammonia, arsenic, cadmium, and nickel were also evaluated, but these did not exceed water quality standards (SWRCB 2010).

The majority of available spawning habitat and subsequent rearing habitat in the Stanislaus River is below Knights Ferry (ESA 2013); this reach coincides with increased amounts of anthropogenic disturbances, primarily agricultural and urban development. In a review of toxicity monitoring data conducted in California, Anderson et al. (2011) found that sites located near agriculture and urban areas had statistically greater occurrences of toxicity in water and sediment samples than near undeveloped areas. In all, 51% and 45% of the streams, rivers, canals, and lakes monitored from 2001 to 2010 had some toxicity in the water column and sediment, respectively. Toxicological effects ranged from sublethal endpoints to full organism mortality. Using correlation analyses and toxicity identification evaluations, Anderson et al. (2011) determined that the majority of toxicity was caused by pesticides (e.g., insecticides, herbicides, and fungicides). Contaminants other than pesticides that were also identified as toxic included metals and ammonia.

The CVRWQCB developed a control program and adopted water quality objectives for diazinon and chlorpyriphos in the Central Valley (CVRWQCB 2018), which should reduce the adverse impacts of these two constituents. However, the use of organophosphate pesticides like diazinon and chlorpyriphos have declined in California since the mid-1990s, and USEPA actions resulted in the phase out of these two pesticides for urban use in the early 2000s (Spurlock and Lee 2008). Much of the pesticide use has shifted to pyrethroids, especially in urban environments. In 2006, pyrethroids accounted for greater than 40% of the insecticide registrations in California. Pyrethroids have been identified as causing much of the surface water and sediment toxicity in California (Anderson et al. 2011). More recently, use of the systemic pesticides "neonicotinoids" has increased; their use has been implicated in global declines of some wildlife (Mason et al. 2013; Gibbons et al. 2014). Current use pesticides are ever changing, and this makes it difficult for regulatory agencies to control the adverse effects that these contaminants create.

Mercury and selenium both occur naturally in the environment; however, anthropogenic activities have resulted in elevated concentrations in surface waters that are detrimental to aquatic life. For centuries, the smelting of large quantities of ore has contributed to the emissions of trace metals worldwide (Nriagu 1996). Recently, mercury water quality impairments in California have been linked to local and international industrial emissions (SFEI 2001; USEPA 2008). Extensive historical mining in California contributed to heavy metal emissions, and abandoned mine waste material continues to pollute Central Valley waterbodies (Alpers and Hunerlach 2000; Domagalski 2001; USEPA 2006). Oil refining and agricultural irrigation have contributed to selenium contamination in San Francisco Bay and the San Joaquin River watershed, respectively (McCarthy and Grober 2001; Presser and Luoma 2006, 2013). In addition, urban stormwater runoff is a major source of metals to California surface waters (TDC 2004; CRWQCBSDR 2007; SFBRWQCB 2007).

Nutrients occur naturally; however, anthropogenic activities create imbalances that may result in impairments to aquatic life. For example, ammonia, nitrite, and nitrate (to a lesser extent) have been

found to be toxic to fish by disrupting oxygen transport by the blood (Russo et al. 1974; Camargo et al. 2005; USEPA 2013). Anthropogenic sources of nutrients (e.g., nitrogen and phosphorus) from activities like agriculture, urbanization, sewage treatment, and livestock operations cause eutrophication in the Central Valley rivers, impairing aquatic uses (CVRWQCB 2018; Gowdy and Grober 2005; Schlegel and Domagalski 2015). Additionally, changes to Delta algae that form the base of the food web have been linked to excessive amounts (or altered ratios) of nutrients discharged to the Delta (DSC 2013).

The following subsections describe the major contaminants (pesticides,[1] mercury, selenium, and nutrients) that have been identified as impairing beneficial uses in the Stanislaus River and downstream migratory corridor. The descriptions of each contaminant will include the general background and the toxicological effects of each contaminant to fish, with emphasis on salmonids where available. If other contaminants or toxins are identified that impede Chinook salmon and *O. mykiss* recovery in the San Joaquin River Basin, then their impacts can be evaluated in the future.

1.3.1.1 Pesticides

Fishes are not the target organisms of pesticides; however, pesticides have been found to cause adverse impacts to fish in surface waters. For example, in a review of Central Valley toxicity data, Markiewicz et al. (2012) found that the fish species tests using fathead minnow *(Pimephales promelas*) had a higher frequency of toxicity than the invertebrate, *Ceriodaphnia dubia,* and the algae, *Selenastrum capricornutum*. Samples were toxic to fish in 62% of the tests versus 49% for invertebrates and 40% for algae. Similar to the statewide survey of Anderson et al. (2011), pesticides were found to be the primary cause of toxicity in the Central Valley (Markiewicz et al. 2012). Importantly, salmonids generally tend to be more sensitive to chemical stressors than many other species of fish; and, if other freshwater fish are killed by use of pesticides, then it is likely that salmonids have also died (NMFS 2012).

Moreover, the life history strategies salmonids evolved to rely on exposes them to higher risks from contaminants. For example, juvenile salmonids typically occupy and rely on shallow freshwater habitats (e.g., floodplains, off-channel, and low flow alcoves) during critical rearing and migratory life history periods. These nearshore, low flow habitats are expected to have higher pesticide loading and concentrations, which subject developing salmonids to higher exposures to pesticides in their preferred habitats (NMFS 2008, 2009b, 2011). Even if salmonids can avoid areas with the elevated concentrations of contaminants, salmonids may be adversely impacted by not benefitting from the uses these habitats provide (e.g., food and cover).

[1] The pesticides section (Section 1.3.1.1) will include a discussion on copper effects because copper is widely used as a pesticide (e.g., fungicide, herbicide, and antifouling paint).

Typically, adult organisms will have a lower risk of mortality to contaminants than the sensitive larvae used for toxicity tests. As a result, toxicity tests with larvae could overestimate the mortality that might occur to adult salmonids. However, pre-spawn adult salmonids are likely less tolerant of chemical stressors because they have used most of their accumulated fat stores for gamete production (NMFS 2008, 2010, 2013). It is probable that some pre-spawn returning adults will die as a result of short-term exposure to pesticides, especially when subjected to additional stressors such as elevated temperatures.

Additionally, pre-spawn mortality can be caused by other contaminants. For example, metals and petroleum hydrocarbons likely contributed to pre-spawn mortality of Coho salmon in urban streams in Washington State (Scholz et al. 2011). Pre-spawn mortality is a particularly important factor in the recovery of salmonid populations with low abundance because every adult is crucial to the population's viability (NMFS 2013).

While direct mortality is an obvious detriment to salmonid populations, many sublethal effects of pesticides can also contribute to population declines. Fish exposed to sublethal toxicants often lose the ability to perform fish behaviors, such as predator avoidance, orientation, reproduction, and kin recognition, that are essential to fitness and survival in natural ecosystems (Potter and Dare 2003; Scott and Sloman 2004). The most commonly observed links with behavioral disruption include cholinesterase (ChE) inhibition, altered brain neurotransmitter levels, sensory deprivation, and impaired gonadal or thyroid hormone levels (Scott and Sloman 2004). For example, Scholz et al. (2000) concluded that Chinook salmon exposed to short-term, sublethal exposures of diazinon experienced reduced anti-predator responses from olfactory disruption by anti-ChE neurotoxins. Additionally, Scholz et al. (2000) concluded that 24-hour exposures to diazinon likely increased the straying of the adult hatchery Chinook salmon over the control group. Furthermore, juvenile salmonids exposed to pesticides during development may fail to imprint to their natal waters, which can lead to increased adulthood straying (NMFS 2009b).

Reproductive experiments have demonstrated the sublethal effects of pesticides on fish populations. For example, the pyrethroid insecticide cypermethrin inhibited male Atlantic salmon from detecting and responding to the reproduction-priming pheromone prostaglandin, which is released by ovulating females (Moore and Waring 2001). The males exposed to cypermethrin did not respond to prostaglandin with the expected increased levels of plasma sex steroids and expressible milt. In addition, zebrafish (*Danio rerio*) exposed to low concentrations (96-hour LC5) of deltamethrin (a synthetic pyrethroid) and Achook (a neem-based nematicide and insecticide) resulted in significant reductions (54% and 18%, respectively) in female fecundity when compared to the controls (Sharma and Ansari 2010). Additionally, both of the studies found that exposures to pesticides decreased the abundance of hatchlings. The percentage of unhatched fertilized eggs increased in adult zebrafish exposures, and the number of unfertilized eggs increased in salmon egg and milt exposures (Moore

and Waring 2001; Sharma and Ansari 2010). Furthermore, the disruption of spawning synchronization could also result in an increase in the number of unfertilized eggs (NMFS 2009b).

Herbicide pesticides also have been shown to reduce the ability of fishes to perform necessary physiological activities. For example, Waring and Moore (1996) observed that concentrations of the herbicide atrazine that caused no lethal effects to Atlantic salmon in freshwater resulted in physiological stress and increased mortality once the fish were exposed to the contaminant in seawater. Subsequent investigations determined that sublethal concentrations of atrazine can reduce sodium-potassium adenosine triphosphate (ATPase) activity and the ability of salmon to osmoregulate (Moore and Fewings 2003). Similarly, Nieves-Puigdoller et al. (2007) found impaired osmoregulation and other forms of endocrine disruption at higher concentrations of atrazine. Other investigations have concluded that the herbicide trifluralin can cause vertebral deformities, which would likely also result in eventual mortality due to predators or reduced prey capture (NMFS 2012). Because pesticides are developed and used for multiple target organisms (e.g., plants, invertebrates, and vertebrates), their mechanisms of action are diverse. This results in a multitude of ways that pesticides can affect salmonid physiology, biochemistry, and behavior, and subsequently, many life history stages of salmonids may be adversely impacted.

Copper compounds are often used as herbicides and pesticides, and copper is one of the most widely applied pesticides in the Central Valley (Johnson et al. 2010). Additionally, copper is a naturally occurring trace element, and non-pesticide-related anthropogenic activities have increased copper pollution to surface waters (e.g., due to urban runoff due to vehicle brake pads, architectural features, industrial uses, mining waste, and soil erosion; CVRWQCB 2002; TDC 2004). Extreme cases of copper and other heavy metal contamination resulted in acid mine drainage that contributed to fish kills and significant declines in Chinook salmon and *O. mykiss* populations in the Sacramento River from the 1960s to the 1980s (CVRWQCB 2002). Heavy metal pollution from the Iron Mountain Mine to the Sacramento River contributed to the listing of winter-run Chinook salmon as endangered (CVRWQCB 2002).

Current copper pollution from pesticides and urban runoff are not as extreme as the Iron Mountain Mine example; however, low levels of copper can have adverse effects on salmonids, other fish, invertebrates, and algae (Hecht et al. 2007; USEPA 2007). The most studied toxicity pathway of copper is its ability to disrupt ATPase-driven pumps and ion channels, resulting in impaired osmoregulation and ion regulation in gills (Kiaune and Singhasemanon 2011). However, fish sensory systems are likely the most sensitive to sublethal copper toxicity. For example, low-level copper exposures have been shown to disrupt olfactory receptor neurons and lateral line mechanosensory neurons in fish (Hansen et al. 1999a; Hecht et al. 2007; Sandahl et al. 2007; McIntyre et al. 2008; Linbo et al. 2009). In addition, these copper exposures resulted in measured behavior alterations (e.g., predator avoidance response, contaminant avoidance, and swimming) in Chinook salmon and

rainbow trout that could result in reduced growth, survivability, and reproduction in salmonid populations (Hansen et al. 1999b; Sandahl et al. 2007; McIntyre et al. 2012).

Through bioenergetics modeling, researchers have worked to understand the impact of contaminant pollution on metabolic processes of fish. For example, Beyers et al. (1999) found that largemouth bass (*Micropterus salmoides*) metabolic rates (measured by oxygen consumption) increased in short-term exposures (1 to 4 days) to dieldrin. However, with longer exposures (16 days), zebrafish metabolic rates increased to compensate for the exposure, but at the cost of reduce growth rates. Similarly, Atlantic salmon survival, growth rates, and growth indices decreased proportionally along a pollution gradient in Onondaga Creek, New York (Coghlan and Ringer 2005). Other factors could lead to reduced survival of salmonids that are exposed to contaminants. These include reduced food consumption, reduced tolerance to other conditions (e.g., high temperature, low DO, and pathogens), and reduced food conversion efficiencies (Beyers et al. 1999; Coghlan and Ringler 2005). Bioenergetic modeling is a useful tool for demonstrating the biological significance of pesticide and other contaminant exposures (Beyers et al. 1999).

1.3.1.1.1 Indirect Effects

Salmonid populations can also be adversely impacted indirectly by pesticides acting upon their target species. For example, herbicides and insecticides target the food web organisms that salmonids depend on during rearing and migration. In addition, pesticides in the aquatic environment can shift algal or invertebrate communities to ones that are less nutritious or preferable to salmonids. Modifications to prey and prey food sources can have noticeable effects on fish populations (NMFS 2012). Reduced food for developing salmonids will result in greater competition, reduced fish growth, and possible starvation during critical life history stages (NMFS 2008). Other possible indirect impacts to salmonid populations include the destruction of riparian vegetation (NMFS 2012). Riparian vegetation is important for providing shade, stabilizing stream banks, and providing allochthonous inputs that are important to maintaining salmonid ecosystems.

1.3.1.1.2 Population-Level Effects

It is very difficult to quantify actual impacts that pesticide stressors have on salmonid populations because the effects can be direct or indirect, lethal or sublethal, long term or short term. To determine the possible combined effects that pesticides might have on salmon populations, researchers at the Northwest Fisheries Science Center used models to predict the effects of ChE inhibitors on anadromous Chinook salmon populations in the western United States (Baldwin et al. 2009; Macneale et al. 2014). They linked ChE activity to the somatic growth of subyearling Chinook salmon using a series of linear relationships (e.g., linked brain enzyme activity to feeding behavior, feeding behavior to food uptake, and food uptake to somatic growth). In addition, the researchers predicted the reduction in Chinook salmon growth due to reduced prey as a result of invertebrate

exposure to pesticides. The predicted size of Chinook salmon at ocean entry is used to predict ocean survival and then subsequent population growth.

The model results indicated that short-term exposures that were representative of real-world seasonal use patterns were enough to reduce the growth and size of juvenile Chinook salmon at the time of ocean entry. Consequently, the reduced size at ocean entry was enough to reduce the survival of individuals, which would, over successive years, reduce the intrinsic productivity of the population. For example, a four-day exposure to an organophosphate pesticide at a level that would produce a 50% reduction in ChE activity would result in a 6% decrease in the intrinsic population growth rate (Baldwin et al. 2009). Furthermore, the model estimated that if similar conditions continued for 20 years, then the exposed population spawner abundance would be only 27% of the unexposed spawner abundance.

Macneale et al. (2014) evaluated additional pesticide classes (e.g., carbamates), exposure durations, and exposure frequencies. Overall, the magnitude of the responses indicates that common pesticides may significantly limit the conservation and recovery of threatened and endangered species in California (Baldwin et al. 2009).

Unfortunately, the models only evaluated the direct and indirect effects of single pesticide exposures at a time, and they did not incorporate possible interactions of multiple pesticides, other environmental stressors (e.g., reduced habitat and stressful temperatures), or other contaminants. Different pesticides can work additively to cause a toxic effect, and other contaminants and stressors can influence pesticides' effectiveness, as well. For example, through transcriptional assays Hasenbein et al. (2014) determined that ammonia likely enhanced the effect of multiple-contaminant exposures to Delta smelt. Similarly, concurrent exposure of salmonids to copper and olfactory inhibitory pesticides could result in toxicological effects, even if both are at concentrations that would not elicit a response in isolation. Furthermore, many pesticides have been found to work synergistically to cause toxicity to salmonids that is multiplicative and not just additive (Laetz et al. 2009). Current estimates of the effects of pesticides on salmonids may underestimate the true responses of salmonid populations in surface waters (Baldwin et al. 2009).

These additive and synergistic effects from multiple contaminants are true concerns for aquatic environments. For example, in the U.S. Geological Survey National Water-Quality Assessment Program's monitoring of pesticides, the researchers found that more than 90% of the streams located in developed areas contained two or more pesticides or degradates (Gilliom et al. 2006). Furthermore, more than 50% of the streams had five or more pesticides or degradates, and the concentrations of the degradates were often higher than that of the parent pesticide. The degradate forms can be less toxic than the parent pesticide; however, some degradates have been found to be as toxic or more toxic than the parent (Gilliom et al. 2006). In addition, pesticide products typically contain additional chemicals like adjuvants, surfactants, and solvents. These chemicals are labeled as

inert ingredients, but they increase the effectiveness of the active ingredients and can be toxic to non-target species (Cox and Surgan 2006; Beggel et al. 2010; Scholz et al. 2012). Very little is known about the fate of these "inert" labeled ingredients once they are in surface waters and their possible impacts on salmonid populations.

1.3.1.2 Mercury

Mercury is a persistent and bioaccumulative toxic pollutant. Methylmercury is the most toxic form in the freshwater environment because it is the form most readily bioaccumulated in fish and through the food web (Wiener et al. 2003). For example, the proportion of mercury that exists as methylmercury generally increases with each level of the food chain, and methylmercury comprises 80% to 100% of the total mercury measured in fish tissue (Bloom 1992; Becker and Bigham 1995; Nichols et al. 1999; Wiener et al. 2003; Slotton et al. 2004; Sveinsdottir and Mason 2005). Fish absorb mercury through their epidermis (e.g., gills, skin) directly from water; however, fish accumulate the majority (greater than 85%) of mercury through their diet in the form of methylmercury (Hall et al. 1997; Wiener et al. 2003). There is evidence that methylmercury bioconcentrates (directly from water) in the laboratory (McKim et al. 1976; Fjeld et al. 1998). However, the minimum concentrations used in the dilution series exposures (160 nanograms per liter [ng/L] and 30 ng/L, respectively) were greater than 25-fold higher than the maximum aqueous methylmercury concentrations found in Central Valley mainstem rivers (Foe et al. 2008). Methylmercury typically becomes elevated in fish, and fish in higher trophic levels tend to have the highest methylmercury concentrations as a result of bioaccumulation and subsequent methylmercury biomagnification.

Fish have evolved in an environment that always contained mercury. Methylmercury is transported via the circulation system to all organs and tissue; however, methylmercury eventually redistributes to the skeletal muscles where it becomes bound to proteins in the muscle tissue (Wiener et al. 2003). In an extensive review of mercury impacts on fish, Wiener and Spry (1996) determined that the binding of assimilated methylmercury to proteins in the skeletal muscles may function as the primary detoxification mechanism for methylmercury in fish. The use of this mechanism reduces exposure of the central nervous system and brain to methylmercury. Because of the eventual redistribution of methylmercury to muscle tissue, the rate of accumulation and exposure time seem to significantly affect the toxicity of methylmercury to fish (Wiener and Spry 1996).

Neurotoxicity seems to be the most probable chronic response of wild fishes to dietary methylmercury. Long-term dietary exposure to methylmercury can cause incoordination, inability to feed, and diminished responsiveness (Wiener and Spry 1996). Other toxicological effects include reproductive impairments (e.g., hatching success, fecundity, and sex steroids), growth inhibition, developmental abnormalities (spinal and jaw deformities), altered behavioral responses (e.g., lethargy, predator response, and aggressiveness), and mortality (Eisler 1987; Beckvar et al. 1996; Wiener and Spry 1996; Beckvar et al. 2005; Dillon et al. 2010; Depew et al. 2012; Weis 2014).

Alterations in biochemistry, gene transcription, and tissue histology from exposure to mercury may also be the cause of the deleterious impacts to fish (Moran et al. 2007; Sandheinrich et al. 2011). For example, Moran et al. (2007) found differential gene expression in trout livers collected from two high-elevation lakes in Washington. The fish collected from the more polluted (primarily higher mercury) lake exhibited upregulation of genes involved with a number of physiological processes, including immune function, stress adaption, reproduction, and metabolism. However, the more polluted lake fish had low levels of mercury contamination (less than 0.06 micrograms per gram [µg/g], wet weight, average of 2-year-long study).

Mercury toxicity can have long-lasting impacts well after exposure has ended. For example, Fjeld et al. (1998) found that sublethal methylmercury exposures permanently impaired graylings (*Thymallus thymallus*) 3 years after exposure. The 10-day egg exposures that resulted in embryo grayling tissue methylmercury concentrations of 3.8 µg/g (wet weight) exhibited immediate effects (e.g., delayed hatching, reduced hatching success, and malformed embryos).However, the embryos with body methylmercury concentrations as low as 0.27 µg/g exhibited reduced foraging success (e.g., feeding efficiency and competitive ability) compared to the control group 3 years after the initial methylmercury exposure. Similarly, Matta et al. (2001) observed transgenerational effects with killifish (*Fundulus heteroclitus*) fed methylmercury-contaminated food. The maternal transfer of methylmercury to offspring resulted in altered sex ratios and other reproductive abnormalities in the next generation.

Reproductive and ELS endpoints appear to be some of the most sensitive for fish species, and these adverse effects are typically seen at methylmercury tissue concentrations about 10-fold lower than for adults (Wiener and Spry 1996; Beckvar et al. 2005; Dillon et al. 2010; Depew et al. 2012). Developing salmonid eggs will be relatively unaffected by contaminants in the water because the vitelline membrane, enveloping layer, and chorion protect salmonids from metals, pathogens, and xenobiotic chemicals (Finn 2007). Accordingly, the methylmercury accumulated in the eggs will be primarily derived from the maternal fish (Wiener and Spry 1996). Hammerschmidtt and Sandheinrich (2005) concluded that egg methylmercury was primarily derived from the maternal diet during oogenesis because offspring from adults fed mercury before and during oogenesis had similar concentrations as offspring from adults only fed during oogenesis. However, using stable isotope-enriched methylmercury diets, Stefansson et al. (2014) found that both the maternal diet during oogenesis and the female tissue accumulated during preoogenesis contributed mercury proportionally to eggs.

The amount of methylmercury transferred from the female to its egg appears to vary depending on variables such as contamination level, maternal length, and species. The following studies provide examples of these variables:

- In a study conducted by Hammerschmidtt and Sandheinrich (2005), the fathead minnow egg concentration percentages increased from 14% to 35% of maternal concentrations, with increasing maternal methylmercury diets and maternal concentrations.
- In a laboratory study with killifish, for the eggs that resulted in methylmercury concentrations above analytical detection limits, the percentage of maternal muscle methylmercury concentration in eggs was 0.9% and 5.3%, also increasing with dosage and maternal concentration (Matta et al. 2001).
- In a field investigation, Johnston et al. (2001) found that egg methylmercury concentrations were 1.1% to 12% of female muscle concentrations for seven walleye (*Stizostedion vitreum*) populations. In addition, the percentage of the maternal concentrations varied with maternal length, egg concentrations, maternal liver and muscle concentrations, female length, and population location.
- Niimi (1983) investigated the maternal transfer of multiple contaminants in five species collected from Lake Ontario and Lake Erie. The percentage of maternal methylmercury concentrations in eggs averaged 0.6% for rainbow trout (*O. mykiss)*, 1.8% for white sucker (*Catostomus commersoni*), 0.3% for white bass (*Morone chrysops*), 0.4% for smallmouth bass (*Micropterus dolomieui*), and 2.3% for yellow perch (*Perca flavescens*). The field investigations are likely most indicative of typical maternal transfer to eggs from the natural environment because these fish reflect the natural bioaccumulation rates, prey methylmercury concentrations, and growth rates.

1.3.1.3 Selenium

Selenium is an essential micronutrient for normal animal nutrition; however, selenium can bioaccumulate and biomagnify to levels that are toxic to fish and other wildlife. Selenium can bioconcentrate directly from water through gills, epidermis, or gut; however, like mercury, the primary route of exposure to levels that exhibit toxicological effects is through the food web (Lemly and Smith 1987; Hamilton 2004; Entrix 2009; Presser and Luoma 2013; USEPA 2015). When dissolved selenium enters the aquatic environment, it may do the following (Lemly and Smith 1987):

- Be absorbed or ingested by organisms
- Bind or complex with particulate matter
- Remain in solution

The speciation of dissolved selenium in its three dominant oxidation states—selenate, selenite, or dissolved organic selenium—is important because the oxidation state of the dissolved form influences the rate of transformations (e.g., oxidation and methylation) that create the particulate

form (Lemly and Smith 1987; Presser and Luoma 2013). The uptake of selenate by plants and phytoplankton appears to be slower than selenite and dissolved organic selenium (Presser and Luoma 2013).

Ecologically, the absorption and ingestion by organisms and binding or complexes with particulate matter are the most important because particulate selenium and selenium associated with plants and phytoplankton are the primary forms that enter the food web (Lemly and Smith 1987; Presser and Luoma 2013; USEPA 2015). Examples of the mechanisms where selenium is made available for biological uptake include the following (Lemly and Smith 1987; Presser and Luoma 2013):

- Oxidation and methylation of inorganic and organic selenium by plant roots and microorganisms
- Biological mixing and associated oxidation of sediments that results from the burrowing of benthic invertebrates and feeding activities of fish and wildlife
- Physical perturbation and chemical oxidation associated with water circulation and mixing
- Oxidation of sediments by plant photosynthesis
- Recycling of particulate phases back into water as detritus or dissolved organic selenium after organisms die and decay

In addition, rooted plants and detrital feeding organisms can input selenium into the food web, even when selenium is absent from the water column (Lemly and Smith 1987).

Selenium has three levels of biological activity in fish: 1) trace concentrations are required for normal growth and development; 2) moderate concentrations can be stored and homeostatic functions maintained; and 3) elevated concentrations can result in toxic effects (Hamilton 2004). Fish exposure to selenium typically follows a biphasic response (i.e., beneficial at low doses and toxic at high doses [Hilton et al. 1980; Lemly and Smith 1987; USFWS 2008]). Toxic effects of selenium to fish typically fall into two categories (Lemly and Smith 1987; USEPA 2015):

- Chronic reproductive (e.g., effects to offspring survival and morphology)
- Chronic non-reproductive (e.g., adult and juvenile growth and survival)

Similar to mercury, reproductive function is the most sensitive to selenium toxicity, and the most documented impacts to reproduction are teratogenesis and larval mortality (USEPA 2015). Often, reproductive failure—whether through effects on adult ovaries or embryonic development—is the first obvious symptom of selenium contamination, and complete reproductive failure can occur with very little or no tissue pathology or mortality of the adult population (Lemly and Smith 1987). USFWS' (2008) review of selenium impacts to threatened and endangered species in the Delta reported statistically significant increases in pre-swimup mortality, increased percentages of edema and craniofacial deformities in swimup fry, and increased egg selenium concentrations in rainbow trout. In addition, others have reported that fish exposed to selenium exhibit ovaries with necrotic

and ruptured egg follicles, anemia and reduced hatch in eggs, or chromosomal aberrations (Eisler 1985). Additional effects of selenium to ELS fish include deformities such as lordosis (concave curvature of lumbar and caudal regions of spine), kyphosis (convex curvature of thoracic region of the spine), scoliosis (lateral curvature of the spine), edema, and brain, heart, and eye problems (Hamilton 2004).

Selenium is transferred from the maternal diet to developing eggs during vitellogenesis, and the embryo is exposed to selenium during yolk absorption (Presser and Luoma 2013; USEPA 2015). The rate of maternal transfer of selenium to gonadal tissue is much greater than for mercury. For example, Linares-Casenave et al. (2015) found that white sturgeon (*Ancipenser transmontanus*) sampled from the San Francisco Bay and Delta had gonadal tissue selenium concentrations 100% and 200% that of muscle selenium concentrations in previtellogenic and vitellogenic females, respectively. This is compared to the maternal transfer of 0.3% to 12% of mercury concentrations in gonadal tissues observed in field-collected fish (see Section 1.3.1.2). For the development of the draft *Aquatic Life Ambient Water Quality Criterion for Selenium*, USEPA (2015) summarized paired maternal and egg-ovary selenium concentrations to estimate conversion factors between tissue concentrations. Individual species conversion factors (maternal muscle to egg - ovary) ranged from 1 to 5.8 (i.e., egg concentrations were 100% to 580% of maternal concentrations), with rainbow trout having the second highest transfer rate (out of 16 species) with a conversion factor of 1.9. The overall high ranking of salmonids continued at the genus level (average *Oncorhynchus* equaled 1.9) and family level (average *Salmonidae* equaled 1.5).

Beyond the reproductive stage and ELS, additional effects can occur in fish at later exposures. For example, juvenile rainbow trout fed selenium-supplemented diets exhibited reduced growth, a higher feed:gain ratio, and higher mortality rates after 20 weeks of feeding (Hilton et al. 1980). In addition, the juveniles exhibited behavior effects (e.g., feeding avoidance) as well as uncoordinated swimming and sensory deprivation approximately 24 hours priors to mortality. Similarly, Hamilton and Wiedmeyer (1990) found that reduced survival and growth of Chinook salmon were strongly correlated to tissue selenium concentrations in 90-day exposures. In addition, Chinook salmon exposed to selenium had a reduced survival rate in a 15-day seawater challenge (Hamilton and Wiedmeyer 1990). Additional effects to fish include loss of equilibrium, lethargy, contraction of dermal chromatophores, loss of coordination, muscle spasms, protruding eyes, swollen abdomen, liver degeneration, reduction in blood hemoglobin and erythrocyte numbers, increases in white blood cells, and swollen gill lamellae with extensive cellular vacuolization (Eisler 1985).

In addition to being an essential micronutrient for organisms, selenium has been found to have protective effects against mercury and other metal toxicity (Eisler 1987; USEPA 2015). However, the mechanism for the antagonistic interactions is not known, the degree of antagonism is highly variable, and some studies found additive and synergistic interactions with mercury. Laboratory

studies by Bjerregaard et al. (2011) suggested that selenium increases the elimination of methylmercury in fish; however, the report acknowledges that others have suggested that selenium may reduce mercury toxicity by redistributing mercury to different tissues or by reducing the assimilation of mercury. Regardless of the mechanism, selenium availability (excess and deficiency) in the aquatic ecosystem must be contemplated when considering supportive concentrations in the environment.

1.3.1.4 Nutrients

Nutrient imbalances have the ability to cause adverse impacts to all the life history stages of salmonids through direct and indirect mechanisms. In addition to direct toxicological impacts to salmonids, nutrient imbalances can adversely impact salmonid habitat through cultural eutrophication or cultural oligotrophication. Detrimental impacts of excessive primary productivity include increased temperatures, hypoxia, disrupted migratory corridors, and reduced habitat associated with macrophytes or the release of biotoxins by cyanobacteria or other phytoplankton (Gowdy and Grober 2005; Berg and Sutula 2015; Boyer and Sutula 2015; Schlegel and Domagalski 2015).

Nutrient enrichment and subsequent eutrophication has been found to result in depressed DO levels in aquatic systems (USEPA 2000; Gowdy and Grober 2005; Tetra Tech 2006; Dodds 2007). Low DO can adversely impact all life history stages of salmonids (see Chapter 7 and Appendix B). Although nutrient enrichment can be a primary driver of depressed DO, there are other factors that contribute to this aquatic impairment (e.g., elevated temperatures, excessive residence time, and channel morphology).

Nutrient enrichment has been found to increase the growth of nuisance aquatic plants in the Delta (DSC 2013). While a balance of macrophyte densities is beneficial for fish, excessive amounts of macrophytes can reduce the suitability of habitat for salmonids (Boyer and Sutula 2015). For example, dense canopies of macrophytes can shade phytoplankton and reduce productivity, draw down DO levels, shift pH levels, and harbor large non-native predator fish (Boyer and Sutula 2015). Dense stands of macrophytes may create conditions that stress adult and juvenile migration through the Delta, San Joaquin River, or Stanislaus River, if they exist across the rivers' channels. Likewise, if dense canopies decrease or alter the phytoplankton communities and food web, the growth rate of rearing juveniles may decrease. Further, the dense macrophytes may increase the susceptibility of juveniles to predation.

Cultural oligotrophication or lack of primary productivity can also have adverse impacts to salmonid populations. Cultural oligotrophication is the anthropogenically induced decrease in nutrient concentrations and primary production (Stockner et al. 2000; Stockner and Ashley 2003). Mechanisms that may contribute to cultural eutrophication in the Stanislaus River include reservoir

creation and reduced anadromous salmonid population returns. Reservoir impoundments tend to trap and settle sediment and particulate organic matter, resulting in a net sink of phosphorus and subsequent reduction of primary productivity downstream (Stockner et al. 2000). In addition, the current reduction of anadromous salmonid populations and escapement has reduced the amount of marine-derived nutrients that historically were inputted to the watershed.

Several studies have documented the importance of marine-derived nutrients in the productivity levels in oligotrophic streams and rivers from Alaska to Northern California (Stockner et al. 2000; Moore et al. 2011). The net result of cultural oligotrophication is the reduction of juvenile growth rates, which can reduce the overall survival and productivity of salmonid populations. The direct link between reduced nutrients and reduced salmonid growth rates has not been documented in Central Valley rivers; however, there is evidence that cultural oligotrophication has reduced fish growth rates and exacerbated mercury impairments in California reservoirs in upstream watersheds (Foe and Louie 2014). However, there is evidence of factors other than a lack of nutrients that may be causing reduced fish growth rates in the Stanislaus River such as the reduced frequency and area of floodplain inundation (see Chapter 5).

1.3.2 Approach

1.3.2.1 Pesticides

The SEP Group relied on adopted numeric water quality objectives or triggers for pesticides from the Sacramento and San Joaquin River Basins Water Quality Control Plan (Basin Plan; CVRWQCB 2018) to determine pesticide levels that should provide no adverse impacts to salmonid populations. In addition, for pesticides that do not have state or federally promulgated objectives or criteria, the SEP Group used the USEPA Office of Pesticide Programs (OPP) aquatic-life benchmarks with a level of concern for impacts to endangered and threatened species as the safe level for pesticides.

Unfortunately, no pesticide monitoring program exists throughout the Stanislaus River, San Joaquin River, Delta, or Bay, nor is there likely a program that will exist in the future that will be able to monitor all possible pesticides that may adversely impact salmonids during entire life history stages. It is difficult to quantify the concentrations of all the pesticides to which salmonids are exposed. For example, more than 1,000 pesticide chemicals were applied in California in 2012 (CDPR 2014). In addition, each commodity or crop type may have multiple pesticide chemical applications (e.g., alfalfa crops were associated with more than 200 pesticide chemicals). Performing chemical analyses for all possible pesticides in the different reaches of the Stanislaus River where salmonids would be exposed would not be cost-feasible. Furthermore, current analytical methodologies do not allow for all pesticides to be detected at levels that may cause adverse effects to aquatic organisms (Hladik et al. 2009; Mekebri 2011; CVRWCB 2018).

Additionally, each pesticide has different impacts to the physiology of salmonids as well as to their prey. For example, Macneale et al. (2014) population modeling determined that the magnitude of a pesticide's effect on salmon population growth is dependent on the relative sensitivity of salmon olfactory senses and prey abundance to the pesticide. For instance, chlorpyriphos had a greater influence on salmon population growth by directly affecting salmon physiology, while another organophosphate, diazinon, had a greater impact by decreasing salmon prey abundance. Attempting to monitor and evaluate the direct and indirect effects of the more than 1,000 possible pesticides and mixtures of pesticides that could occur in the Stanislaus River and downstream corridor would very difficult.

The SEP Group has relied on a pesticide prediction model (Hoogeweg et al. 2011) to estimate the current frequency of pesticide water quality objective or benchmark exceedances to categorize supportive, stressful, and detrimental conditions for Chinook salmon and *O. mykiss* pesticide environmental objectives. That is, the categories are an evaluation of the risks that a species is exposed to pesticide concentrations that could cause harm in a river reach by month. The categories assume that, while no occurrence of pesticides is preferred, such low levels of exposure may not be achievable considering the amount of urban and agricultural development in the Central Valley. Models, monitoring, toxicity bioassays, and other information will need to be updated, developed, conducted, and further gathered as needed to determine if pesticide concentrations are adversely impacting salmonids through their life history stages.

1.3.2.2 Mercury

Current mercury numeric water quality objectives or criteria were developed to protect human health and other fauna that consume fish, rather than to protect fish. For example, the USEPA-promulgated California Toxics Rule (CTR) numeric criteria for mercury are for the protection of human health only (40 Code of Federal Regulations [CFR] Part 131). Fish with elevated concentrations of mercury are frequently observed in waterbodies that do not exceed the CTR criterion of 0.05 micrograms per liter (µg/L) total mercury (Wood et al. 2010). Similarly, water quality objectives developed for the San Francisco Bay and the Delta were developed as fish tissue objectives for the protection of human and wildlife consumers of fish (SFBWQCB 2006; Wood et al. 2010). This is in part due to the fact that until approximately the beginning of this decade (i.e., 2010)), the majority of studies concluded that fish were not impacted by mercury toxicity as much as fish consumers (e.g., wildlife, humans; Wiener and Spry 1996). For example, Wiener and Spry (1996) concluded that estimated no-observed-effect mercury concentration for salmonids was 3 µg/g (wet weight, whole body), whereas the fish tissue mercury concentration to protect human and wildlife consumers of fish from the San Francisco Bay

and Delta is more than 10-fold lower at approximately 0.2 µg/g (wet weight, muscle tissue[2]; SFBWQCB 2006; Wood et al. 2010).

Since 1996, many studies have reported adverse effects to fish species at concentrations lower than the papers reviewed by Wiener and Spry (1996), and there is now evidence that fish species are more sensitive to mercury toxicity than previously thought (Dillon et al. 2010). For example, Beckvar et al. (2005) developed approaches (i.e., simple ranking, empirical percentile, tissue threshold-effect level (t-TEL), and cumulative distribution function) to determine the fish tissue mercury concentrations that would be protective against adverse mercury toxicity using studies that measured mercury tissue concentrations and corresponding biological responses (e.g., reproduction, growth, and behavior) in adults, juvenile eggs, and ELS fish. Dillon et al. (2010) used dose-response curves on lethality-equivalent test endpoints to estimate the percent injury to fish by mercury. The SEP Group relied on these benchmark concentrations as the levels that would be supportive, stressful, and detrimental to salmonids during their life history stages.

1.3.2.3 Selenium

The SEP Group relied on the *USEPA National Freshwater Selenium Ambient Water Quality Criterion for Aquatic Life* (2016) for the environmental objectives to protect salmonid species in the Stanislaus River against adverse effects.

1.3.2.4 Nutrients

Nutrient imbalances can affect salmonid populations through both direct toxicity and ecological use impairments, so the SEP Group used two approaches to develop nutrient environmental objectives. To evaluate the possible direct toxicity of ammonia, nitrite, and nitrate to salmonids in the Stanislaus River, the SEP Group used available aquatic-life criteria or other available toxicological benchmark values. Phosphate does not appear to have direct toxicological impacts to fish or daphnids at ecologically relevant concentrations (Kim et al. 2013), so it is not considered further for this evaluation.

The second category of nutrient environmental objective is ecological use impairments, which include nutrient imbalances that result in a reduction of beneficial habitat for salmonids. Recent efforts for evaluating environmental impacts from nutrients have moved away from the strict application of a single nutrient concentration criterion across broad landscapes or watersheds (USEPA 2000; Tetra Tech 2006). These efforts were developed, in part, because pre-defined nutrient limits may or may not result in eutrophication in all waterbodies. The evaluation of appropriate nutrient levels requires the evaluation of aquatic beneficial uses needing protection, classification of waterbodies by type and trophic status, and consideration of other external environmental factors

[2] Muscle tissue (filet) mercury concentrations can be converted to whole-body mercury (Hg) concentrations using the following equation (Peterson et al. 2007): Log [filet biopsy Hg] = 0.2545 + 1.0623 × Log [whole-fish Hg].

(USEPA 2000; Tetra Tech 2006). For example, an indirect way to evaluate possible nutrient impairments is to examine some of the detrimental outcomes of nutrient impairments (e.g., depressed DO levels, excessive macrophytes, or chlorophyll-a concentrations).

1.3.3 Objectives

Some of the identified contaminants have associated USEPA-promulgated numeric aquatic life water quality or human health criteria (CTR, 40 CFR Part 131) and Regional Board-specific water quality objectives. Unfortunately, most currently used pesticides do not have promulgated water quality criteria or objectives. Additionally, the CTR criteria were developed to protect human health and against short-term (4-day) effects on aquatic life. However, these criteria may not be protective of long-term (e.g., weeks, months, and years) adverse impacts on salmonids and other wildlife. For example, results of an evaluation of the Delta Estuary Total Maximum Daily Load (TMDL) for methylmercury indicated that although the CTR criterion for mercury has not yet been exceeded in the Delta, fish tissue mercury concentrations significantly impact threatened and endangered wildlife species and humans that consume these fish (Wood et al. 2010). Additionally, many of the toxicological studies to be discussed in Sections 1.3.3.1 through 1.3.3.4 have observed adverse effects to salmonids below established water quality criteria.

1.3.3.1 Pesticide Objectives

Numeric water quality objectives have not been established for the majority of currently used pesticides in the Central Valley. Table C-11 presents the CVRWQCB-adopted numeric water quality objectives for pesticides that are included in the Basin Plan and the water quality triggers for pyrethroid pesticides (CVRWQCB 2018).

Table C-11
Central Valley Regional Water Quality Control Board Adopted Water Quality Objectives and Triggers for Current Use Pesticides

Pesticide	Acute (µg/L)	Chronic (µg/L)
Adopted Water Quality Objectives[1]		
Diazinon	0.16	0.1
Chlorpyriphos	0.025	0.015
Carbofuran	40	40
Simazine	4	4
Thiobencarb	1	1
Pentachlorophenol	5.3	4
Copper	5.7	4.1
Adopted Water Quality Triggers[1]		
Bifenthrin	0.0008	0.0001
Cyfluthrin	0.0008	0.0002
Lambda-Cyhalothrin	0.0007	0.0003
Cypermethrin	0.001	0.0003
Esfenvalerate	0.002	0.0003
Permethrin	0.006	0.001

Notes:
1. CVRWQCB 2018

USEPA OPP developed aquatic toxicity benchmarks for use in risk assessment and pesticide registration decisions under the Federal Insecticide, Fungicide, and Rodenticide Act (USEPA 2004). OPP has developed aquatic life benchmarks for more than 400 registered pesticides. Table C-12 provides benchmarks for the 40 pesticides that are predicted to pose the greatest risks in the Central Valley (Lu and Davis 2009; Hoogeweg et al. 2011). Table C-12 also includes benchmarks for the protection of the critical habitat for listed species and an additional safety factor (USEPA 2004).

The aquatic life benchmarks can be used for initial environmental assessments. However, a more detailed evaluation (or site-specific evaluations) may determine that the aquatic life benchmarks are not protective of the most sensitive species. For example, a comparison between the OPP benchmarks (Table C-12) and the established (or proposed) water quality objectives (Table C-11) shows that all but one of the water quality objectives predicts that a lower concentration than the OPP benchmarks is necessary to protect beneficial uses. Attaining the lower of either the aquatic life benchmarks or the water quality objectives should reasonably allow for the protection of salmonid species as well as their habitat.

Table C-12
U.S. Environmental Protection Agency Office of Pesticide Programs' Aquatic Life Benchmarks for the 40 Pesticides that Pose the Greatest Risk in the Central Valley Region

Pesticide	Pesticide Type	Acute Benchmark (µg/L)	Endangered and Threatened Acute Benchmark (µg/L)	Chronic Benchmark (µg/L)	Source of Acute/ Chronic Value[1]
Abamectin	Insecticide	0.17	0.017	0.006	IA/IC
Bifenthrin	Insecticide	0.075	0.0075	0.0013	FA/IC
Bromacil	Herbicide	6.8	0.68	3000	AA/FC
Captan	Fungicide	13.1	1.31	16.5	FA/FC
Carbaryl	Insecticide	0.85	0.085	0.5	IA/IC
Chlorothalonil	Fungicide	1.8	0.18	0.6	IA/IC
Chlorpyrifos	Insecticide	0.05	0.005	0.04	IA/IC
Clomazone	Herbicide	167	16.7	350	AA/FC
Copper hydroxide	Fungicide	5.9	0.59	4.3	IA/IC
Copper sulphide	Insecticide/Algaecide	5.9	0.59	4.3	IA/IC
Cyfluthrin	Insecticide	0.0125	0.00125	0.007	IA/IC
Cyhalofop butyl	Herbicide	245	24.5	134	FA/FC
Cypermethrin	Insecticide	0.195	0.0195	0.069	FA/IC
Deltamethrin	Insecticide	0.055	0.0055	0.0041	IA/IC
Diazinon	Insecticide	0.11	0.011	0.17	IA/IC
Dimethoate	Insecticide	21.5	2.15	0.5	IA/IC
Diuron	Herbicide	2.4	0.24	26	AA/FC
Esfenvalerate	Insecticide	0.025	0.0025	0.017	IA/IC
Hexazinone	Herbicide	7	0.7	17000	AA/FC
Imidacloprid	Insecticide	35	3.5	1.05	IA/IC
Indoxacarb	Insecticide	12	1.2	3.6	FA/IC
Lambda cyhalothrin	Insecticide	0.0035	0.00035	0.002	IA/IC
Malathion	Insecticide	0.3	0.03	0.035	IA/IC
Mancozeb	Fungicide	47	4.7	N/A	AA/na
Maneb	Fungicide	13.4	1.34	N/A	AA/na
Methomyl	Insecticide	2.5	0.25	0.7	IA/IC
(s)-Metolachlor	Herbicide	8	0.8	30	AA/FC
Naled	Insecticide	25	2.5	0.045	AA/IC
Oxyfluorfen	Herbicide	0.29	0.029	1.3	AA/FC
Paraquat	Herbicide	0.396	0.0396	N/A	AA/na
Pendimethalin	Herbicide	5.2	0.52	6.3	AA/FC
Permethrin	Insecticide	0.01	0.001	0.0014	IA/IC
Propanil	Herbicide	16	1.6	9.1	AA/FC

Pesticide	Pesticide Type	Acute Benchmark (µg/L)	Endangered and Threatened Acute Benchmark (µg/L)	Chronic Benchmark (µg/L)	Source of Acute/ Chronic Value[1]
Propargite	Insecticide	37	3.7	9	IA/IC
Pyraclostrobin	Fungicide	0.0015	0.00015	0.002	FA/FC
Simazine	Herbicide	36	3.6	960	AA/FC
Thiobencarb	Herbicide	17	1.7	1	AA/IC
Tralomethrin	Insecticide	0.055	0.0055	0.0041	IA/IC
Trifluralin	Herbicide	7.52	0.752	1.14	AA/FC
Ziram	Fungicide	9.7	0.97	39	FA/IC

Notes:

1. Identifies which taxa was the most sensitive to the pesticide from available toxicity evaluations defined as FA = fish acute; IA = invertebrate acute; AA = Algae Acute; FC = fish chronic; IC = invertebrate chronic; na = not available. Sources: USEPA OPP. Table modified from Hoogeweg et al. (2011).

Aquatic life benchmarks are used by the USEPA OPP for risk assessments in the registration of pesticides. The entire list of pesticide benchmarks can be acquired at https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/aquatic-life-benchmarks-pesticide-registration

The pesticide criteria and benchmarks were developed assuming organismal exposure to single pollutants. Additional considerations are necessary when multiple pesticides are present (e.g., additive toxicity equations; CVRWQCB 2018; Hasenbein et al. 2014). In addition, assessments of the full impact of pesticides on aquatic organisms may need to consider the bioavailability of the pesticides (CVRWQCB 2018). For example, the majority of dissolved copper is likely bound as ligand complexes and largely not bioavailable (SFBRWQCB 2007; McIntyre et al. 2008; Linbo et al. 2009). Consequently, copper, pesticides, and other metals toxicity evaluations should involve adjustments for site-specific conditions (e.g., hardness, biotic ligand models, or dissolved organic concentrations; SFBRWQCB 2007; CVRWQCB 2018).

The Hoogeweg et al. (2011) model allowed the determination of the magnitude of pesticide effects on Stanislaus River salmonids and the relative risk of pesticide exposures by month and river reach (Figure B-1 and Table C-13). Limitations in monitoring and chemical analyses, and the multitude of possible pesticide chemicals. preclude the use of strict concentration limits to evaluate overall pesticide impacts on salmonids throughout the Stanislaus River and downstream waterbodies. In turn, current pesticide impacts to salmonid life history stages in the Stanislaus River are based on the relative frequency of pesticides exceeding aquatic life benchmarks.

Table C-13
Categories of Predicted Pesticide Aquatic Life Benchmark Exceedances

Bin Category	Condition	Range of the Frequency of Benchmark Exceedances
1	Supportive	0 to 0.017
2	Stressful	0.018 to 0.055
3		0.056 to 0.1
4		0.101 to 0.153
5		0.154 to 0.206
6		0.207 to 0.303
7	Detrimental	0.304 to 0.447
8		0.448 to 0.5
9		0.501 to 0.589
10		0.59 to 0.994

Notes:
Frequencies were calculated from the total number of predicted exceedance days for each month from 2000 to 2009. Any day that had at least one pesticide that exceeded benchmarks was counted as an exceedance day.
Source: Adapted from Hoogeweg et al. 2011.

To be fully protective of aquatic life beneficial uses, current pesticide water quality objectives and criteria require that pesticide thresholds are not exceeded more than once every 3 years (40 CFR Part 131; CVRWQCB 2018). Similarly, meeting the frequency range of Bin 1 (Table C-13) of pesticide exposure in the Stanislaus River and freshwater migratory corridor should allow the full expression of salmonid life history stages, and this represents the supportive condition. Furthermore, the analysis for the development of the Central Valley diazinon, chlorpyriphos, and pyrethroid TMDLs concluded that the adopted and proposed numeric criteria for these pesticides should be reasonably achievable (CVRWQCB 2018).

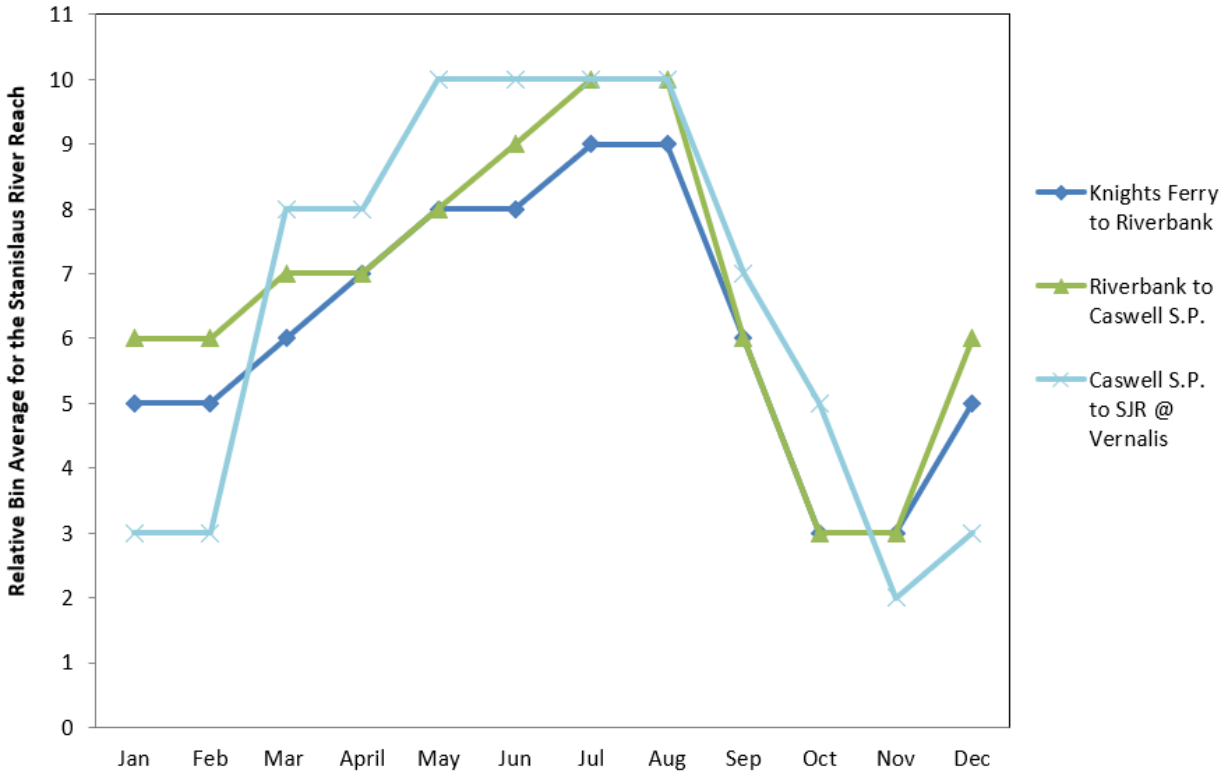
Determining the frequency of pesticide exposures that are predicted to result in stressful versus detrimental impacts is much more difficult. Modeling completed by the Northwest Fisheries Science Center determined that the effect of pesticides on the intrinsic population growth of salmon was dependent on the relative sensitivity of salmon olfactory function versus prey abundance, the binding affinity of specific pesticides, the concentration of pesticides in the habitat, and the duration and frequency of pesticide exposures (Baldwin et al. 2009; Macneale et al. 2014). Overall, the models predicted that the impact to prey abundance had a greater effect on salmon intrinsic population growth than the direct physiological effects to salmon with regards to juvenile growth.

A single, 4-day pulse of high pesticide concentrations (e.g., 1.15 × prey abundance effective concentration 50% [EC_{50}], or 60-fold acute water quality objective), resulted in a 1% to 11% reduction in salmonid population growth depending on prey recovery rates (Macneale et al. 2014). In terms of spawner abundance, a 1% and 7% decrease in intrinsic population growth would equate to a 14%

and 73%, respectively, reduction in spawner abundance compared to an unexposed control after 20 years (Baldwin et al. 2009). However, this high concentration of pesticides is at the upper range of pesticides observed in salmonid habitats and may not represent typical conditions (Baldwin et al. 2009). Fortunately, the researchers modeled a continuous, low pesticide concentration exposure (e.g., salmon olfaction inhibition effective concentration 10% [EC_{10}], or 6-fold acute water quality objective), which lasted 105 out of 140 days (or 75% of the modeled rearing period). The estimated reduction in population growth was 4% (i.e., a 53% reduction in spawner abundance after 20 years).

A 4% reduction in intrinsic population growth (or 75% frequency of pesticide exposure) would likely represent detrimental conditions to salmonid populations. However, a 2% reduction in intrinsic population growth (e.g., 1.08 versus the 1.1 control population) would likely represent conditions where salmonid populations are impacted but can still attain biological objectives. Accordingly, Bins 7 to 10 (Table C-13)—which represent approximately one-half of the 75% exposure frequency and greater—are considered to be detrimental to salmonid populations. These reductions in population growth were through impairments in salmon olfaction. The SEP Group assumes that the degree of olfaction disruption would have an equivalent impact on overall fitness during each life history stage.

Figure C-1
Relative Bin Value of Specified Stanislaus River



Note: The values were derived from qualitative averaging of the frequency of benchmark exceedances model maps for years 2000 to 2009 in Hoogeweg et al. (2011). Due to a lack of data, upstream of Knights Ferry in the Stanislaus River was not modeled.

1.3.3.2 Mercury Objectives

Using the methodology described in Section 1.3.2, a whole-fish mercury concentration of 0.2 µg/g wet weight (filet equals 0.33 µg/g, wet weight) is predicted to be protective of juvenile and adult fish using the t-TEL method. Using the simple ranking method, Beckvar et al. (2005) estimated that 0.02 µg/g whole body would be protective of ELS fish, which is consistent with the hypothesis that embryonic and larval stages have a higher sensitivity to sublethal effects. These values are consistent with the percent estimate of injury to fish from mercury exposure by Dillon et al. (2010) using dose-response curves on lethality-equivalent test endpoints. Stressful and detrimental conditions are provided in Table C-14. Beckvar et al. (2005) and Dillon et al. (2010) developed the fish mercury concentration thresholds using multiple species. However, these thresholds should also be protective of salmonids because the thresholds consider the most sensitive species and endpoints (Beckvar et al. 2005; Dillon et al. 2010). In addition, there is evidence that salmonid species are less sensitive to the toxicity of dietary methylmercury (Berntssen et al. 2004 as cited in Depew et al. 2012).

Table C-14
Mercury Objectives for Chinook Salmon and *O. mykiss* for Juveniles, Adults, Eggs, Ovaries, and Early-Life Stages

Condition	Egg/Ovary/ELS mg/kg (wet wt.)	Adult and Juvenile Fish mg/kg whole body (wet wt.)
Supportive	< 0.02	< 0.2
Stressful	0.02 to 0.1	0.2 to 1
Detrimental[1]	> 0.1	> 1

Notes:

1. Sublethal impacts to fish are estimated to occur above supportive conditions. Detrimental impacts are assumed to occur at mercury tissue concentrations that are expected to create 25% or greater injury to the fish. A 25% effect or EC25 metric is a consistent threshold to determine chronic toxicity assessments for regulatory compliance (SWRCB 2012).

mg/kg: milligrams per kilogram

1.3.3.3 Selenium Objectives

USEPA reserved the aquatic life criteria for selenium in the CTR because a USFWS and NMFS biological opinion found that the proposed criteria for selenium may not be protective for threatened and endangered species (USFWS and NMFS 2000). In 2015, USEPA drafted proposed selenium ambient chronic water quality criteria for the protection of aquatic life (Table C-15). The proposed criteria allows for multiple matrices to be evaluated (e.g., egg/ovaries, adult fish, and water), and it takes into consideration that reproduction and ELS are the most sensitive to selenium toxicity. In addition, the criteria defaults to tissue selenium concentrations over aqueous selenium concentrations because aqueous concentrations may not reflect the principal exposure routes such as food web and maternal transfer (Entrix 2009; USEPA 2015).

Table C-15
U.S. Environmental Protection Agency National Freshwater Selenium Ambient Water Quality Criteria for Aquatic Life

Media Type	Fish Tissue		Water Column	
Criteria Element	**Egg/Ovary**	**Fish Whole Body or Muscle**	**Monthly Average Exposure**	**Intermittent Exposure**
Magnitude	15.1 mg/kg (dry wt.)	8.5 mg/kg whole body or 11.3 mg/kg muscle (skinless, boneless filet) (dry wt.)	1.5 µg/L in lentic aquatic systems; 3.1 µg/L in lotic aquatic systems	$WQC_{int} = \frac{WQC_{30\text{-}day} - C_{bkgrnd}(1 - f_{int})}{f_{int}}$
Duration	Instantaneous measurement	Instantaneous measurement	30 days	Number of days/month with an elevated concentration
Frequency	Never to be exceeded	Never to be exceeded	Not more than once in 3 years on average	Not more than once in 3 years on average

Notes:
Source: USEPA 2016.

The criteria for selenium is similar to other criteria and levels of concern determined by others. For example, the CVRWQCB water quality objectives for selenium are 5 µg/L and 2 µg/L in the San Joaquin River and Salt Slough, respectively. The draft USEPA aquatic life criteria presents two different concentrations because it considers the differences in selenium exposure and bioaccumulation rates of lentic and lotic systems. Based on laboratory toxicity tests, Hamilton and Wiedmeyer (1990) suggested that adverse effects could occur between 3 and 5 µg/g in young salmon (5 grams or less) and between 4 and 8 µg/g in older salmon (18 grams or more). In a later review by Hamilton (2004), the author reported that effects were typically not observed below 4 µg/g (whole body, dry weight) and suggested that the majority of the literature supports thresholds starting around 4 µg/g.

1.3.3.4 Nutrients

Nutrient environmental objectives for ammonia, nitrate, and nitrite toxicity are provided in Table C-16.

Table C-16
Nutrient Toxicity Objectives for All Life History Stages of Chinook Salmon and *O. mykiss*

Nitrogen Species	Maximum Average Continuous Concentration
Ammonia[1]	1.9 mg total NH_3^+-N/L @ pH 7 and 20°C (68°F)
Nitrate[2]	2 mg NO_3-N/L
Nitrite[3]	0.06 mg NO_2-N/L

Notes:

1. USEPA (2013) Aquatic Life Ambient Water Quality Criteria for Ammonia – Freshwater 2013. Ammonia toxicity is temperature- and pH-dependent. Actual ammonia limits can be calculated using the following equation:
$$CCC = 0.8876 \times \left(\frac{0.0278}{1 + 10^{7.688-pH}} + \frac{1.1994}{1 + 10^{pH-7.688}}\right) \times \left(2.126 \times 10^{0.028 \times (20-MAX(T,7))}\right)$$
2. Camargo et al. (2005)
3. Russo et al. (1974)

Ammonia: NH_3^+-N/L = milligrams of ammonium-nitrogen per liter
Nitrate: NO_3-N/L = milligrams of nitrate-nitrogen per liter
Nitrite: NO_2-N/L = milligrams of nitrite-nitrogen per liter

USEPA (2013) has promulgated aquatic-life ambient water quality criteria for ammonia for the protection of sensitive species, including salmonids. USEPA has not developed water quality criteria for protection from direct toxicity to fish or other aquatic life for nitrate or nitrite, so the SEP Group relied on literature benchmarks for these constituents. Camargo et al. (2005) reviewed published data on nitrate toxicity to freshwater animals, including invertebrates, fish, and amphibians, and

concluded that levels below 2 mg nitrate-nitrogen per liter (NO_3-N/L) would be protective of the most sensitive species.

Nitrite toxicity occurs to salmonids at lower concentrations than nitrate. For example, Westin (1974) found that the relative activity of nitrite was approximately 2,000 times that of nitrate for Chinook fingerlings. Reviews of nitrite toxicity to fish indicate that salmonids, particularly *O. mykiss*, appear to be the most sensitive to nitrite toxicity (Smith and Williams 1974; Lewis and Morris 1986). In a series of toxicity tests to various sizes of *O. mykiss*, Russo et al. (1974) found that the nitrite 96-hour lethal concentration 50% (LC_{50}) ranged from 0.19 to 0.39 mg nitrite-nitrogen per liter (NO_2-N/L). However, Smith and Williams (1974) found that even though yearling trout did not die at 0.15 mg/L, they were stressed and had statistically higher levels of methemoglobin than the controls. Westin (1974) suggested 0.12 mg/L of nitrite as a maximum allowable concentration (based on 0.10 of 10-day lethal concentration 10% (LC_{10}) for Chinook salmon). However, this concentration would likely not provide protection against the sublethal effects observed at 0.15 mg/L in trout. Russo et al. (1974) observed zero mortality in *O. mykiss* exposed to 0.06 mg/L of nitrite for 10 days. This concentration appears to be an initial safe benchmark for nitrite because the researchers also found that LC_{50} values remained constant at exposures greater than 8 days.

The toxicity of ammonia, nitrate, and nitrite are highly dependent on other environmental factors. These contaminants reduce the blood's ability to transport oxygen, so environments with lower DO increase the toxicity of these constituents (Thurston et al. 1981; Lewis and Morris 1986). Ammonia toxicity is highly dependent on temperature and pH. As a result, the water quality criterion is calculated using ambient temperature and pH levels (USEPA 2013). Similarly, data suggest that nitrite toxicity is negatively associated to chloride ions (Lewis and Morris 1986). Like the other stressors and environmental conditions considered by the SEP Group, nutrient toxicity to salmonids must consider multiple environmental factors during the evaluation.

Another category of nutrient environmental objectives beside toxicity is ecological use impairments, which would include nutrient imbalances that result in a reduction of beneficial habitat for salmonids. Recent efforts for evaluating environmental impacts from nutrients have moved away from the strict application of a single nutrient concentration criterion across broad landscapes or watersheds (Tetra Tech 2006; USEPA 2000). These efforts were developed, in part, because pre-defined nutrient limits may (or may not) result in eutrophication in all waterbodies. The evaluation of appropriate nutrient levels requires consideration of the protection of aquatic beneficial uses, classification of waterbodies by type and trophic status, and consideration of other external environmental factors (USEPA 2000; Tetra Tech 2006).

USEPA (2000) has provided guidance for developing nutrient criteria for rivers and streams. The generalized environmental conditions that define oligotrophic, mesotrophic, and eutrophic lotic systems are provided in Table C-17. The San Diego Regional Water Quality Control Board adopted

water quality objectives for nitrate (10 mg/L), total nitrogen (1 mg/L), and total phosphorus (0.1 mg/L), not to be exceeded 10% of the time, as part of a Rainbow Creek nutrient TMDL (SDRWQCB 2006). These objectives are waterbody-specific, but they can be used as a general level of nutrients that may cause impairments to aquatic life beneficial uses. Nutrient concentrations and other environmental conditions (e.g., DO and primary productivity metrics) should be assessed in combination to determine ecological support for salmonid life history stages.

Table C-17
Suggested Boundaries for Trophic Classifications of Lotic Systems

Variable (Units)	Oligotrophic to Mesotrophic Boundary	Mesotrophic to Eutrophic Boundary
Mean benthic chlorophyll (mg/m^2)	20	70
Maximum benthic chlorophyll (mg/m^2)	60	200
Sestonic chlorophyll (µg/L)	10	30
Total nitrogen (µg/L)	700	1,500
Total phosphorus (µg/L)	25	75

Note:
Source: USEPA (2000)
mg/m^2: milligram per square meter

2 References

Alpers, C., and M. Hunerlach, 2000. *Mercury Contamination from Historic Gold Mining in California*. U.S. Geological Survey. Fact Sheet. May 2000.

Anderson B., J. Hunt, D. Markiewicz, and K. Larsen, 2011. *Toxicity in California Waters*. Surface Water Ambient Monitoring Program. California State Water Resources Control Board. Sacramento, California.

Baker, P.F., T.P. Speed, and F.K. Ligon, 1995. Estimating the influence of temperature on the survival of Chinook salmon smolts (*Oncorhynchus tshawytscha*) migrating through the Sacramento-San Joaquin River Delta of California. *Canadian Journal of Fisheries and Aquatic Sciences* 52:855-863.

Baldwin, D., J. Spromberg, T. Collier, and N. Scholz, 2009. A fish of many scales: extrapolating sublethal pesticide exposures to the productivity of wild salmon populations. *Ecological Applications* 19(8):2004-2015.

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

Beckvar, N., J. Field, S. Salazar, and R. Hoff, 1996. *Contaminants in Aquatic Habitats at Hazardous Waste Sites: Mercury*. NOAA Technical Memorandum NOS ORCA 100. Seattle: Hazardous Materials Response and Assessment Division, National Oceanic and Atmospheric Administration. 74 pp.

Beckvar, N., T. Dillon, and L. Read, 2005. Approaches for linking whole-body fish tissue residues of mercury or DDT to biological effects thresholds. *Environmental Toxicology and Chemistry* 24:2094-2105.

Beggel, S., I. Werner, R. Connon, and J. Geist, 2010. Sublethal toxicity of commercial insecticide formulations and their active ingredients to larval fathead minnow (*Pimephales promelas*). *Science of the Total Environment* 408:3169-3175.

Berg, M., and M. Sutula, 2015. *Factors affecting the growth of cyanobacteria with special emphasis on the Sacramento-San Joaquin Delta*. Southern California Coastal Water Research Project. Technical Report No. 869. Costa Mesa, California. 107 pp.

Berntssen, M., K. Hylland, K. Julshamn, A. Lundebye, and R. Waagbo, 2004. Maximum limits of organic and inorganic mercury in fish feed. *Aquaculture Nutrition* 10(2):83-97. doi:http://dx.doi.org/10.1046/j.1365-2095.2003.00282.x.

Beyers, D.W., J.A. Rice, W.H. Clements and C.J. Henry, 1999. Estimating physiological cost of chemical exposure: integrating energetics and stress to quantify toxic effects in fish. *Canadian Journal of Fisheries and Aquatic Sciences* 56:814-822.

Bjerregaard, P., S. Fjordside, M.G. Hansen, and M.B. Petrova, 2011. Dietary selenium reduces retention of methylmercury in freshwater fish. *Environmental Science Technology* 45:9793-9798.

Bjornn, T., and D. Reiser, 1991. Habitat requirements of salmonids in streams. In: Influences of Forest and Rangeland Management on Salmonids Fishes and Their Habitat, edited by W. Meehan. *American Fisheries Society Special Publication* 19:83-138.

Bloom, N.S., 1992. On the chemical form of mercury in edible fish and marine invertebrate tissue. *Canadian Journal of Fisheries and Aquatic Sciences* (49):1010-1017.

Boyer, K., and M. Sutula, 2015. *Factors Controlling Submerged and Floating Macrophytes in the Sacramento-San Joaquin Delta*. Southern California Coastal Water Research Project. Technical Report No. 870. Costa Mesa, California. 98 pp.

Camargo, J.A., A. Alonso, and A. Salamanca, 2005. Nitrate toxicity to aquatic animals: a review with new data for freshwater invertebrates. *Chemosphere* 58:1255-1267.

Carter, K., 2005. *The Effects of Dissolved Oxygen on Steelhead Trout, Coho Salmon, and Chinook Salmon Biology and Function by Life Stage*. California Regional Water Quality Control Board North Coast Region.

CDFG (California Department of Fish and Game), 2004a. *Sacramento Winter-run Chinook Salmon: 2002-2003 Biennial Report*. California Department of Fish and Game, Habitat Conservation Division, Native Anadromous Fish and Watershed Branch. June 2004.

CDFG, 2004b. *Sacramento Spring-run Chinook Salmon: 2002-2003 Biennial Report*. California Department of Fish and Game, Habitat Conservation Division, Native Anadromous Fish and Watershed Branch. June 2004.

CDPR (California Department of Pesticide Regulation), 2014. Summary of Pesticide Use Report Data 2012, Indexed by Chemical. California Department of Pesticide Regulation. Sacramento, California.

Coghlan, Jr., S.M. and N.H. Ringler, 2005. Survival and bioenergetic responses of juvenile Atlantic salmon along a perturbation gradient in a natural stream. *Ecology of Freshwater Fish* 14:111-124.

Cox, C., and M. Surgan, 2006. Unidentified inert ingredients in pesticides: Implications for human and environmental health, Commentary. *Environmental Health Prospective* 114(12):1803-1806.

CRWQCBSDR (California Regional Water Quality Control Board San Diego Region), 2007. *Total Maximum Daily Loads for Dissolved Copper, Lead, and Zinc in Chollas Creek, Tributary to San Diego Bay*. Technical Report. California Regional Water Quality Control Board, San Diego Region. San Diego, CA. May 2007.

CVRWQCB (Central Valley Regional Water Quality Control Board), 2002. *Upper Sacramento River TMDL for Cadmium, Copper, and Zinc*. Final Report. Central Valley Regional Water Quality Control Board. Sacramento. April.

CVRWQCB, 2018. *The Water Quality Control Plan for the California Regional Water Quality Control Board Central Valley Region*. Fifth Edition, Revised May 2018.

Davis, J.C., 1975. Minimal dissolved oxygen requirements of aquatic life with emphasis on Canadian species: a review. *Journal of the Fisheries Research Board of Canada* 32:2295-2332.

Depew, D., N. Basu, N. Burgess, L. Campbell, E. Devlin, P. Drevnick, C. Hammerschmidt, C. Murphy, M. Sandeinrich, and J. Wiener, 2012. Toxicity of dietary methylmercury to fish: Derivation of ecologically meaningful threshold concentrations. *Environmental Toxicology and Chemistry* 1-12.

Dillon, T., N. Beckwar, and J. Kern, 2010. Residue-based mercury dose-response in fish: An analysis using lethality-equivalent test endpoints. *Environmental Toxicology and Chemistry* 11:2559-2565.

Dodds, W.K., 2007. Trophic state, eutrophication and nutrient criteria in streams. Review. *Trends in Ecology and Evolution* 22(12):669-676

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

DSC (Delta Stewardship Council), 2013. *The Delta Plan. Ensuring a reliable water supply for California, a healthy Delta ecosystem, and a place of enduring value.* Delta Stewardship Council. Sacramento, California. 374 pp.

DWR (Department of Water Resources), 2010. *Climate Change Characterization and Analysis in California Water Resources Planning Studies*. Final Report.

Eisler, R., 1985. *Selenium hazards to fish, wildlife and invertebrates: a synoptic review*. U.S. Fish and Wildlife Service Biological Report 85 (1.5).

Eisler, R., 1987. *Mercury hazards to fish, wildlife, and invertebrates: a synoptic review*. U.S. Fish and Wildlife Service Biological Report 85 (1.1 0).

Entrix, 2009. *Grasslands Bypass Project, 2010-2019. Environmental Impact Statement and Environmental Impact Report*. Final. Prepared for the U.S. Bureau of Reclamation and San Luis and Delta-Mendota Water Authority. August 2009.

ESA (ESA Associates), 2013. *Stanislaus River Limiting Factors Assessment*. San Joaquin River Tributaries Settlement Process. Draft Memorandum. ESA Associates. 65 pp.

Farrell, P., N.A. Fangue, C.E. Verhille, D.E. Cocherelle, and K.K. English, 2015. *Thermal Performance of Wild Juvenile Oncorhynchus mykiss in the Lower Tuolumne River: A Case for Local Adjustment to High River Temperature*. Draft Report prepared for Turlock Irrigation District – Turlock, California; Modesto Irrigation District – Modesto, California.

Finn, R., 2007. The physiology and toxicology of salmonid eggs and larvae in relation to water quality criteria. *Aquatic Toxicology* 81:337-354.

Fjeld, E., T. Haugen, and L. Vollestad, 1998. Permanent impairment in the feeding behavior of grayling (*Thaymallus thmallus*) exposed to methylmercury during embryogenesis. *Science of the Total Environment* 213:247-254.

Foe, C., and S. Louie, 2014. Appendix A: Importance of Primary and Secondary Production in Controlling Fish Tissue Mercury Concentrations. Review Draft. *Statewide Mercury Control Program for Reservoirs Technical Staff Report*. State Water Resources Control Board. Sacramento, California. 37 pp.

Foe, C., S. Louie, and D. Bosworth, 2008. *Methylmercury Concentrations and Loads in the Central Valley and Freshwater Delta.* Final Report submitted to the CALFED Bay-Delta Program for the project "Transport, Cycling and Fate of Mercury and Monomethylmercury in the San Francisco Delta and Tributaries" Task 2. Central Valley Regional Water Quality Control Board. Available from: http://mercury.mlml.calstate.edu/reports/reports/.

Gibbons, D., C. Morrissey, and P. Mineau, 2014. A review of the direct and indirect effects of neonicotinoids and fipronil on vertebrate wildlife. *Environmental Science and Pollution Research* DOI 10.1007/s11356-014-3180-5.

Gilliom R., J. Barbash, C. Crawford, P. Hamilton, J. Martin, N. Nakagaki, L. Nowell, J. Scott, P. Stackelberg, G. Thelin, and D. Wolock, 2006. *The Quality of Our Nation's Waters—Pesticides in the Nation's Streams and Ground Water, 1992–2001*. U.S. Geological Survey Circular 1291, 172 p.

Gowdy, M., and L. Grober, 2005. *Amendments to the Water Quality Control Plan for the Sacramento River and San Joaquin River Basins for the Control Program for Factors Contributing to the Dissolved Oxygen Impairment in the Stockton Deep Water Ship Channel*. Final Staff Report. Central Valley Regional Water Quality Control Board. Rancho Cordova, California. 104 pp

Hall, B.D., R.A. Bodaly, R.J.P. Fudge, J.W.M. Rudd, and D.M. Rosenberg, 1997. Food as the dominant pathway of methylmercury up-take by fish. *Water, Air, and Soil Pollution* 100:13–24.

Hallock, R.J., Elwell, R.F., and D.H. Fry, Jr., 1970. Migrations of adult King Salmon Oncorhynchus tshawytscha in San Joaquin Delta as demonstrated by the use of sonic tags. California Department of Fish and Game. *Fish Bulletin* 151.

Hallock, R.J., Van Woert, W.F., L. Shapovalov, 1961. An evaluation of stocking hatchery-reared steelhead rainbow trout (*Salmon gairdnerii gairdnerii*) in the Sacramento River System. California Department of Fish and Game. *Fish Bulletin* 114:73.

Hamilton, S., 2004. Review of selenium toxicity in the aquatic food chain. *Science of the Total Environment* 326:1-31.

Hamilton, S., and R. Wiedmeyer, 1990. Concentrations of Boron, Molybdenum, and Selenium in Chinook Salmon. *Transactions of the American Fisheries Society* 119(3):500-510

Hammerschmidt, C., and M. Sandheinrich, 2005. Maternal diet during oogenesis is the major source of methylmercury in fish embryos. *Environmental Science and Technology* 39(10):3580-3584.

Hansen, J., J. Rose, R. Jenkins, K. Gerow, and H. Bergman, 1999a. Chinook salmon (*Onchorhynchus tshawytcha*) and rainbow trout (*Oncorhynchus mykiss*) exposed to copper: Neurophysiological and histological effects on the olfactory system. *Environmental Toxicology and Chemistry* 18:1979-1991.

Hansen, J., J. Marr, J. Lipton, D. Cacela, and H. Bergman, 1999b. Differences in responses of Chinook salmon (*Onchorhynchus tshawytcha*) and rainbow trout (*Oncorhynchus mykiss*) exposed to copper and cobalt: Behavior avoidance. *Environmental Toxicology and Chemistry* 18:1972-1978.

Harvey, C.D., 1995. *Adult steelhead counts in Mill and Deer Creeks, Tehama County, October 1993-June 1994*. Inland Fisheries Division, Department of Fish and Game, State of California.

Hasenbein, M., I. Werner, L. Deanovic, J. Geist, E. Fritsch, A. Javidmehr, C. Foe, N. Fangue, and R. Connon, 2014. Transcriptomic profiling permits the identification of pollutant sources and effects in ambient water samples. *Science of the Total Environment* 468-469:688-698.

Healey, M.C., 1991. Life history of Chinook salmon (*Oncorhynchus tshawytscha*). In: *Pacific Salmon Life Histories*, edited by Groot et al., 311-394.

Hecht, S., D Baldwin, C. Mebane, T. Hawkes, S. Gross, and N. Scholz, 2007. *An overview of sensory effects on juvenile salmonids exposed to dissolved copper: Applying a benchmark concentration approach to evaluate sublethal neurobehavioral toxicity*. U.S. Department of Commerce, NOAA Technical Memorandum. NMFS-NWFSC-83, 39 p.

Hilton, J., P. Hodson, and J. Slinger, 1980. The requirement and toxicity of selenium in rainbow trout (*Salmo gairderi*). *The Journal of Nutrition* 110:2527-2535.

Hladik, M., K. Smalling, and K. Kuivila, 2009. *Methods of analysis—Determination of pyrethroid insecticides in water and sediment using gas chromatography/mass spectrometry*. U.S. Geological Survey Techniques and Methods 5–C2, 18 p.

Hoogeweg, C.G., W.M. Williams, R. Breuer, D. Denton, B. Rook, and C. Watry, 2011. *Spatial and Temporal Quantification of Pesticide Loadings to the Sacramento River, San Joaquin River, and Bay-Delta to Guide Risk Assessment for Sensitive Species*. CALFED Science Grant No. 1055. 293 p.

Jeffres, C., U.C. Davis Watershed Sciences. Unpublished data.

Jeffres, C., 2013. The Center for Watershed Sciences at the University of California Davis. Unpublished data.

Johnson, M., I. Werner, S. Teh, and F. Loge, 2010. *Evaluation of chemical, toxicological, and histopathologic data to determine their role in the pelagic organism decline*. Report prepared for the State Water Resources Control Board. April 2010.

Johnston, T., R. Bodaly, M. Latif, R. Fudge, and N. Strange, 2001. Intra- and interpopulation variability in maternal transfer of mercury to eggs of walleye (*Stizostedion vitreum*). *Aquatic Toxicology* 52(1):73-85.

Katz, J. 2013, CalTrout. Unpublished Data.

Kiaune, L. and N. Singhasemanon, 2011. Pesticidal copper (I) oxide. Environmental fate and aquatic toxicology. *Reviews of Environmental Contamination and Toxicology* 213:1-26.

Kim, E., S. Yoo, H. Ro, H. Han, Y. Baek, I. Eom, H. Kim, P. Kim, and K. Choi, 2013. Aquatic Toxicity Assessment of Phosphate Compounds. *Environmental Health and Technology* 28: e2013002.

Laetz, C., D. Baldwin, T. Collier, V. Herbert, J. Stark, N. Scholz, 2009. The synergistic toxicity of pesticide mixtures: Implications for risk assessment and the conservation of endangered Pacific salmon. *Environmental Health Perspectives* 117(3):348-353.

Lemly, A. and G. Smith, 1987. *Aquatic Cycling of Selenium: Implications for fish and wildlife*. Fish and Wildlife Leaflet 12. U.S. Fish and Wildlife Service. Washington D.C.

Lewis, W.M., and D.P. Morris, 1986. Toxicity of Nitrite to Fish: A Review. *Transactions of the American Fisheries Society* 115:183-195.

Linares-Casenave, J., R. Linville, J. Van Eenennaam, J. Muguet, and S. Doroshov, 2015. Selenium tissue burden compartmentalization in resident white sturgeon (*Acipenser transmontanus*) of the San Francisco Bay Delta Estuary. Environmental Toxicology and Chemistry 34(2015):152-160.Linbo, T., D. Baldwin, J. McIntyre, and N. Scholz, 2009. Effects of water hardness, alkalinity, and dissolved organic carbon on the toxicology of copper to the lateral line of developing fish. *Environmental Toxicology and Chemistry* 28(7):1455-1461.

Lindley, S.T., R.S. Schick, E. Mora, P.B. Adams, J.J. Anderson, S. Greene, C. Hanson, B. May, D. McEwan, R.B. MacFarlane, C. Swanson, and J.G. Williams, 2007. Framework for assessing the viability of threatened and endangered Chinook salmon and steelhead in the Sacramento-San Joaquin Basin. *San Francisco Estuary and Watershed Sciences* 5:1. Available from: http://repositories.cdlib.org/jmie/sfews/vol5/iss1/art4.

Lu, Z. and G. Davis, 2009. *Relative-Risk Evaluation for Pesticides Used in the Central Valley Pesticides Basin Plan Amendment Project Area*. Final Staff Report. Central Valley Regional Water Quality Control Board. Sacramento. February 2009.

Macneale, K, J. Spromberg, D. Baldwin, N. Scholz, 2014. A Modeled Comparison of Direct and Food Web-Mediated Impacts of Common Pesticides on Pacific Salmon. *PLoS One* 9(3).

Marine, K. R., and J.J. Cech, 2004. Effects of high water temperature on growth, smoltification, and predator avoidance in juvenile Sacramento River Chinook Salmon. *North American Journal of Fisheries Management* 24:198–210.

Markiewicz, D., M. Stillway, and S. Teh, 2012. *Toxicity in California Waters: Central Valley Region*. Surface Water Ambient Monitoring Program. California State Water Resources Control Board. Sacramento, California.

Mason, R., H. Tennekes, F. Sanchez-Bayo, and P. Jepsen, 2013. Immune Suppression by neonicotinoid insecticides at the root of global wildlife declines. *Journal of Environmental Immunology and Toxicology* 1:3-12.

Matta, M., J. Linse, C. Cairncross, L. Francendese, and R. Kocan, 2001. Reproductive and transgenerational effects of methylmercury or Aroclor 1268 on Fundulus heteroclitus. *Environmental Toxicology and Chemistry* 20(2):327-335.

McCarthy, M., and L. Grober, 2001. *Total Maximum Daily Load for Selenium in the Lower San Joaquin River*. Central Valley Regional Water Quality Control Board Staff Report. Sacramento. August 2001.

McCullough, D., S. Spalding, D. Sturdevant, M. Hicks, 2001. Issue Paper 5. *Summary of technical literature examining the physiological effects of temperature on salmonids*. Prepared as part of USEPA Region 10 Temperature Water Quality Criteria Guidance Development Project. EPA-910-D-01-005. Available from: http://yosemite.epa.gov/R10/WATER.NSF/.

McEwan, D., and Jackson, T.A., 1996. *Steelhead Restoration and Management Plan for California*. California Department of Fish and Wildlife. 244 p.

McEwan, D., 2001. Central Valley Steelhead. In Brown, R.L. (ed.), Contributions to the Biology of Central Valley Salmonids, Volume 1, pages 1-44. California Department of Fish and Wildlife, *Fish Bulletin* 179:1-43.

McIntyre, J., D. Baldwin, J. Meador, and N. Scholz, 2008. Chemosensory deprivation in juvenile Coho salmon exposed to copper under varying water chemistry conditions. *Environmental Science and Technology* 42:1352-1358.

McIntyre, J.K., D.H. Baldwin, D.A. Beauchamp, and N.L. Scholz, 2012. Low-level copper exposures increase visibility and vulnerability of juvenile Coho salmon to cutthroat trout predators. *Ecological Applications* 222:1460-1471.

McKim, J., G. Olson, G. Holcombe, and E. Hunt, 1976. Long-term effects of methylmercuric chloride on three generations of brook trout (*Salvelinus fontinalis*): Toxicity, accumulation, distribution, and elimination. *Journal of the Fisheries Research Board of Canada* 33:2726-2739.

Mekebri, A., 2011. Recent advances in the analysis of pyrethroid insecticides in surface water and sediment. Presentation. California Department of Fish and Game, Office of Spill Prevention and Response, Fish and Wildlife Water Pollution Control Laboratory. Surface Water Ambient Monitoring Program. California State Water Resources Control Board. Sacramento, California. Available from: http://www.waterboards.ca.gov/water_issues/programs/swamp/tools.shtml#qa

Mesa, M.G., L.K. Weiland, and P. Wagner, 2002. Effects of acute thermal stress on the survival, predator avoidance, and physiology of juvenile fall Chinook salmon. *Northwest Science* 76:118-128.

Moore, A., and G. Fewings, 2003. *The effect of atrazine exposure on the timing of salmon (Salmo salar L.) smolt emigration*. R&D Technical Report, W2-052/TR. Environmental Agency and Centre for Environmental Fisheries and Aquaculture Science.

Moore, A., and C. Waring, 2001. The effects of a synthetic pyrethroid pesticide on some aspects of reproduction in Atlantic salmon (*Salmo salar L.*). *Aquatic Toxicology* 52:1-12.

Moore, J.W., S.A. Hayes, W. Duffy, S. Gallagher, C.J. Michel, and D. Wright, 2011. Nutrient fluxes and the recent collapse of coastal California salmon populations. *Canadian Journal of Fisheries and Aquatic Sciences* 68:1161-1170.

Moran, P.W., N. Aluru, R.W. Black, and M.M. Vijayan, 2007. Tissue contaminants and associated transcriptional response in trout liver from high elevation lakes of Washington. *Environmental Science and Technology* 41:6591-6597.

Moyle, P.B., 2002. *Inland Fishes of California*. Revised and expanded. Berkeley: University of California Press. 502 pp.

Moyle, P.B., 2002. *Salmon and Trout, Salmonidae-Chinook Salmon (Oncorhynchus tshawytscha) in Inland Fishes of California*. Los Angeles, California: University of California Press, 251-263.

Myrick, C.A., and J.J. Cech, 2004. Temperature effects on juvenile anadromous salmonids in California's central valley: what don't we know? *Reviews in Fish Biology and Fisheries* 14:113-123.

Myrick, C.A., and J.J. Cech, 2005. Effects of temperature on the growth, food consumption, and thermal tolerance of age-0 Nimbus-strain steelhead. *North American Journal of Aquaculture* 67:324–330.

Nichols, J., S. Bradbury, and J. Swartout, 1999. Derivation of wildlife values for mercury. *Journal of Toxicology and Environmental Health* 4:325-355.

Nickel, D.K., M.T. Brett, and A.D. Jassby, 2004. Factors regulating Shasta Lake (California) cold water accumulation, a resource for endangered salmon conservation. *Water Resources Research* 40. doi: 10.1029/2003WR002669. issn: 0043-1397.

Nieves-Puigdoller, K., B. Bjornsson, and S. McCormick, 2007. Effects of hexazinone and atrazine on the physiology and endocrinology of smolt development in Atlantic salmon. *Aquatic Toxicology* 84:27-37.

Niimi, A., 1983. Biological and toxicological effects of environmental contaminants in fish and their eggs. *Canadian Journal of Fisheries and Aquatic Sciences* 40:306-312.

NMFS (National Marine Fisheries Service), 2008. Endangered Species Act Section 7 Consultation: Environmental Protection Agency registration of pesticides containing chlorpyriphos, diazinon, and malathion. Biological Opinion. Silver Spring, Maryland, U.S. Department of Commerce: 482 p.

NMFS, 2009a. Biological Opinion and Conference Opinion on the Long-Term Operations of the Central Valley Project and State Water Project. Southwest Region. June 4, 2009.

NMFS, 2009b. Endangered Species Act Section 7 Consultation: Biological opinion and conference opinion on the long-term operations of the Central Valley Project and State Water Project. National Marine Fisheries Service, Southwest Region. June 4, 2009.

NMFS, 2010. Endangered Species Act Section 7 Consultation: Environmental Protection Agency registration of pesticides containing azinphos methyl, bensulide, dimethoate, disulfoton, ethoprop, fenamiphos, naled, methamidophos, methidathion, methyl parathion, phorate, and phosmet. Biological Opinion. Silver Spring, Maryland, U.S. Department of Commerce: 1010 p.

NMFS, 2011. Endangered Species Act Section 7 Consultation: Environmental Protection Agency registration of pesticides containing 2,4-D, triclopyr BEE, diuron, linuron, captan, and chlorothalonil. Biological Opinion. Silver Spring, Maryland, U.S. Department of Commerce: 1131 p.

NMFS, 2012. Endangered Species Act Section 7 Consultation: Environmental Protection Agency registration of pesticides containing oryzalin, pendimethaline, and trifluralin. Biological Opinion. Silver Spring, Maryland, U.S. Department of Commerce: 1094 p.

NMFS, 2013. Endangered Species Act Section 7 Consultation: Environmental Protection Agency registration of pesticides containing diflubenzuron, fentutatin oxide, and propargite. Draft Biological Opinion. Silver Spring, Maryland, U.S. Department of Commerce: 924 p.

NMFS, 2014. Public Final Recovery Plan for the Evolutionary Significant Units of Sacramento River Winter-run Chinook Salmon and Central Valley Spring-run Chinook Salmon and the Distinct Population Segment of Central Valley Steelhead. Sacramento Protected Resources Division. July 2014.

Noga, E.J., 1996. Fish Diseases Diagnosis and Treatment. Mosbey Year-Book, Inc. Nriagu, J.O., 1996. A history of global metal pollution. *Science* 272(5259): 223-224.

Peterson, S., J. Van Sickle, A. Herlihy, and R. Hughes, 2007. Mercury concentrations in fish from streams and rivers throughout the western United States. *Environmental Science and Technology* 41:58-68.

Potter, E., and P. Dare, 2003. *Research on migratory salmonids, eels, and freshwater fish stocks and fisheries*. Science Series Technical Report, CEFAS Lowestoft, 119: 64 pp.

Presser, T., and S. Luoma, 2006. *Forecasting selenium discharges to the San Francisco Bay-Delta Estuary: Ecological effects of a proposed San Luis Drain extension*. U.S. Geological Service. Professional Paper 1646. 196.

Presser, T., and S. Luoma, 2013. Ecosystem-scale selenium model for the San Francisco Bay-Delta Regional Ecosystem Restoration Implementation Plan. *San Francisco Estuary and Watershed Science* 11(1).

Quinn, T.P., 2005. *The behavior and ecology of Pacific salmon and trout*. Seattle: University of Washington Press.

Reese, C.D., and B.C. Harvey, 2002. Temperature-dependent competition between juvenile steelhead and Sacramento pikeminnow. *Transactions of the American Fisheries Society* 131:599-606.

Richter, A., and S.A. Kolmes, 2005. Maximum Temperature Limits for Chinook, Coho, and Chum Salmon, and Steelhead Trout in the Pacific Northwest. *Reviews in Fisheries Science* 13:23-49.

Russo, R.C., C.E. Smith, and R.V. Thurston, 1974. Acute toxicity of nitrite to rainbow trout (Salmo gairdneri). *Canadian Journal of Fisheries and Aquatic Sciences* 31:1653-1655.

Sandahl, J., D. Baldwin, J. Jenkins, and N. Scholz, 2007. A sensory system at the interface between urban stormwater runoff and salmon survival. *Environmental Science and Technology* 41(8):2998-3004.

Sandheinrich, M.B., S.P. Bhavsar, R.A. Bodaly, P.E. Drevnick, and E.A. Paul, 2011. Ecological risk of methylmercury to piscivorous fish of the Great Lakes region. *Ecotoxicology* 20:1577-1587.

Schlegel, B., and J.L. Domagalski, 2015. Riverine Nutrient Trends in the Sacramento and San Joaquin Basins, California: A Comparison to State and Regional Water Quality Policies. *San Francisco Estuary and Watershed Science* 13:2.

Scholz, N., N. Truelove, B. French, B. Berejikian, T. Quinn, E. Casillas, and T. Collier, 2000. Diazinon disrupts antipredator and homing behavior in Chinook salmon (*Oncorhynchus tshawytscha*). *Canadian Journal of Fisheries and Aquatic Sciences* 57:1911-1918.

Scholz, N., M. Myers, S. McCarthy, J. Labenia, J. McIntyre, G.M. Ylitalo, L.D. Rhodes, C.A. Laetz, C.M. Stehr, B.L. French, B. McMillan, D. Wilson, L. Reed, K.D. Lynch, S. Damm, J.W. Davis, and T.K. Collier, 2011. Recurrent Die-Offs of Adult Coho Salmon Returning to Spawn in Puget Sound Lowland Urban Streams. *PLoS ONE* 6(12).

Scholz, N., E. Fleishman, L. Brown, I. Werner, M. Johnson, M. Brooks, C. Mitchelmore, and D. Schlenk,, 2012. A perspective on modern pesticides, pelagic fish declines, and unknown ecological resilience in highly managed ecosystems. *Bioscience* 62(4):428-434.

Scott, G., and K. Sloman, 2004. The effects of environmental pollutants on complex fish behavior: integrating behavior and physiological indicators of toxicity. *Aquatic Toxicology* 68:369-392.

SDRWQCB (San Diego Regional Water Quality Control Board), 2006. *Basin Plan Amendment and Final Technical Report for Total Nitrogen and Total Phosphorus Total Maximum Daily Loads For Rainbow Creek*. California Water Quality Control Board, San Diego Region. San Diego, California.

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

SFBRWQCB, 2007. *Copper Site-Specific Objectives in the San Francisco Bay*. Proposed Basin Plan Amendment and Draft Staff Report. San Francisco Bay Regional Water Quality Control Board. June.

SFEI (San Francisco Estuary Institute), 2001. *San Francisco Bay Atmospheric Deposition Pilot Study Part 1: Mercury*. San Francisco Estuary Institute (SFEI) Contribution 72. July 2001.

Sharma, D., and A. Ansari, 2010. Effect of the synthetic pyrethroid deltamethrin and the neem-based pesticide anchook on the reproductive ability of zebrafish, Danio rerio (Cyprinidae). *Archives of Polish Fisheries* 18:157-161.

Slotton, D.G., S.M. Ayers, T.H. Suchanek, R.D. Weyland, and A.M. Liston, 2004. *Mercury Bioaccumulation and Trophic Transfer in the Cache Creek Watershed, California, in Relation to Diverse Aqueous Mercury Exposure Conditions*. Subtask 5B. Final Report, University of California, Davis, Department of Environmental Science and Policy and Department of Wildlife, Fish and Conservation Biology. Prepared for the CALFED Bay-Delta Program, Directed Action #99-B06. August 2004.

Smith, C.E., and W.G. Williams, 1974. Experimental Nitrite Toxicity in Rainbow Trout and Chinook Salmon. *Transactions of the American Fisheries Society* 103(2):389-390.

Spurlock, F. and M. Lee, 2008. Synthetic pyrethroid use patterns, properties, and environmental effects. In *Synthetic Pyrethroids*, edited by Gan et al. ACS Symposium Series. Washington, D.C.: American Chemical Society.

Stefansson, E., A. Heyes, and C. Rowe, 2014. Tracing Maternal Transfer of Methylmercury in the Sheepshead Minnow (*Cyprinodon variegatus*) with an Enriched Mercury Stable Isotope. *Environmental Science and Technology* 48(3):1957.

Stockner, J., and K. Ashley, 2003. Salmon Nutrients: Closing the Circle. In: *Nutrients in salmonid ecosystems: sustaining production and biodiversity*. Edited by J. Stockner. American Fisheries Society Symposium 34, Bethesda, Md. 3-15 pp.

Stockner, J., E. Rydin, and P. Hyenstrand, 2000. Cultural Oligotrophication: Causes and consequences for fisheries resources. *Fisheries* 25(5):7-14.

Sveinsdottir, A.Y., and R.P. Mason, 2005. Factors Controlling Mercury and Methylmercury Concentrations in Largemouth Bass (*Micropterus salmoides*) and Other Fish from Maryland Reservoirs. *Archives of Environmental Contamination and Toxicology* 49:528-545.

SWRCB (State Water Resources Control Board), 2010. *Final California Integrated Report (303(d) List/305(b) Report)*. Staff Report. State Water Resources Control Board. Sacramento, California.

SWRCB, 2012. *Policy for Toxicity Assessment and Control*. Public Review Draft. State Water Resources Control Board. Sacramento, California. June 2012.

TDC (TDC Environmental), 2004. *Copper Sources in Urban Runoff and Shoreline Activities. Information Update*. Prepared for the Clean Estuary Partnership by TDC Environmental. November 2004.

Tetra Tech, 2006. *Technical Approach to Develop Nutrient Numeric Endpoints for California*. Technical Report prepared for the U.S. EPA Region IX and California State Water Resources Control Board. Tetra Tech, Inc. Lafayette, California. 137 pp.

Thurston, R.V., G.R. Phillips, R.C. Russo, and S.M. Hinkins, 1981. Increased toxicity of ammonia to rainbow trout (*Salmo gairdneri*) resulting from reduced concentrations of dissolved oxygen. *Canadian Journal of Fisheries and Aquatic Sciences* 38: 983-988.

USEPA (U.S. Environmental Protection Agency), 1986. *Ambient Water Quality Criteria for Dissolved Oxygen*. Office of Water, Regulations and Standards Division. U.S. Environmental Protection Agency, Washington, D.C. EPA 440/5-86-003.

USEPA, 1999. *A review and synthesis of effects of alterations to the water temperature regime on freshwater life stages of salmonids, with special reference to Chinook salmon*. U.S. Environmental Protection Agency, Region 10.

USFWS (U.S. Fish and Wildlife Service), 2008. Species at Risk from Selenium Exposure in the San Francisco Estuary. U.S. Fish and Wildlife Service, Sacramento Fish and Wildlife Office, Environmental Contaminants Division. Sacramento, California. March 2008. 81 pp.

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

Wiener, J.G., D.P. Krabbenhoft, G.H. Heinz, and A.M. Scheuhammer, 2003. *Ecotoxicology of Mercury. In Handbook of Ecotoxicology*. Second Edition, edited by Hoffman et al. CRC Press.

Appendix D
Long-term Stressor Priorities for Fall-run and Spring-run Chinook Salmon and *O. mykiss*

Appendix D
Long-term Stressor Priorities for Fall-run Chinook Salmon

Fall-run Chinook Salmon - Stressor Response Prioritization (Long-term, Coarse Scale)

Life History Stage	Stressor	Score Magnitude	Cert	Total	Priority	Conservation Measure Type
Juvenile Rearing/ Migration	Lack of suitable migratory conditions - Multiple Factors	4	4	8	A-1	Priority 1 Action - and associated monitoring
Juvenile Rearing/ Migration	Lack of Suitable Rearing Habitat - Multiple Factors	4	4	8	A-1	Priority 1 Action - and associated monitoring
Juvenile Rearing/ Migration	Compression of the Rearing and Migration Window - Multiple Factors	4	4	8	A-1	Priority 1 Action - and associated monitoring
Egg Development	Inadequate Egg Development Conditions - Multiple Factors	3	4	7	A-2	Priority 2 Action - and associated monitoring
Adult Migration	Negative Sub-lethal Effects (indirect; e.g., reduced fecundity or mortality via disease) - Multiple Factors	4	3	7	A-2	Priority 2 Action - with adaptive management and monitoring
Adult Spawning	Inadequate availability of high-quality habitat - Multiple Factors	4	3	7	A-2	Priority 2 Action - with adaptive management and monitoring
Adult Spawning	Interactions with hatchery fish and other runs - Multiple Factors	4	3	7	A-2	Priority 2 Action - with adaptive management and monitoring
Juvenile Rearing/ Migration	Lack of suitable migratory cues - Multiple Factors	4	3	7	A-2	Priority 2 Action - with adaptive management and monitoring
Adult Holding	Lack of Suitable Habitat - Multiple Factors	3	3	6	A-3	Priority 3 Action - with adaptive management and monitoring
Juvenile Rearing/ Migration	Lack of suitable over-summering habitat - Multiple Factors	2	3	5	A-4	Priority 4 Action - with adaptive management and monitoring
Adult Spawning	Compression of the Spawning window - Multiple Factors	4	2	6	R-1	Priority 1 Research - to inform action design
Adult Holding	Loss of Fecumdidty - Multiple Factors	3	2	5	R-2	Priority 2 Research - to inform action design
Adult Migration	Late access to river (relative to migration window) do to impassable or unsiutable conditions - Multiple Factors	3	2	5	R-2	Priority 2 Research - to inform action design
Adult Migration	Significant Delay and/or Failure to Reach Natal Stream (direct effects) - Multiple Factors	3	1	4	R-3	Priority 3 Research - to confirm need for action

Fall-run Chinook Salmon - Stressor Response Prioritization (Long-term, Fine Scale)

Life History Stage	Stressor	Score Magnitude	Cert	Total	Priority	Conservation Measure Type
Juvenile Rearing/ Migration	Coarse Sediment Input	4	4	8	A-1	Priority 1 Action - and associated monitoring
Juvenile Rearing/ Migration	Lack of suitable migratory conditions- Temp	4	4	8	A-1	Priority 1 Action - and associated monitoring
Juvenile Rearing/ Migration	Compression of the Rearing and Migration Window - Temp	4	4	8	A-1	Priority 1 Action - and associated monitoring
Egg Development	Inadequate Egg Development Conditions - Temp	3	4	7	A-2	Priority 2 Action - and associated monitoring
Adult Migration	Negative Sub-lethal Effects (indirect; e.g., reduced fecundity or mortality via disease) - Temperature	4	3	7	A-2	Priority 2 Action - with adaptive management and monitoring
Adult Spawning	Inadequate availability of high-quality habitat - Temp	4	3	7	A-2	Priority 2 Action - with adaptive management and monitoring
Adult Spawning	Interactions with hatchery fish and other runs - Hatchery	4	3	7	A-2	Priority 2 Action - with adaptive management and monitoring
Adult Spawning	Interactions with hatchery fish and other runs - Run Segregation	4	3	7	A-2	Priority 2 Action - with adaptive management and monitoring
Juvenile Rearing/ Migration	Lack of fitness/ genetic maladaptation - Hatchery Introgression	4	3	7	A-2	Priority 2 Action - with adaptive management and monitoring
Juvenile Rearing/ Migration	Lack of suitable migratory cues - Velocity	4	3	7	A-2	Priority 2 Action - with adaptive management and monitoring
Juvenile Rearing/ Migration	Lack of Suitable Rearing Habitat - Contaminants/ Toxins	4	3	7	A-2	Priority 2 Action - with adaptive management and monitoring
Juvenile Rearing/ Migration	Lack of Suitable Rearing Habitat - Temp	4	3	7	A-2	Priority 2 Action - with adaptive management and monitoring
Adult Holding	Lack of Suitable Habitat - Temperature	3	3	6	A-3	Priority 3 Action - with adaptive management and monitoring
Adult Spawning	Inadequate availability of high-quality habitat - Spatial Distribution	3	3	6	A-3	Priority 3 Action - with adaptive management and monitoring
Juvenile Rearing/ Migration	Compression of the Rearing and Migration Window - DO	3	3	6	A-3	Priority 3 Action - with adaptive management and monitoring
Juvenile Rearing/ Migration	Lack of suitable migratory conditions - Depth	3	3	6	A-3	Priority 3 Action - with adaptive management and monitoring
Juvenile Rearing/ Migration	Lack of Suitable Rearing Habitat - Cover	3	3	6	A-3	Priority 3 Action - with adaptive management and monitoring
Juvenile Rearing/ Migration	Lack of Suitable Rearing Habitat - Depth	3	3	6	A-3	Priority 3 Action - with adaptive management and monitoring

Appendix D
Long-term Stressor Priorities for Fall-run Chinook Salmon

Life History Stage	Stressor	Score Magnitude	Cert	Total	Priority	Conservation Measure Type
Juvenile Rearing/ Migration	Lack of suitable migratory conditions - Contaminants/ Toxins	2	3	5	A-4	Priority 4 Action - with adaptive management and monitoring
Juvenile Rearing/ Migration	Lack of suitable over-summering habitat - Temp	2	3	5	A-4	Priority 4 Action - with adaptive management and monitoring
Adult Migration	Negative Sub-lethal Effects (indirect; e.g., reduced fecundity or mortality via disease) - DO	4	2	6	R-1	Priority 1 Research - to inform action design
Adult Spawning	Compression of the Spawning window - Temp	4	2	6	R-1	Priority 1 Research - to inform action design
Juvenile Rearing/ Migration	Lack of suitable migratory conditions - Habitat Distribution	4	2	6	R-1	Priority 1 Research - to inform action design
Juvenile Rearing/ Migration	Lack of suitable migratory cues - Temp	4	2	6	R-1	Priority 1 Research - to inform action design
Adult Holding	Disease	3	2	5	R-2	Priority 2 Research - to inform action design
Adult Holding	Loss of Fecumdidty - Temp	3	2	5	R-2	Priority 2 Research - to inform action design
Adult Migration	Late access to river (relative to migration window) do to impassable or unsiutable conditions - Temperature	3	2	5	R-2	Priority 2 Research - to inform action design
Adult Migration	Late access to river (relative to migration window) do to impassable or unsiutable conditions -Contaminants/ Attraction Flows	3	2	5	R-2	Priority 2 Research - to inform action design
Adult Migration	Late access to river (relative to migration window) do to impassable or unsiutable conditions -DO	3	2	5	R-2	Priority 2 Research - to inform action design
Adult Migration	Negative Sub-lethal Effects (indirect; e.g., reduced fecundity or mortality via disease) - Attraction Flow	3	2	5	R-2	Priority 2 Research - to inform action design
Adult Migration	Negative Sub-lethal Effects (indirect; e.g., reduced fecundity or mortality via disease) - Contaminants/ Toxins	3	2	5	R-2	Priority 2 Research - to inform action design
Adult Spawning	Coarse Sediment Input	3	2	5	R-2	Priority 2 Research - to inform action design
Adult Spawning	Inadequate availability of high-quality habitat - Contaminants	3	2	5	R-2	Priority 2 Research - to inform action design
Juvenile Rearing/ Migration	Disease	3	2	5	R-2	Priority 2 Research - to inform action design
Juvenile Rearing/ Migration	Lack of suitable migratory conditions - Cover	3	2	5	R-2	Priority 2 Research - to inform action design
Juvenile Rearing/ Migration	Lack of suitable migratory conditions - Velocity	3	2	5	R-2	Priority 2 Research - to inform action design
Juvenile Rearing/ Migration	Lack of suitable migratory cues - Turbidity	3	2	5	R-2	Priority 2 Research - to inform action design
Adult Migration	Late access to river (relative to migration window) do to impassable or unsiutable conditions -Contaminants/ Toxins	3	1	4	R-3	Priority 3 Research - to confirm need for action
Adult Migration	Significant Delay and/or Failure to Reach Natal Stream (direct effects) - Attraction flows	3	1	4	R-3	Priority 3 Research - to confirm need for action
Juvenile Rearing/ Migration	Lack of suitable migratory conditions - Prey Density	3	1	4	R-3	Priority 3 Research - to confirm need for action
Juvenile Rearing/ Migration	Predator Density	3	1	4	R-3	Priority 3 Research - to confirm need for action
Adult Holding	Lack of Suitable Habitat - Contaminants	2	2	4	R-3	Priority 3 Research - To inform action design
Adult Holding	Lack of Suitable Habitat - Cover	2	2	4	R-3	Priority 3 Research - To inform action design
Adult Holding	Loss of Fecumdidty - Contaminants	2	2	4	R-3	Priority 3 Research - To inform action design
Adult Holding	Poaching	2	2	4	R-3	Priority 3 Research - To inform action design
Adult Holding	Predator Density	2	2	4	R-3	Priority 3 Research - To inform action design
Adult Spawning	Disease	2	2	4	R-3	Priority 3 Research - To inform action design
Adult Spawning	Poaching	2	2	4	R-3	Priority 3 Research - To inform action design
Egg Development	Inadequate Egg Development Conditions - Pesticides	2	2	4	R-3	Priority 3 Research - To inform action design
Juvenile Rearing/ Migration	Lack of suitable migratory conditions - Turbidity	2	2	4	R-3	Priority 3 Research - To inform action design
Juvenile Rearing/ Migration	Lack of suitable over-summering habitat - Velocity	2	2	4	R-3	Priority 3 Research - To inform action design

Appendix D
Long-term Stressor Priorities for Fall-run Chinook Salmon

Life History Stage	Stressor	Score Magnitude	Cert	Total	Priority	Conservation Measure Type
Juvenile Rearing/ Migration	Lack of Suitable Rearing Habitat - Turbidity	2	2	4	R-3	Priority 3 Research - To inform action design
Juvenile Rearing/ Migration	Lack of Suitable Rearing Habitat - Velocity	2	2	4	R-3	Priority 3 Research - To inform action design
Adult Migration	Negative Sub-lethal Effects (indirect; e.g., reduced fecundity or mortality via disease) - Passable physical barriers (including low water)	2	1	3	R-4	Priority 4 Research - to evaluate need for action
Adult Migration	Significant Delay and/or Failure to Reach Natal Stream (direct effects) - DO	2	1	3	R-4	Priority 4 Research - to evaluate need for action
Adult Migration	Significant Delay and/or Failure to Reach Natal Stream (direct effects) - Temp	2	1	3	R-4	Priority 4 Research - to evaluate need for action
Adult Spawning	Compression of the Spawning window - DO	2	1	3	R-4	Priority 4 Research - to evaluate need for action
Adult Spawning	Inadequate availability of high-quality habitat -DO	2	1	3	R-4	Priority 4 Research - to evaluate need for action
Egg Development	Inadequate Egg Development Conditions - Fine Sediments	2	1	3	R-4	Priority 4 Research - to evaluate need for action
Egg Development	Inadequate Egg Development Conditions - Flow Fluctuation, Redd Scour	2	1	3	R-4	Priority 4 Research - to evaluate need for action
Juvenile Rearing/ Migration	Lack of suitable over-summering habitat - Cover	2	1	3	R-4	Priority 4 Research - to evaluate need for action
Juvenile Rearing/ Migration	Lack of Suitable Rearing Habitat - Prey Density	2	1	3	R-4	Priority 4 Research - to evaluate need for action
Adult Holding	Lack of Suitable Habitat - Depth	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Adult Holding	Lack of Suitable Habitat - DO	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Adult Holding	Lack of Suitable Habitat - Velocity	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Adult Holding	Loss of Fecumdidty - Depth	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Adult Holding	Loss of Fecumdidty - DO	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Adult Holding	Loss of Fecumdidty - Velocity	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Adult Spawning	Inadequate availability of high-quality habitat - Cover	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Adult Spawning	Inadequate availability of high-quality habitat - Depth	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Adult Spawning	Inadequate availability of high-quality habitat - Velocity	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Juvenile Rearing/ Migration	Lack of suitable migratory conditions - DO	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Juvenile Rearing/ Migration	Lack of Suitable Rearing Habitat - DO	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Juvenile Rearing/ Migration	Lack of suitable over-summering habitat - Contaminants/ Toxins	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Adult Migration	Significant Delay and/or Failure to Reach Natal Stream (direct effects) - Contaminants/ Toxins	1	1	2	R-5	Priority 5 Research - to understand magnitude
Adult Migration	Significant Delay and/or Failure to Reach Natal Stream (direct effects) - Poaching	1	1	2	R-5	Priority 5 Research - to understand magnitude
Adult Spawning	Predator Density	1	1	2	R-5	Priority 5 Research - to understand magnitude
Juvenile Rearing/ Migration	Lack of suitable migratory cues - DO	1	1	2	R-5	Priority 5 Research - to understand magnitude
Juvenile Rearing/ Migration	Lack of suitable over-summering habitat - Depth	1	1	2	R-5	Priority 5 Research - to understand magnitude
Juvenile Rearing/ Migration	Lack of suitable over-summering habitat - DO	1	1	2	R-5	Priority 5 Research - to understand magnitude
Juvenile Rearing/ Migration	Lack of suitable over-summering habitat - Turbidity	1	1	2	R-5	Priority 5 Research - to understand magnitude
Adult Holding	Coarse Sediment Input	1	3	4	T-1	Priority 1 Monitoring (General/ Baseline) - to track magnitude/ ensure no action is warranted
Egg Development	Inadequate Egg Development Conditions - Flow Fluctuation, Redd Dewatering	1	3	4	T-1	Priority 1 Monitoring (General/ Baseline) - to track magnitude/ ensure no action is warranted

Appendix D
Long-term Stressor Priorities for Fall-run Chinook Salmon

Life History Stage	Stressor	Score Magnitude	Cert	Total	Priority	Conservation Measure Type
Egg Development	Inadequate Egg Development Conditions - Contaminants/ Toxins	1	4	5	T-2	Priority 2 Monitoring (General/ Baseline) -to track magnitude
Egg Development	Inadequate Egg Development Conditions - DO	1	4	5	T-2	Priority 2 Monitoring (General/ Baseline) -to track magnitude

Appendix D
Long-term Stressor Priorities for Spring-run Chinook Salmon

Spring-run Chinook Salmon - Stressor Response Prioritization (Long-term, Coarse Scale)

Life History Stage	Stressor	Score Magnitude	Certainty	Total	Priority	Conservation Measure Type
Adult Holding	Lack of Suitable Habitat - Multiple Factors	4	4	8	A-1	Priority 1 Action - and associated monitoring
Egg Development	Inadequate Egg Development Conditions - Multiple Factors	4	4	8	A-1	Priority 1 Action - and associated monitoring
Juvenile Rearing/ Migration	Lack of suitable migratory conditions - Multiple Factors	4	4	8	A-1	Priority 1 Action - and associated monitoring
Juvenile Rearing/ Migration	Lack of Suitable Rearing Habitat - Multiple Factors	4	4	8	A-1	Priority 1 Action - and associated monitoring
Adult Spawning	Inadequate availability of high-quality habitat - Multiple Factors	4	3	7	A-2	Priority 2 Action - with adaptive management and monitoring
Adult Spawning	Interactions with hatchery fish and other runs - Multiple Factors	4	3	7	A-2	Priority 2 Action - with adaptive management and monitoring
Juvenile Rearing/ Migration	Lack of suitable migratory cues - Multiple Factors	4	3	7	A-2	Priority 2 Action - with adaptive management and monitoring
Juvenile Rearing/ Migration	Lack of suitable over-summering habitat - Multiple Factors	3	3	6	A-3	Priority 3 Action - with adaptive management and monitoring
Adult Migration	Negative Sub-lethal Effects (indirect, e.g., reduced fecundity or mortality via disease) - Multiple Factors	4	2	6	R-1	Priority 1 Research - to inform action design
Adult Spawning	Compression of the Spawning window - Multiple Factors	4	2	6	R-1	Priority 1 Research - to inform action design
Adult Holding	Loss of Fecundity - Multiple Factors	3	2	5	R-2	Priority 2 Research - to inform action design
Adult Migration	Significant Delay and/or Failure to Reach Natal Stream (direct effects) - Multiple Factors	3	2	5	R-2	Priority 2 Research - to inform action design
Juvenile Rearing/ Migration	Compression of the Rearing and Migration Window - Multiple Factors	3	2	5	R-2	Priority 2 Research - to inform action design

Spring-run Chinook Salmon - Stressor Response Prioritization (Long-term, Fine Scale)

Life History Stage	Stressor	Score Magnitude	Certainty	Total	Priority	Conservation Measure Type
Adult Holding	Lack of Suitable Habitat - Temperature	4	4	8	A-1	Priority 1 Action - and associated monitoring
Egg Development	Inadequate Egg Development Conditions - Temp	4	4	8	A-1	Priority 1 Action - and associated monitoring
Juvenile Rearing/ Migration	Coarse Sediment Input	4	4	8	A-1	Priority 1 Action - and associated monitoring
Juvenile Rearing/ Migration	Lack of suitable migratory conditions - Velocity	4	4	8	A-1	Priority 1 Action - and associated monitoring
Juvenile Rearing/ Migration	Lack of suitable migratory conditions- Temp	4	4	8	A-1	Priority 1 Action - and associated monitoring
Juvenile Rearing/ Migration	Lack of Suitable Rearing Habitat - Velocity	4	4	8	A-1	Priority 1 Action - and associated monitoring
Adult Spawning	Coarse Sediment Input	4	3	7	A-2	Priority 2 Action - with adaptive management and monitoring
Adult Spawning	Inadequate availability of high-quality habitat - Spatial Distribution	4	3	7	A-2	Priority 2 Action - with adaptive management and monitoring
Adult Spawning	Inadequate availability of high-quality habitat - Temp	4	3	7	A-2	Priority 2 Action - with adaptive management and monitoring
Adult Spawning	Interactions with hatchery fish and other runs - Hatchery	4	3	7	A-2	Priority 2 Action - with adaptive management and monitoring
Adult Spawning	Interactions with hatchery fish and other runs - Run Segregation	4	3	7	A-2	Priority 2 Action - with adaptive management and monitoring
Juvenile Rearing/ Migration	Lack of suitable migratory cues - Velocity	4	3	7	A-2	Priority 2 Action - with adaptive management and monitoring
Juvenile Rearing/ Migration	Lack of Suitable Rearing Habitat - Contaminants/ Toxins	4	3	7	A-2	Priority 2 Action - with adaptive management and monitoring
Juvenile Rearing/ Migration	Lack of Suitable Rearing Habitat - Temp	4	3	7	A-2	Priority 2 Action - with adaptive management and monitoring
Juvenile Rearing/ Migration	Compression of the Rearing and Migration Window - Temp	3	3	6	A-3	Priority 3 Action - with adaptive management and monitoring
Juvenile Rearing/ Migration	Lack of fitness/ genetic maladaptation - Hatchery Introgression	3	3	6	A-3	Priority 3 Action - with adaptive management and monitoring
Juvenile Rearing/ Migration	Lack of suitable migratory conditions - Depth	3	3	6	A-3	Priority 3 Action - with adaptive management and monitoring
Juvenile Rearing/ Migration	Lack of suitable over-summering habitat - Contaminants/ Toxins	3	3	6	A-3	Priority 3 Action - with adaptive management and monitoring
Juvenile Rearing/ Migration	Lack of Suitable Rearing Habitat - Cover	3	3	6	A-3	Priority 3 Action - with adaptive management and monitoring
Juvenile Rearing/ Migration	Lack of Suitable Rearing Habitat - Depth	3	3	6	A-3	Priority 3 Action - with adaptive management and monitoring
Juvenile Rearing/ Migration	Lack of suitable over-summering habitat - Temp	3	3	6	A-3	Priority 3 Action - with adaptive management and monitoring
Juvenile Rearing/ Migration	Lack of suitable migratory conditions - Contaminants/ Toxins	2	3	5	A-4	Priority 4 Action - with adaptive management and monitoring

Appendix D
Long-term Stressor Priorities for Spring-run Chinook Salmon

Life History Stage	Stressor	Score Magnitude	Certainty	Total	Priority	Conservation Measure Type
Juvenile Rearing/ Migration	Lack of suitable migratory cues - Temp	2	3	5	A-4	Priority 4 Action - with adaptive management and monitoring
Adult Migration	Negative Sub-lethal Effects (indirect; e.g., reduced fecundity or mortality via disease) - Attraction Flow	4	2	6	R-1	Priority 1 Research - to inform action design
Adult Migration	Negative Sub-lethal Effects (indirect; e.g., reduced fecundity or mortality via disease) - Temperature	4	2	6	R-1	Priority 1 Research - to inform action design
Adult Spawning	Compression of the Spawning window - Temp	4	2	6	R-1	Priority 1 Research - to inform action design
Juvenile Rearing/ Migration	Lack of suitable migratory conditions - Habitat Distribution	4	2	6	R-1	Priority 1 Research - to inform action design
Adult Holding	Disease	3	2	5	R-2	Priority 2 Research - to inform action design
Adult Holding	Loss of Fecundity - Contaminants	3	2	5	R-2	Priority 2 Research - to inform action design
Adult Holding	Loss of Fecundity - Temp	3	2	5	R-2	Priority 2 Research - to inform action design
Adult Holding	Predator Density	3	2	5	R-2	Priority 2 Research - to inform action design
Adult Migration	Significant Delay and/or Failure to Reach Natal Stream (direct effects) - DO	3	2	5	R-2	Priority 2 Research - to inform action design
Adult Migration	Significant Delay and/or Failure to Reach Natal Stream (direct effects) - Temp	3	2	5	R-2	Priority 2 Research - to inform action design
Adult Migration	Significant Delay and/or Failure to Reach Natal Stream (direct effects) - Attraction flows	3	2	5	R-2	Priority 2 Research - to inform action design
Adult Migration	Negative Sub-lethal Effects (indirect; e.g., reduced fecundity or mortality via disease) - DO	3	2	5	R-2	Priority 2 Research - to inform action design
Adult Spawning	Inadequate availability of high-quality habitat - Contaminants	3	2	5	R-2	Priority 2 Research - to inform action design
Juvenile Rearing/ Migration	Disease	3	2	5	R-2	Priority 2 Research - to inform action design
Juvenile Rearing/ Migration	Lack of suitable migratory conditions - Cover	3	2	5	R-2	Priority 2 Research - to inform action design
Juvenile Rearing/ Migration	Lack of suitable migratory cues - Turbidity	3	2	5	R-2	Priority 2 Research - to inform action design
Adult Holding	Lack of Suitable Habitat - Contaminants	2	2	4	R-3	Priority 3 Research - To inform action design
Adult Holding	Lack of Suitable Habitat - Cover	2	2	4	R-3	Priority 3 Research - To inform action design
Adult Holding	Lack of Suitable Habitat - DO	2	2	4	R-3	Priority 3 Research - To inform action design
Adult Holding	Poaching	2	2	4	R-3	Priority 3 Research - To inform action design
Egg Development	Inadequate Egg Development Conditions - Pesticides	2	2	4	R-3	Priority 3 Research - To inform action design
Juvenile Rearing/ Migration	Lack of suitable migratory conditions - Turbidity	2	2	4	R-3	Priority 3 Research - To inform action design
Juvenile Rearing/ Migration	Lack of suitable over-summering habitat - Velocity	2	2	4	R-3	Priority 3 Research - To inform action design
Juvenile Rearing/ Migration	Lack of Suitable Rearing Habitat - Turbidity	2	2	4	R-3	Priority 3 Research - To inform action design
Juvenile Rearing/ Migration	Predator Density	3	1	4	R-3	Priority 3 Research - To inform action design
Adult Migration	Negative Sub-lethal Effects (indirect; e.g., reduced fecundity or mortality via disease) - Contaminants/ Toxins	2	1	3	R-4	Priority 4 Research - to evaluate need for action
Adult Migration	Negative Sub-lethal Effects (indirect; e.g., reduced fecundity or mortality via disease) - Passable physical barriers (including low water)	2	1	3	R-4	Priority 4 Research - to evaluate need for action
Adult Migration	Significant Delay and/or Failure to Reach Natal Stream (direct effects) - Contaminants/ Toxins	2	1	3	R-4	Priority 4 Research - to evaluate need for action
Adult Migration	Significant Delay and/or Failure to Reach Natal Stream (direct effects) - Poaching	2	1	3	R-4	Priority 4 Research - to evaluate need for action

Appendix D
Long-term Stressor Priorities for Spring-run Chinook Salmon

Life History Stage	Stressor	Score Magnitude	Certainty	Total	Priority	Conservation Measure Type
Adult Spawning	Compression of the Spawning window - DO	2	1	3	R-4	Priority 4 Research - to evaluate need for action
Adult Spawning	Inadequate availability of high-quality habitat -DO	2	1	3	R-4	Priority 4 Research - to evaluate need for action
Egg Development	Inadequate Egg Development Conditions - Fine Sediments	2	1	3	R-4	Priority 4 Research - to evaluate need for action
Egg Development	Inadequate Egg Development Conditions - Flow Fluctuation, Redd Scour	2	1	3	R-4	Priority 4 Research - to evaluate need for action
Juvenile Rearing/ Migration	Lack of suitable migratory conditions - Prey Density	2	1	3	R-4	Priority 4 Research - to evaluate need for action
Juvenile Rearing/ Migration	Lack of suitable over-summering habitat - Cover	2	1	3	R-4	Priority 4 Research - to evaluate need for action
Juvenile Rearing/ Migration	Lack of Suitable Rearing Habitat - Prey Density	2	1	3	R-4	Priority 4 Research - to evaluate need for action
Adult Holding	Lack of Suitable Habitat - Depth	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Adult Holding	Lack of Suitable Habitat - Velocity	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Adult Holding	Loss of Fecundity - Depth	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Adult Holding	Loss of Fecundity - DO	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Adult Holding	Loss of Fecundity - Velocity	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Adult Spawning	Disease	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Adult Spawning	Inadequate availability of high-quality habitat - Cover	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Adult Spawning	Inadequate availability of high-quality habitat - Depth	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Adult Spawning	Inadequate availability of high-quality habitat - Velocity	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Adult Spawning	Poaching	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Adult Spawning	Predator Density	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Juvenile Rearing/ Migration	Compression of the Rearing and Migration Window - DO	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Juvenile Rearing/ Migration	Lack of suitable migratory conditions - DO	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Juvenile Rearing/ Migration	Lack of Suitable Rearing Habitat - DO	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Juvenile Rearing/ Migration	Lack of suitable migratory cues - DO	1	1	2	R-5	Priority 5 Research - to understand magnitude
Juvenile Rearing/ Migration	Lack of suitable over-summering habitat - Depth	1	1	2	R-5	Priority 5 Research - to understand magnitude
Juvenile Rearing/ Migration	Lack of suitable over-summering habitat - Turbidity	1	1	2	R-5	Priority 5 Research - to understand magnitude
Adult Holding	Coarse Sediment Input	1	3	4	T-1	Priority 1 Monitoring (General/ Baseline) - to track magnitude/ ensure no action is warranted
Egg Development	Inadequate Egg Development Conditions - Flow Fluctuation, Redd Dewatering	1	3	4	T-1	Priority 1 Monitoring (General/ Baseline) - to track magnitude/ ensure no action is warranted
Juvenile Rearing/ Migration	Lack of suitable over-summering habitat - DO	1	3	4	T-1	Priority 1 Monitoring (General/ Baseline) - to track magnitude/ ensure no action is warranted
Egg Development	Inadequate Egg Development Conditions - Contaminants/ Toxins	1	4	5	T-2	Priority 2 Monitoring (General/ Baseline) -to track magnitude
Egg Development	Inadequate Egg Development Conditions - DO	1	4	5	T-2	Priority 2 Monitoring (General/ Baseline) -to track magnitude

Appendix D
Long-term Stressor Priorities for *O. mykiss*

O. mykiss **- Stressor Response Prioritization (Long-term, Coarse Scale)**

Life History Stage	Stressor	Score Mag	Cert	Total	Priority	Conservation Measure Type
Adult Holding	Lack of Suitable Habitat - Multiple Factors	4	4	8	A-1	Priority 1 Action - and associated monitoring
Egg Development	Inadequate Egg Development Conditions - Multiple Factors	4	4	8	A-1	Priority 1 Action - and associated monitoring
Juvenile Rearing/ Migration	Lack of Suitable Rearing Habitat - Multiple Factors	4	4	8	A-1	Priority 1 Action - and associated monitoring
Juvenile Rearing/ Migration	Lack of suitable migratory conditions - Multiple Factors	4	4	8	A-1	Priority 1 Action - and associated monitoring
Juvenile Rearing/ Migration	Lack of suitable migratory cues - Multiple Factors	4	3	7	A-2	Priority 2 Action - with adaptive management and monitoring
Adult Spawning	Inadequate availability of high-quality habitat - Multiple Factors	3	2	5	R-2	Priority 2 Research - to inform action design
Adult Migration	Negative Sub-lethal Effects (indirect, e.g., reduced fecundity or mortality via disease) - Multiple Factors	3	1	4	R-3	Priority 3 Research - To inform action design
Adult Spawning	Compression of the Spawning window - Multiple Factors	3	1	4	R-3	Priority 3 Research - To inform action design
Juvenile Rearing/ Migration	Compression of the Rearing and Migration Window - Multiple Factors	2	2	4	R-3	Priority 3 Research - To inform action design
Adult Migration	Significant Delay and/or Failure to Reach Natal Stream (direct effects) - Multiple Factors	2	1	3	R-4	Priority 4 Research - to evaluate need for action
Juvenile Rearing/ Migration	Lack of suitable over-summering habitat - Multiple Factors	1	4	5	T-2	Priority 2 Monitoring (General/ Baseline) -to track magnitude

O. mykiss **- Stressor Response Prioritization (Long-term, Fine Scale)**

Life History Stage	Stressor	Score Mag	Cert	Total	Priority	Conservation Measure Type
Adult Holding	Lack of Suitable Habitat - Temperature	4	4	8	A-1	Priority 1 Action - and associated monitoring
Egg Development	Inadequate Egg Development Conditions - Temp	4	4	8	A-1	Priority 1 Action - and associated monitoring
Juvenile Rearing/ Migration	Lack of Suitable Rearing Habitat - Velocity	4	4	8	A-1	Priority 1 Action - and associated monitoring
Juvenile Rearing/ Migration	Coarse Sediment Input	4	4	8	A-1	Priority 1 Action - and associated monitoring
Juvenile Rearing/ Migration	Lack of suitable migratory conditions - Velocity	4	4	8	A-1	Priority 1 Action - and associated monitoring
Juvenile Rearing/ Migration	Lack of Suitable Rearing Habitat - Contaminants/ Toxins	4	3	7	A-2	Priority 2 Action - with adaptive management and monitoring
Juvenile Rearing/ Migration	Lack of suitable migratory cues - Velocity	4	3	7	A-2	Priority 2 Action - with adaptive management and monitoring
Adult Holding	Coarse Sediment Input	3	3	6	A-3	Priority 3 Action - with adaptive management and monitoring
Adult Spawning	Coarse Sediment Input	3	3	6	A-3	Priority 3 Action - with adaptive management and monitoring
Juvenile Rearing/ Migration	Lack of Suitable Rearing Habitat - Depth	3	3	6	A-3	Priority 3 Action - with adaptive management and monitoring
Juvenile Rearing/ Migration	Lack of Suitable Rearing Habitat - Cover	3	3	6	A-3	Priority 3 Action - with adaptive management and monitoring
Juvenile Rearing/ Migration	Lack of suitable migratory conditions - Depth	3	3	6	A-3	Priority 3 Action - with adaptive management and monitoring
Juvenile Rearing/ Migration	Lack of suitable over-summering habitat - Contaminants/ Toxins	3	3	6	A-3	Priority 3 Action - with adaptive management and monitoring
Juvenile Rearing/ Migration	Lack of suitable migratory conditions- Temp	2	4	6	A-3	Priority 3 Action - with associated Monitoring
Juvenile Rearing/ Migration	Lack of Suitable Rearing Habitat - Temp	2	4	6	A-3	Priority 3 Action - with associated Monitoring
Adult Spawning	Inadequate availability of high-quality habitat -DO	2	3	5	A-4	Priority 4 Action - with adaptive management and monitoring
Juvenile Rearing/ Migration	Lack of suitable migratory conditions - Contaminants/ Toxins	2	3	5	A-4	Priority 4 Action - with adaptive management and monitoring
Juvenile Rearing/ Migration	Lack of suitable migratory cues - Temp	4	2	6	R-1	Priority 1 Research - to inform action design
Adult Holding	Lack of Suitable Habitat - Contaminants	3	2	5	R-2	Priority 2 Research - to inform action design
Adult Spawning	Inadequate availability of high-quality habitat - Temp	3	2	5	R-2	Priority 2 Research - to inform action design
Adult Spawning	Inadequate availability of high-quality habitat - Contaminants	3	2	5	R-2	Priority 2 Research - to inform action design
Adult Spawning	Inadequate availability of high-quality habitat - Spatial Distribution	3	2	5	R-2	Priority 2 Research - to inform action design
Adult Spawning	Interactions with hatchery fish and other runs - Hatchery	3	2	5	R-2	Priority 2 Research - to inform action design
Juvenile Rearing/ Migration	Predator Density	3	2	5	R-2	Priority 2 Research - to inform action design

Appendix D
Long-term Stressor Priorities for *O. mykiss*

Life History Stage	Stressor	Score Mag	Cert	Total	Priority	Conservation Measure Type
Juvenile Rearing/ Migration	Disease	3	2	5	R-2	Priority 2 Research - to inform action design
Juvenile Rearing/ Migration	Lack of suitable migratory conditions - Cover	3	2	5	R-2	Priority 2 Research - to inform action design
Juvenile Rearing/ Migration	Lack of suitable over-summering habitat - Depth	3	2	5	R-2	Priority 2 Research - to inform action design
Adult Holding	Lack of Suitable Habitat - Cover	2	2	4	R-3	Priority 3 Research - To inform action design
Adult Holding	Predator Density	2	2	4	R-3	Priority 3 Research - To inform action design
Adult Holding	Disease	2	2	4	R-3	Priority 3 Research - To inform action design
Adult Holding	Poaching	2	2	4	R-3	Priority 3 Research - To inform action design
Adult Migration	Negative Sub-lethal Effects (indirect; e.g., reduced fecundity or mortality via disease) - Temperature	3	1	4	R-3	Priority 3 Research - To inform action design
Adult Migration	Negative Sub-lethal Effects (indirect; e.g., reduced fecundity or mortality via disease) - Contaminants/ Toxins	3	1	4	R-3	Priority 3 Research - To inform action design
Adult Migration	Negative Sub-lethal Effects (indirect; e.g., reduced fecundity or mortality via disease) - Attraction Flow	3	1	4	R-3	Priority 3 Research - To inform action design
Adult Spawning	Predator Density	2	2	4	R-3	Priority 3 Research - To inform action design
Adult Spawning	Compression of the Spawning window - Temp	3	1	4	R-3	Priority 3 Research - To inform action design
Egg Development	Inadequate Egg Development Conditions - Pesticides	2	2	4	R-3	Priority 3 Research - To inform action design
Juvenile Rearing/ Migration	Compression of the Rearing and Migration Window - Temp	2	2	4	R-3	Priority 3 Research - To inform action design
Juvenile Rearing/ Migration	Compression of the Rearing and Migration Window - DO	2	2	4	R-3	Priority 3 Research - To inform action design
Juvenile Rearing/ Migration	Lack of Suitable Rearing Habitat - Turbidity	2	2	4	R-3	Priority 3 Research - To inform action design
Juvenile Rearing/ Migration	Lack of suitable migratory conditions - Turbidity	2	2	4	R-3	Priority 3 Research - To inform action design
Juvenile Rearing/ Migration	Lack of suitable migratory cues - Turbidity	2	2	4	R-3	Priority 3 Research - To inform action design
Juvenile Rearing/ Migration	Lack of suitable migratory cues - Prey Density	3	1	4	R-3	Priority 3 Research - To inform action design
Juvenile Rearing/ Migration	Lack of fitness/ genetic maladaptation - Hatchery Introgression	3	1	4	R-3	Priority 3 Research - To inform action design
Juvenile Rearing/ Migration	Lack of Suitable Habitat - Prey density	2	2	4	R-3	Priority 3 Research - To inform action design
Adult Migration	Significant Delay and/or Failure to Reach Natal Stream (direct effects) - Temp	2	1	3	R-4	Priority 4 Research - to evaluate need for action
Adult Migration	Significant Delay and/or Failure to Reach Natal Stream (direct effects) - DO	2	1	3	R-4	Priority 4 Research - to evaluate need for action
Adult Migration	Significant Delay and/or Failure to Reach Natal Stream (direct effects) - Attraction flows	2	1	3	R-4	Priority 4 Research - to evaluate need for action
Adult Migration	Negative Sub-lethal Effects (indirect; e.g., reduced fecundity or mortality via disease) - DO	2	1	3	R-4	Priority 4 Research - to evaluate need for action
Adult Spawning	Disease	2	1	3	R-4	Priority 4 Research - to evaluate need for action
Adult Spawning	Compression of the Spawning window - DO	2	1	3	R-4	Priority 4 Research - to evaluate need for action
Egg Development	Inadequate Egg Development Conditions - Fine Sediments	2	1	3	R-4	Priority 4 Research - to evaluate need for action
Egg Development	Inadequate Egg Development Conditions - Flow Fluctuation, Redd Scour	2	1	3	R-4	Priority 4 Research - to evaluate need for action
Juvenile Rearing/ Migration	Lack of Suitable Rearing Habitat - Prey Density	2	1	3	R-4	Priority 4 Research - to evaluate need for action
Juvenile Rearing/ Migration	Lack of suitable migratory conditions - Prey Density	2	1	3	R-4	Priority 4 Research - to evaluate need for action
Juvenile Rearing/ Migration	Lack of suitable over-summering habitat - Cover	2	1	3	R-4	Priority 4 Research - to evaluate need for action
Adult Holding	Lack of Suitable Habitat - DO	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Adult Holding	Lack of Suitable Habitat - Velocity	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Adult Holding	Lack of Suitable Habitat - Depth	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted

Appendix D
Long-term Stressor Priorities for *O. mykiss*

Life History Stage	Stressor	Score Mag	Cert	Total	Priority	Conservation Measure Type
Adult Spawning	Inadequate availability of high-quality habitat - Velocity	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Adult Spawning	Inadequate availability of high-quality habitat - Depth	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Adult Spawning	Inadequate availability of high-quality habitat - Cover	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Adult Spawning	Poaching	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Juvenile Rearing/ Migration	Lack of Suitable Rearing Habitat - DO	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Juvenile Rearing/ Migration	Lack of suitable migratory conditions - DO	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Juvenile Rearing/ Migration	Lack of suitable over-summering habitat - Velocity	1	2	3	R-5	Priority 5 Research - to confirm that action is not warranted
Adult Migration	Significant Delay and/or Failure to Reach Natal Stream (direct effects) - Contaminants/ Toxins	1	1	2	R-5	Priority 5 Research - to understand magnitude
Adult Migration	Significant Delay and/or Failure to Reach Natal Stream (direct effects) - Poaching	1	1	2	R-5	Priority 5 Research - to understand magnitude
Juvenile Rearing/ Migration	Lack of suitable migratory cues - DO	1	1	2	R-5	Priority 5 Research - to understand magnitude
Juvenile Rearing/ Migration	Lack of suitable over-summering habitat - DO	1	1	2	R-5	Priority 5 Research - to understand magnitude
Juvenile Rearing/ Migration	Lack of suitable over-summering habitat - Turbidity	1	1	2	R-5	Priority 5 Research - to understand magnitude
Adult Migration	Negative Sub-lethal Effects (indirect; e.g., reduced fecundity or mortality via disease) - Passable physical barriers (including low water)	1	3	4	T-1	Priority 1 Monitoring (General/ Baseline) - to track magnitude/ ensure no action is warranted
Egg Development	Inadequate Egg Development Conditions - Flow Fluctuation, Redd Dewatering	1	3	4	T-1	Priority 1 Monitoring (General/ Baseline) - to track magnitude/ ensure no action is warranted
Egg Development	Inadequate Egg Development Conditions - DO	1	4	5	T-2	Priority 2 Monitoring (General/ Baseline) -to track magnitude
Egg Development	Inadequate Egg Development Conditions - Contaminants/ Toxins	1	4	5	T-2	Priority 2 Monitoring (General/ Baseline) -to track magnitude
Juvenile Rearing/ Migration	Lack of suitable over-summering habitat - Temp	1	4	5	T-2	Priority 2 Monitoring (General/ Baseline) -to track magnitude