



— BUREAU OF —
RECLAMATION

Long-Term Operation

Appendix M – Folsom Reservoir Flow and Temperature Management

Central Valley Project, California

Interior Region 10 – California-Great Basin

Mission Statements

The U.S. Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; honors its trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated Island Communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Contents

	Page
Tables	iii
Figures.....	iii
1. Introduction	4
2. Initial Alternatives Report	6
2.1 Management Questions	6
2.2 Initial Analyses.....	6
2.3 Initial Findings	7
3. Public Draft EIS Scenarios	8
3.1 Run of River.....	8
3.2 No Action.....	8
3.3 Alternative 1 – WQCPs	8
3.4 Alternative 2 – Multi-Agency Consensus.....	8
3.5 Alternative 3 – Modified Natural Hydrograph	8
3.6 Alternative 4 – Reservoir Flexibility	8
4. Performance Metrics.....	10
4.1 Biological.....	10
4.2 Water Supply	10
4.3 NEPA Resources.....	10
5. Methods	12
5.1 Datasets.....	12
5.2 Literature.....	13
5.3 Models.....	29
5.3.1 Water Operations	29
5.3.2 Temperature	29

6.	Lines of Evidence	30
6.1	Habitat Suitability	30
6.2	Temperature and Storage Levels	30
6.3	Storage Planning Minimum and Coldwater Bypasses.....	32
6.4	Planning Minimum and Water Supply Intakes in Folsom Reservoir	33
6.5	50% exceedance forecast early in the water year	33
6.6	Effects of Releases on the American River to Shasta Reservoir, the Bay-Delta Water Quality Control Plan, and exports.....	33
6.7	Historic Steelhead Redd Dewatering	33
6.8	Historic Steelhead Juvenile Stranding	33
7.	Uncertainty	36
8.	References	38

Tables

Table 1. Juvenile Salmonid Stranding Survey Results in the American River 34

Figures

Figure 1. Degree Days above the Temperature Target as a function of Folsom End-of-April
Storage 31

Figure 2. Degree Days above the Temperature Target as a Function of Folsom September
Carryover Storage 31

1. Introduction

Folsom Reservoir flow and temperature management address the tradeoffs for minimum releases and the use of available cold water pool in Folsom Reservoir for water supply, power production and steelhead and fall-run Chinook salmon in the American River.

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2. Initial Alternatives Report

An Initial Alternative Report (*LTO 2021 Consultation Initial Alternatives Appendix M – Folsom Reservoir Flow and Temperature Management 20220127 DRAFT*) developed potential options for the long-term operation (LTO) of the Central Valley Project (CVP) and State Water Project (SWP) to inform alternative formulation by seeking the bounds of potential decisions and a contrast between approaches. Initial alternative options generally considered flow actions, non-flow actions, and the use of real-time information. Management questions, analyses, and findings provided information for public draft Environmental Impact Statement (EIS) alternatives.

2.1 Management Questions

United States Department of the Interior, Bureau of Reclamation’s (Reclamation) management questions to inform the formulation of alternatives included:

- What habitat is created for steelhead and fall-run Chinook salmon at different releases?
- What is the additional water temperature capability at different storage levels?
- How does planning minimum storage for both the end of September and the end of December improve potential cold water habitat?
- What planning-minimum reservoir storage maintains water supply intakes in Folsom Reservoir?
- What risks occur from operating to a 50% exceedance forecast early in the water year?
- What water temperature targets reasonably protect steelhead, while leaving sufficient cold water for fall-run Chinook salmon?
- How do releases on the American River affect Shasta Reservoir, the *Bay-Delta Water Quality Control Plan* (Bay-Delta WQCP), and exports?

2.2 Initial Analyses

Reclamation completed a literature and data review regarding Folsom operations related to redd dewatering and stranding.

2.3 Initial Findings

Folsom Reservoir flow and temperature management address the tradeoffs for minimum releases and the use of the available cold water pool for water supply and steelhead and fall-run Chinook salmon in the American River. The alternatives analyzed and compared the effects of American River operations in the No Action Alternative to Alternative 1, Alternative 2, and Alternative 3. The CalSim II and HEC-5Q models were used to conduct the analysis for the flows and temperature elements of cold water pool management for Folsom Reservoir. Assumptions were made based on criteria for the current Folsom Reservoir flow and temperature conditions, regulatory requirements and projection for future conditions.

The Alternatives for Folsom flow and temperature management focus on analyzing changes to the Modified Flow Management Standard (MFMS) by adjusting the end-of-December carryover target and the MFMS Minimum Required Release.

3. Public Draft EIS Scenarios

Under the National Environmental Policy Act, Reclamation compares action alternatives to a “no action” alternative. Under the Endangered Species Act, Reclamation’s discretionary actions over an environmental baseline determine the effects on listed species.

3.1 Run of River

[Placeholder]

3.2 No Action

[Placeholder]

3.3 Alternative 1 – WQCPs

[Placeholder]

3.4 Alternative 2 – Multi-Agency Consensus

[Placeholder]

3.5 Alternative 3 – Modified Natural Hydrograph

[Placeholder]

3.6 Alternative 4 – Reservoir Flexibility

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4. Performance Metrics

Performance metrics describe criteria that can be measured, estimated, or calculated relevant to informing trade-offs for alternative management actions.

4.1 Biological

Biological metrics consider direct observations and environmental surrogates.

- Days of 65 degrees Fahrenheit (°F) or lower water temperature at Watt Avenue, starting from May through September for steelhead juveniles
- Days of 56° or lower water temperature at Watt Avenue starting from mid-October through December for fall-run Chinook salmon spawning
- Juvenile survival probability downstream of Watt Avenue
- Juvenile survival probability to Chipps Island
- Redd dewatering numbers

4.2 Water Supply

Water supply metrics consider the multipurpose beneficial uses of Folsom Reservoir.

- North-of-Delta agricultural deliveries (average and critical/dry years)
- South-of-Delta agricultural deliveries (average and critical/dry years)
- State Water Resources Control Board Water Right Decision 1641 (D-1641) standards
- Flood conservation pool releases (“spills”)

CalSim II would support the evaluation of water supply metrics.

4.3 NEPA Resources

Analysis of the range of alternatives, as required by the National Environmental Policy Act, is anticipated to describe changes in multiple resource areas. Key resources are anticipated to include surface water supply, water quality, power, aquatic resources, terrestrial biological resources, regional economics, land use and agricultural resources, recreation, cultural resources, socioeconomics, environmental justice, and climate change.

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5. Methods

Reclamation solicited input from the stakeholders and agencies for the knowledge base paper focused on steelhead biology and life-history expression (Steelhead Juvenile Production Estimate). Reclamation identified the following datasets, literature, and models to help in evaluating Folsom reservoir flow and temperature management.

5.1 Datasets

Several efforts to characterize historical and ongoing steelhead monitoring programs in the California Central Valley have been completed over the past two decades. A few years after the completion of the Central Valley Steelhead Monitoring Plan, a series of related monitoring projects, identified as the Central Valley Steelhead Monitoring Program (CVSMP), were initiated on the Sacramento River and its tributaries (Fortier et al. 2014).

Annual American River steelhead spawning survey reports completed mostly annually since 2002.

Annual American River Chinook salmon escapement survey reports

CalFish (2019). CalFish – A California cooperative anadromous fish and habitat data program. Middle Sacramento River salmon and Steelhead monitoring. Available: <https://www.calfish.org/ProgramsData/ConservationandManagement/CentralValleyMonitoring/SacramentoValleyTributaryMonitoring/MiddleSacramentoRiverSalmonandSteelheadMonitoring.a.spx>.

SacPAS: Central Valley Prediction & Assessment of Salmon provides a platform for data queries of juvenile steelhead salvage and loss. Available: http://www.cbr.washington.edu/sacramento/data/juv_salvage_loss.html.

Use CalFishTrack to understand juvenile steelhead routing and survival into the Delta. <https://oceanview.pfeg.noaa.gov/CalFishTrack/>

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Use CalFishTrack to understand juvenile steelhead routing and survival into the Delta. <https://oceanview.pfeg.noaa.gov/CalFishTrack/>

<https://www.waterforum.org/habitat2022/>

<https://www.waterforum.org/the-river/habitat-management/>

https://www.waterforum.org/wp-content/uploads/2020/09/18-1027_LAR_Salmonid_Rearing_Site_ID_Report_FINAL_2020-08-31.pdf

5.2 Literature

The documents listed below were compiled from the 2019 Biological Opinions, 2020 ITP, fact sheets produced for the February 2021 joint Delta Science Program – U.S. Bureau of Reclamation Steelhead Workshop, and a Google Scholar search.

- Abadía-Cardoso, A., A. J. Clemento, and J. C. Garza. 2011. Discovery and characterization of single- nucleotide polymorphisms in steelhead/rainbow trout, *Oncorhynchus mykiss*. *Molecular Ecology Resources* 11:31–49.
- Adams, B. L., W. S. Zaugg, and L. R. McLain. 1975. Inhibition of Salt Water Survival and Na-KATPase Elevation in Steelhead Trout (*Salmo gairdneri*) by Moderate Water Temperatures. *Transactions of the American Fisheries Society* 104(4):766–769.
- Alston, N. O., J. M. Newton, and M. R. Brown. 2007. Monitoring adult Chinook salmon, rainbow trout, and steelhead in Battle Creek, California, from November 2003 through November 2004. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Beakes, M. P., W. H. Satterthwaite, E. M. Collins, D. R. Swank, J. E. Merz, R.G. Titus, S.M. Sogard, and M. Mangel, 2010. Smolt transformation in two California steelhead populations: effects of temporal variability in growth. *Transactions of the American Fisheries Society* 139(5) 1263–1275.
- Beakes, M. P., J. W. Moore, S. A. Hayes, and S. M. Sogard. 2014. Wildfire and the effects of shifting stream temperature on salmonids. *Ecosphere* 5(5):1–14.
- Beakes, M. P., S. Sharron, R. Charish, J. W. Moore, W. H. Satterthwaite, E. Sturm, B. K. Wells, S. M. Sogard, and M. Mange. 2014. Using scale characteristics and water temperature to reconstruct growth rates of juvenile steelhead *Oncorhynchus mykiss*. *Journal of Fish Biology* 84(1):58–72.
- Beakes, M., R. Bilski, B. Mattias, B. Byrne, P. Vick, and P. Goertler. 2021. *Oncorhynchus mykiss* Monitoring and Research Gap Analysis. In Monitoring Steelhead Populations in the San Joaquin Basin. Edited by Delta Science Program - Delta Stewardship Council, Joint Delta Science Program – U.S. Bureau of Reclamation Workshop, Sacramento, CA. DOI: 10.13140/RG.2.2.29383.21927 (<https://deltacouncil.ca.gov/pdf/science-program/factsheets/2021-02-03-monitoring-steelhead-populations-monitoring-and-research-gap-analysis.pdf>)
- Beakes, M., and C. Phillis. 2021. Life-History Variation in *Oncorhynchus mykiss*. In Monitoring Steelhead Populations in the San Joaquin Basin. Edited by Delta Science Program - Delta Stewardship Council, Joint Delta Science Program – U.S. Bureau of Reclamation Workshop, Sacramento, CA. DOI: 10.13140/RG.2.2.15438.79685 (<https://deltacouncil.ca.gov/pdf/science-program/fact-sheets/2021-02-04-monitoringsteelhead-populations-life-history-variation.pdf>).

- Beakes, M., and C. Phillis. 2021. Life-History Variation in *Oncorhynchus mykiss*. In Monitoring Steelhead Populations in the San Joaquin Basin. Edited by Delta Science Program - Delta Stewardship Council, Joint Delta Science Program – U.S. Bureau of Reclamation Workshop, Sacramento, CA. DOI: 10.13140/RG.2.2.15438.79685 (<https://deltacouncil.ca.gov/pdf/science-program/fact-sheets/2021-02-04-monitoringsteelhead-populations-life-history-variation.pdf>).
- Berejikian, B. A., L. A. Campbell, and M. E. Moore. 2013. Large-scale freshwater habitat features influence the degree of anadromy in eight Hood Canal *Oncorhynchus mykiss* populations. *Canadian Journal of Fisheries and Aquatic Sciences* 70(5):756–765.
- Bjornn, T. C. 1978. Survival, production, and yield of trout and chinook salmon in the Lemhi River, Idaho A Final Report for Federal Aid to Fish Restoration, Project F-49-R, Salmon and Steelhead Investigations. Idaho Cooperative Fishery Research Unit.
- Boughton, D. A., and A. S. Pike. 2013. Floodplain rehabilitation as a hedge against hydroclimatic uncertainty in a migration corridor of threatened steelhead. *Conservation Biology* 27(6):1158–1168.
- Bottaro, R. J., L. A. Earley, and M. R. Brown. 2012. Monitoring adult Chinook salmon, rainbow trout, and steelhead in Battle Creek, California, from March through November 2010. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Bottaro, R. J., and M. R. Brown. 2012. Monitoring adult Chinook salmon, rainbow trout, and steelhead in Battle Creek, California, from March through November 2011. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Bottaro, R. J., L. A. Earley, and M. R. Brown. 2013. Monitoring adult Chinook salmon, rainbow trout, and steelhead in Battle Creek, California, from March through November 2012. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Bottaro, R. J., L. A. Earley, and M. R. Brown. 2014. Monitoring adult Chinook Salmon, Rainbow Trout, and Steelhead in Battle Creek, California, from March through November 2013. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Bottaro, R. J., and M. R. Brown. 2018. Monitoring adult Chinook Salmon, Rainbow Trout, and Steelhead in Battle Creek, California, from March through November 2014. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Bottaro, R. J., and M. R. Brown. 2018. Monitoring adult Chinook Salmon, Rainbow Trout, and Steelhead in Battle Creek, California, from March through November 2015. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.

- Bottaro, R. J., and L. A. Earley. 2018. Monitoring Adult Chinook Salmon, Rainbow Trout, and Steelhead in Battle Creek, California, from March through November 2016. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Bottaro, R. J., and L. A. Earley. 2019. Monitoring adult Chinook Salmon, Rainbow Trout, and Steelhead in Battle Creek, California, from March through November 2017. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Bottaro, R. J., and L. A. Earley. 2020. Monitoring adult Chinook Salmon, Rainbow Trout, and Steelhead in Battle Creek, California, from March through November 2018. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Brown, M. R. 1996. Benefits of Increased Minimum Instream Flows on Chinook Salmon and Steelhead in Clear Creek, Shasta County, California 1995-6, USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Brown, M. R., and J. M. Newton. 2002. Monitoring adult Chinook salmon, rainbow trout, and steelhead in Battle Creek, California, from March through October 2001. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Brown, M. R., N. O. Alston, and J. M. Newton. 2005. Monitoring adult Chinook salmon, rainbow trout, and steelhead in Battle Creek, California, from March through November 2002. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Brown, M. R., and N. O. Alston. 2007. Monitoring adult Chinook salmon, rainbow trout, and steelhead in Battle Creek, California, from November 2002 through November 2003. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Buchanan, R. A., E. Buttermore, and J. Israel. 2021. Outmigration survival of a threatened steelhead population through a tidal estuary. *Canadian Journal of Fisheries and Aquatic Sciences* 78(12):1869–1886.
- Cada, G. F., M. D. Deacon, S. V. Mitz, and M. S. Bevelhimer. 1997. Effects of water velocity on the survival of downstream-migrating juvenile salmon and steelhead: A review with emphasis on the Columbia River basin. *Reviews in Fisheries Science* 5(2):131–183.
- California Department of Water Resources. 2008. Quantification of Pre-Screen Loss of Juvenile Steelhead within Clifton Court Forebay. Page 136. Fishery Improvements Section, editor.
- California Department of Fish and Wildlife. 2016. Memorandum to Amanda Cranford, National Marine Fisheries Service from Rob Titus, California Department of Fish and Wildlife, Trends in Central Valley Steelhead Harvest. Page 3. California Department of Fish and Wildlife, editor.

- California Department of Water Resources. 2018. Effects of the South Delta Agricultural Barriers on Emigrating Juvenile Salmonids. Page 244. California Department of Water Resources, editor, Sacramento, CA.
- Carlson, S. M., and T. R. Seamons. 2008. A review of quantitative genetic components of fitness in salmonids: implications for adaptation to future change. *Evolutionary Applications* 1(2):222–238.
- Carter, K. 2005. The Effects of Dissolved Oxygen on Steelhead Trout, Coho Salmon, and Chinook Salmon Biology and Function by Life Stage. Page 10. California Regional Water Quality Control Board, editor, North Coast Region.
- Cech Jr, J., and C. A. Myrick. 1999. Steelhead and Chinook Salmon Bioenergetics: Temperature, Ration, and Genetic Effects. University of California, Davis.
- Chapman, E. D., Hearn, A.R., Singer, G.P., Brostoff, W.N., LaCivita, P.E. and A.P. Klimley. 2015. Movements of steelhead (*Oncorhynchus mykiss*) smolts migrating through the San Francisco Bay Estuary. *Environmental Biology of Fishes* 98(4):1069–1080.
- Chapman, E. P., Hearn, A.R., Michel, C.J., Ammann, A.J., Lindley, S.T., Thomas, M.J., Sandstrom, P.T., Singer, G.P., Peterson, M.L., MacFarlane, R.B. and A.P. Klimley. 2013. Diel movements of Out-migrating Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead trout (*Oncorhynchus mykiss*) smolts in the Sacramento/San Joaquin watershed. *Environmental Biology of Fishes* 96:273–286.
- Clark, K. W., M. D. Bowen, R. B. Mayfield, K. P. Zehfuss, J. D. Taplin, and C. H. Hanson. 2009. Quantification of pre-screen loss of juvenile steelhead in Clifton Court Forebay. California Department of Water Resources, Bay-Delta Office, Fishery Improvements Section, Sacramento, CA. March 2009.
- Colby, D. J., and M. R. Brown. 2012. Juvenile salmonid monitoring in Battle Creek, California, November 2010 through June 2011. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Courter, I., C. Justice, and S. Cramer. 2009. Flow and temperature effects on life history diversity of *Oncorhynchus mykiss* in the Yakima River basin. Cramer Fish Sciences, Gresham, Oregon.
- Courter, I. I., Courter, L., Garrison, T., Cramer, D., Duery, S., Child, D., Hanna, T. and E. Buckner. 2012. Effects of the Aquatic Herbicide Cascade on survival of Salmon and Steelhead Smolts during Seawater transition.
- Earley, J. T., D. J. Colby, and M. R. Brown. 2008. Juvenile salmonid monitoring in Clear Creek, California, from July 2002 through September 2003. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California

- Earley, J. T., D. J. Colby, and M. R. Brown. 2008. Juvenile salmonid monitoring in Clear Creek, California, from July 2002 through September 2003. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Earley J.T., D.J. Colby, and M.R. Brown. 2008. Juvenile Salmonid Monitoring in Clear Creek, California, from October 2003 through September 2004. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Earley, J. T., D. J. Colby, and M.R. Brown. 2008. Juvenile salmonid monitoring in Clear Creek, California, from October 2006 through September 2007. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Earley, J. T., D. J. Colby, and M. R. Brown. 2009. Juvenile salmonid monitoring in Clear Creek, California, from October 2007 through September 2008. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Earley, J. T., D. J. Colby, and M. R. Brown. 2010. Juvenile salmonid monitoring in Clear Creek, California, from October 2008 through September 2009. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Earley, J. T., D. J. Colby, and M. R. Brown. 2013. Juvenile salmonid monitoring in Clear Creek, California, from October 2009 through September 2010. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Earley, J. T., D. J. Colby, and M. R. Brown. 2013. Juvenile salmonid monitoring in Clear Creek, California, from October 2010 through September 2011. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Ebersole, J. L., W. J. Liss, and C. A. Frissell. 2001. Relationship between stream temperature, thermal refugia and rainbow trout *Oncorhynchus mykiss* abundance in arid-land streams in the northwestern United States. *Ecology of Freshwater Fish* 10:1–10.
- Eilers, C. D. 2010. Review of present steelhead monitoring programs in the California Central Valley May 2008. Fisheries Branch Administrative Report Number: 2010-1
- Ellrott, B., H. Brown, and R. Johnson. California Central Valley Steelhead Distinct Population Segment. In Monitoring Steelhead Populations in the San Joaquin Basin. Edited by Delta Science Program - Delta Stewardship Council, Joint Delta Science Program – U.S. Bureau of Reclamation Workshop, Sacramento, CA. DOI: 10.13140/RG.2.2.30997.04329 (<https://deltacouncil.ca.gov/pdf/science-program/fact-sheets/2021-02-04-california-central-valley-steelhead-distinct-population-segment-factsheet.pdf>)
- Eschenroeder, J. C., M. L. Peterson, M. Hellmair, T. J. Pilger, D. Demko, and A. Fuller. 2022. Counting the Parts to Understand the Whole: Rethinking Monitoring of Steelhead in California’s Central Valley. *San Francisco Estuary and Watershed Science* 20(1).

- Fortier, R., J. Nelson, R. Bellmer, and R. Nielson. 2014. Implementation Plan for the Central Valley Steelhead Monitoring Program. California Department of Fish and Wildlife, Fisheries Branch. July 2014.
- Gaines, P. D., and C.D. Martin. 2001. Abundance and seasonal, spatial and diel distribution patterns of juvenile salmonids passing the Red Bluff Diversion Dam, Sacramento River. Red Bluff Research Pumping Plant Report Series, Volume 14. U.S. Fish and Wildlife Service, Red Bluff, CA.
- Gaines, P. D., R. E. Null and M. R. Brown. 2003. Estimating the abundance of Clear Creek juvenile chinook salmon and steelhead trout by use of a rotary-screw trap. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office. Progress Report (Vol.1), February 2003.
- Giovannetti, S. L., M. R. Brown. 2007. Central Valley Steelhead and Late Fall Chinook Salmon Redd Surveys on Clear Creek, California 2007. U.S. Fish and Wildlife Service, Red Bluff, CA.
- Giovannetti, S. L., M. R. Brown. 2008. Steelhead and Late-fall Chinook Salmon Redd Surveys on Clear Creek, California 2008 Annual Report. U.S. Fish and Wildlife Service, Red Bluff, CA.
- Giovannetti, S.L., M. R. Brown. 2009. Adult Steelhead and Late-fall Chinook Salmon Monitoring on Clear Creek, California. 2009 Annual Report. U.S. Fish and Wildlife Service, Red Bluff, CA.
- Giovannetti, S. L., R. J. Bottaro, and M. R. Brown. 2013. Adult steelhead and late-fall Chinook salmon Monitoring on Clear Creek, California: 2010 Annual report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Giovannetti, S. L., R. J. Bottaro, and M. R. Brown. 2013. Adult steelhead and late-fall Chinook salmon Monitoring on Clear Creek, California: 2011 Annual report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Good, T. P., R. S. Waples, and P. Adams. 2005. Updated status of federally listed ESUs of West Coast salmon and steelhead. National Oceanic and Atmospheric Administration, National Marine Fisheries Service. NOAA Technical Memorandum NMFS-NWFSC-66. June 2005.
- Greenwald, G. M., J. T. Earley, and M. R. Brown. 2003. Juvenile salmonid monitoring in Clear Creek, California, from July 2001 to July 2002. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Hallock, R. J., D. H. Fry Jr., and D. A. LaFauce. 1957. The Use of Wire Fyke Traps to Estimate the Runs of Adult Salmon and Steelhead in the Sacramento River. *California Fish and Game* 43(4):271-298.

- Hallock, R. J., W. F. Van Woert, and L. Shapovalov. 1961. An Evaluation of Stocking Hatchery-reared Steelhead Rainbow Trout (*Salmo gairdnerii gairdnerii*) in the Sacramento River System. *Fish Bulletin* 114:3–74.
- Hannon, J. 2013. American River Steelhead (*Oncorhynchus mykiss*) Spawning - 2013, with Comparison to Prior Years. Pages 1-32. U.S. Bureau of Reclamation.
- Hannon, J., and B. Deason. 2008. American River Steelhead (*Oncorhynchus mykiss*) Spawning 2001–2007. U.S. Department of the Interior, Bureau of Reclamation, Mid-Pacific Region.
- Hannon, J., M. Healey, and B. Deason. 2003. American River Steelhead (*Oncorhynchus mykiss*) Spawning 2001–2003. Pages 36. U.S. Bureau of Reclamation, and California Department of Fish and Game, Sacramento, California.
- Hayes, S. A., M. H. Bond, C. V. Hanson, A.W. Jones, A. J. Ammann, J. A. Harding, A. L. Collins, J. Perez, and R. B. MacFarlane. 2011. Down, up, down and “smolting” twice? Seasonal movement patterns by juvenile steelhead (*Oncorhynchus mykiss*) in a coastal watershed with a bar closing estuary. *Canadian Journal of Fisheries and Aquatic Sciences* 68(8):1341–1350.
- Hodge, B. W., M. A. Wilzbach, W. G. Duffy, R. M. Quiñones, and J. A. Hobbs. 2016. Life history diversity in Klamath River steelhead. *Transactions of the American Fisheries Society* 145(2): 227–238.
- Hutchings, J. A. 2011. Old wine in new bottles: reaction norms in salmonid fishes. *Heredity* 106(3):421–437.
- IEP. 1999. Monitoring, Assessment, and Research on Central Valley Steelhead: Status of Knowledge, Review of Existing Programs, and Assessment of Needs. Interagency Ecological Program Steelhead Project Work Team.
- Israel, J., H. Brown, and L. Conrad. 2021. Workshop Objectives and Regulatory Background. In Monitoring Steelhead Populations in the San Joaquin Basin. Edited by Delta Science Program - Stewardship Council, Joint Delta Science Program – U.S. Bureau of Reclamation Workshop, Sacramento, CA. DOI: 10.13140/RG.2.2.33390.33606 (<https://deltacouncil.ca.gov/pdf/science-program/fact-sheets/2021-02-03-monitoring-steelhead-populations-workshop-objectives-and-regulatory-background.pdf>)
- Karp, C., B. Wu, and K. Kumagai. 2017. Juvenile Chinook Salmon, Steelhead, and Adult Striped Bass Movements and Facility Efficiency at the Tracy Fish Collection Facility Tracy Technical Bulletin 2017-1. Pages 81
- Keefer, M. L., C. A. Peery, and B. High. 2009. Behavioral thermoregulation and associated mortality trade-offs in migrating adult steelhead (*Oncorhynchus mykiss*): variability among sympatric populations. *Canadian Journal Fisheries Aquatic Science* 66:1734–1747.
- Keeley, E. R. 2001. Demographic responses to food and space competition. *Ecology* 82:1247–1259.

- Kelson, S. J., M. R. Miller, T. Q. Thompson, S. M. O'Rourke, and S. M. Carlson. 2019. Do genomics and sex predict migration in a partially migratory salmonid fish, *Oncorhynchus mykiss*? *Canadian Journal of Fisheries and Aquatic Sciences* 76(11):2080–2088.
- Kelson, S.J., S. M. Carlson, and M. R. Miller. 2020. Indirect genetic control of migration in a salmonid fish. *Biology Letters* 16(8), p.20200299.
- Kendall, N.W., J. R. McMillan, M. R. Sloat, T. W. Buehrens, T. P. Quinn, G. R. Pess, K.V Kuzishchin, M. M. McClure, and R. W. Zabel. 2015. Anadromy and residency in steelhead and rainbow trout (*Oncorhynchus mykiss*): a review of the processes and patterns. *Canadian Journal of Fisheries and Aquatic Sciences* 72(3):319–342.
- Lee, D. P., and J. Chilton. 2007. Hatchery and Genetic Management Plan for Nimbus Fish Hatchery Winter-Run Steelhead Program.
- Lindley, S.T., R. Schick, E. Mora, P.B. Adams, J.J. Anderson, S. Greene, C. Hanson, B.P. May, D.R. McEwan, R.B. MacFarlane, C. Swanson, and J.G. Williams (2007). Framework for assessing viability of threatened and endangered Chinook salmon and steelhead in the Sacramento-San Joaquin Basin. *San Francisco Estuary and Watershed Science* 5(1).
- Louie, S., R. Henery, J. Rosenfield, J. Shelton, J. Zimmerman, M. Gutierrez, B. Ellrott, J. Wikert, J. Howard, T. Heyne, and A. Weber-Stover. 2019. Conservation Planning Foundation for Restoring Chinook Salmon (*Oncorhynchus Tshawytscha*) and *O. mykiss* in the Stanislaus River.
- Lufkin, A., editor. 1991. *California's Salmon and Steelhead: The Struggle to Restore an Imperiled Resource*. Berkeley: University of California Press, Berkeley.
- Mangel, M., and W. H. Satterthwaite. 2008. Combining proximate and ultimate approaches to understand life history variation in salmonids with application to fisheries, conservation, and aquaculture. *Bulletin of Marine Science* 83(1):107–130.
- McEwan, D., and T. A. Jackson. 1996. Steelhead Restoration and Management Plan for California. Pages 1-234.
- McMillan, J., S. L. Katz, and G. R. Pess. 2007. Observational evidence of spatial and temporal structure in a sympatric anadromous (winter steelhead) and resident rainbow trout mating system on the Olympic Peninsula, Washington. *Transactions of the American Fisheries Society* 136(3):736–748.
- McMillan, J. R., J. Dunham, G. H. Reeves, J. S. Mills, and C. E. Jordan. 2012. Individual condition and stream temperature influence early maturation of rainbow and steelhead trout, *Oncorhynchus mykiss*. *Environmental Biology of Fishes* 93:343–355. doi:10.1007/s10641-011-9921-0.
- Miller, M. R., J. P. Brunelli, P. A. Wheeler, S. Liu, C. E. Rexroad III, Y. Palti, C. Q. Doe, and G. H. Thorgaard. 2012. A conserved haplotype controls parallel adaptation in geographically distant salmonid populations. *Molecular Ecology* 21(2):237–249.

- Moyle, P. B. 2002. *Inland Fishes of California*, 2nd edition. Berkeley, CA: University of California Press.
- Moffitt, 2014. Histological assessment of organs in sexually mature and post-spawning steelhead trout and insights into iteroparity. *Rev Fish Biol Fisheries* (2014) 24:781–801.
- Myrick, C., and J. Cech Jr. 2000. Growth and thermal biology of Feather River steelhead under constant and cyclical temperatures. University of California, Davis, Department of Wildlife, Fish, and Conservation Biology.
- Myrick, C. A., and J. J. Cech. 2001. Temperature effects on Chinook salmon and steelhead: a review focusing on California's Central Valley populations. Bay-Delta Modeling Forum.
- Myrick, C. A., and J. J. Cech Jr. 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.
- Narum S. R., D. Hatch, A. J. Talbot, P. Moran, and M. Powell, 2008. Iteroparity in complex mating systems of steelhead *Oncorhynchus mykiss* (Walbaum). *Journal of Fish Biology* 72(1):45–60
- National Marine Fisheries Service. 2011. 5-Year Review: Summary and Evaluation of Central Valley Steelhead Distinct Population Segment.
- National Marine Fisheries Service. 2014. Final recovery plan for the evolutionarily significant units of Sacramento River winter-run Chinook salmon and Central Valley spring-run Chinook salmon and the distinct population segment of California Central Valley steelhead. National Oceanic and Atmospheric Administration, National Marine Fisheries Service. July 2014.
- National Marine Fisheries Service. 2016a. 5-Year Status Review: Summary and Evaluation of California Central Valley Steelhead Distinct Population Segment. Sacramento, California.
- National Marine Fisheries Service. 2016b. 2016 5-Year Review: Summary & Evaluation of Central California Coast Steelhead. West Coast Region.
- Newton, J. M., and M. R. Brown. 2003. Middle Battle Creek reconnaissance survey, 2001. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Newton, J. M., N. O. Alston, and M. R. Brown. 2007. Monitoring adult Chinook salmon, rainbow trout, and steelhead in Battle Creek, California, from November 2004 through November 2005. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.

- Newton, J. M., N. O. Alston, and M. R. Brown. 2007. Monitoring adult Chinook salmon, rainbow trout, and steelhead in Battle Creek, California, from March through November 2006. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Newton, J. M., L. A. Stafford, and M. R. Brown. 2008. Monitoring adult Chinook salmon, rainbow trout, and steelhead in Battle Creek, California, from March through November 2007. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Newton, J. M., and L.A. Stafford. 2011. Monitoring adult Chinook salmon, rainbow trout, and steelhead in Battle Creek, California, from March through November 2009. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Nichols, K. M., A. F. Edo, P. A. Wheeler, and G. H. Thorgaard. 2008. The genetic basis of smoltification-related traits in *Oncorhynchus mykiss*. *Genetics* 179(3):1559–1575.
- Nielsen, J. L., T. E. Lisle, and V. Ozaki. 1994. Thermally Stratified Pools and Their Use by Steelhead in Northern California Streams. *Transactions of the American Fisheries Society* 123(4):613–626.
- Nielson, J. L., S. Pavey, T. Wiacek, G. K. Sage, and I. Williams. 2003. Genetic Analyses of Central Valley Trout Populations 1999–2003. California Department of Fish and Game and U. S. Fish and Wildlife Service, 44 pp.
- Nobriga, M. L., and P. Cadrett. 2001. Differences among Hatchery and Wild Steelhead; Evidence from Delta Fish Monitoring Programs Pages 56 in IEP Newsletter Summer.
- Ohms, H. A., M. R. Sloat, G. H. Reeves, C. E. Jordan, and J. B. Dunham. 2014. Influence of sex, migration distance, and latitude on life history expression in steelhead and rainbow trout (*Oncorhynchus mykiss*). *Canadian Journal of Fisheries and Aquatic Sciences* 71(1):70–80.
- Pearse, D. E., M. R. Miller, A. Abadía-Cardoso, and J. C. Garza. 2014. Rapid parallel evolution of standing variation in a single, complex, genomic region is associated with life history in steelhead/rainbow trout. *Proceedings of the Royal Society B: Biological Sciences*, 281(1783), p.20140012.
- Pearse, D. E., and J. C. Garza. 2015. You can't unscramble an egg: Population genetic structure of *Oncorhynchus mykiss* in the California Central Valley inferred from combined microsatellite and single nucleotide polymorphism data. *San Francisco Estuary and Watershed Science* 13(4).
- Pearsons, T. N., G. M. Temple, A. L. Fritts, C. L. Johnson, and T. D. Webster. 2008. Ecological interactions between non-target taxa of concern and hatchery supplemented salmon. 2007 Annual Report Project, (1995-063), p.25.

- Phillips, R. W., and H. J. Campbell. 1961. The Embryonic Survival of Coho Salmon and Steelhead Trout as Influenced by Some Environmental Conditions in Gravel Beds. Pages 60-72 in Fourteenth annual report. Pacific Marine Fisheries Commission, Portland, Oregon.
- Phillis, C. C., J. W. Moore, M. Buoro, S. A. Hayes, J. C. Garza, and D. E. Pearse. 2016. Shifting thresholds: rapid evolution of migratory life histories in steelhead/rainbow trout, *Oncorhynchus mykiss*. *Journal of Heredity* 107(1):51–60.
- Poytress, W. R., J. J. Gruber, F. D. Carrillo, and S. D. Voss. 2014. Compendium Report of Red Bluff Diversion Dam Rotary Trap Juvenile Anadromous Fish Production Indices for Years 2002-2012. Report of U.S. Fish and Wildlife Service to California Department of Fish and Wildlife and U.S. Bureau of Reclamation.
- Provins, S. S. and C. D. Chamberlain 2019. Distribution and abundance of Rainbow Trout/steelhead and late-fall run Chinook Salmon redds in Clear Creek, winter 2011 to spring 2012. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Provins S.S. and C.D. Chamberlain 2019. Distribution and abundance of Rainbow Trout/steelhead and late-fall run Chinook Salmon redds in Clear Creek; winter 2012 to spring 2013. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Provins S.S. and C.D. Chamberlain. 2019. Distribution and abundance of Rainbow Trout/steelhead and late-fall run Chinook Salmon redds in Clear Creek; winter 2013 to spring 2014. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Provins, S.S. and C.D. Chamberlain 2019. Distribution and abundance of Rainbow Trout/steelhead and late-fall run Chinook Salmon redds in Clear Creek; winter 2014 to spring 2015. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Provins S.S. and C.D. Chamberlain. 2019. Distribution and abundance of Rainbow Trout/steelhead and late-fall run Chinook Salmon redds in Clear Creek; winter 2016 to spring 2017. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Provins S. S. and C. D. Chamberlain. 2020. Distribution and abundance of Rainbow Trout/steelhead and late-fall run Chinook Salmon redds in Clear Creek; winter 2017 to spring 2018. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Raquel, P. F. 1989. Effects of Handling and Trucking on Chinook salmon, striped bass, American Shad, Steelhead Trout, Threadfin Shad, and White Catfish salvaged at the John E. Skinner Delta Fish Protective Facility.
- 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(1):23–49.

- Rombough, P. J. 1988. Growth, Aerobic Metabolism, and Dissolved-Oxygen Requirements of Embryos and Alevins of Steelhead, *Salmo-Gairdneri*. *Canadian Journal of Zoology-Revue Canadienne De Zoologie* 66(3):651–660.
- Sasaki, S. 1966. Distribution and Food Habits of king salmon (*Oncorhynchus tshawytscha*) and steelhead rainbow trout, *Salmo gairdnerii*, in the Sacramento-San Joaquin Delta. *Fish Bulletin* 136:108–114.
- Satterthwaite, W.H., M.P. Beakes, E. M. Collins, D. R. Swank, J. E. Merz, R. G. Titus, S. M. Sogard, and M. Mangel. 2009. Steelhead life history on California's central coast: insights from a state-dependent model. *Transactions of the American Fisheries Society* 138(3):532–548.
- Satterthwaite, W.H., M. P. Beakes, E. M. Collins, D. R. Swank, J. E. Merz, R. G. Titus, S. M. Sogard, and M. Mangel. 2010. State-dependent life history models in a changing (and regulated) environment: steelhead in the California Central Valley. *Evolutionary Applications* 3(3):221–243.
- Schaefer, R. A., S. L. Gallagher, and C. D. Chamberlain. 2019. Distribution and Abundance of California Central Valley steelhead/Rainbow Trout and Late-fall Chinook Salmon Redds in Clear Creek, Winter 2015 to Spring 2016. Red Bluff, CA.
- Schaefer, R. A., S. L. Gallagher, and C.D. Chamberlain. 2019. Distribution and abundance of California Central Valley steelhead/Rainbow Trout and late-fall Chinook Salmon redds in Clear Creek, winter 2015 to spring 2016. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Schraml C. M., J. T. Earley, and L. A. Earley. 2018. Brood Year 2011 Juvenile Salmonid Monitoring in Battle Creek, California. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Schraml, C. M., J. T. Earley, and L. A. Earley. 2019. Brood Year 2012 Juvenile Salmonid Monitoring in Battle Creek, California. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Schraml, C. M. and L. A. Earley. 2019. Brood Year 2013 Juvenile Salmonid Monitoring in Battle, California. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Schraml, C. M., and L. A. Earley. 2019. Brood Year 2014 Juvenile Salmonid Monitoring in Battle Creek, California. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Schraml, C. M. and L. A. Earley. 2019. Brood Year 2015 Juvenile Salmonid Monitoring in Battle Creek, California. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.

- Schraml, C. M. and L. A. Earley. 2019. Brood Year 2016 Juvenile Salmonid Monitoring in Battle Creek, California. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Schraml, C. M. and L. A. Earley. 2020. Brood Year 2016 Juvenile Salmonid Monitoring in Battle Creek, California. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Schraml, C. M. and L. A. Earley. 2021. Brood Year 2018 Juvenile Salmonid Monitoring in Battle Creek, California. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Schraml, C. M., J. T. Earley, and C. D. Chamberlain. 2018. Brood Year 2011 Juvenile Salmonid Monitoring in Clear Creek, California. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Schraml, C. M., and C. D. Chamberlain. 2019. Brood Year 2012 Juvenile Salmonid Monitoring in Clear Creek, California. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Schraml, C. M., and C. D. Chamberlain. 2019. Brood Year 2013 Juvenile Salmonid Monitoring in Clear Creek. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Schraml, C. M. and C. D. Chamberlain. 2019. Brood Year 2014 Juvenile Salmonid Monitoring in Clear Creek, California. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Schraml, C. M. and C. D. Chamberlain. 2019. Brood Year 2015 Juvenile Salmonid Monitoring in Clear Creek, California. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Schraml, C. M. and C. D. Chamberlain. 2020. Brood Year 2016 Juvenile Salmonid Monitoring in Clear Creek, California. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Schraml, C. M., J. R. Knight, and C. D. Chamberlain. 2020. Brood Year 2017 Juvenile Salmonid Monitoring in Clear Creek, California. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Schraml, C. M., and C. D. Chamberlain. 2021. Brood Year 2018 Juvenile Salmonid Monitoring in Clear Creek, California. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Shapovalov, L., and A. C. Taft. 1954. The life histories of the steelhead rainbow trout (*Salmo gairdneri gairdneri*) and silver salmon (*Oncorhynchus kisutch*): with special reference to Waddell Creek, California, and recommendations regarding their management (p. 575). Sacramento, California, USA: California Department of Fish and Game.

- Shelton, A. O., W. H. Satterthwaite, M. P. Beakes, S. B. Munch, S. M. Sogard, and M. Mangel. 2013. Separating intrinsic and environmental contributions to growth and their population consequences. *The American Naturalist* 181(6):799–814.
- Sigler, J. W., T. C. Bjornn, and F. H. Everest. 1984. Effects of Chronic Turbidity on Density and Growth of Steelheads and Coho Salmon. *Transactions of the American Fisheries Society* 113(2):142–150.
- Sloat, M. R., and A. M. K. Osterback. 2013. Maximum stream temperature and the occurrence, abundance, and behavior of steelhead trout (*Oncorhynchus mykiss*) in a southern California stream. *Canadian Journal of Fisheries and Aquatic Sciences* 70(1):64–73.
- Sloat, M. R., and G. H. Reeves. 2014. Individual condition, standard metabolic rate, and rearing temperature influence steelhead and rainbow trout (*Oncorhynchus mykiss*) life histories. *Canadian Journal of Fisheries and Aquatic Sciences* 71(4):491–501.
- Sogard, S. M., J. E. Merz, W. H. Satterthwaite, M. P. Beakes, D. R. Swank, E. M. Collins, R. G. Titus, and M. Mangel. 2012. Contrasts in habitat characteristics and life history patterns of *Oncorhynchus mykiss* in California's Central Coast and Central Valley. *Transactions of the American Fisheries Society* 141(3):747–760.
- Stafford, L.A., and J.M. Newton. 2010. Monitoring adult Chinook salmon, rainbow trout, and steelhead in Battle Creek, California, from March through November 2008. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Stanley, C. E., R. J. Bottaro, and L. A. Earley. 2020. Monitoring adult Chinook Salmon, Rainbow Trout, and Steelhead in Battle Creek, California, from March through November 2019. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Teo, S.L. and multiple co-authors, 2013. Archival and acoustic tags reveal the post-spawning migrations, diving behavior, and thermal habitat or hatchery-origin Sacramento River steelhead kelts. *Environmental Biology of Fishes* 96. DOI:10.1007/s10641-011-9938-4.
- Thrower, F. P., J. J. Hard, and J. E. Joyce. 2004. Genetic architecture of growth and early life-history transitions in anadromous and derived freshwater populations of steelhead. *Journal of Fish Biology* 65:286–307.
- Turner, M. A., M. R. Viant, S. J. Teh, and M. L. Johnson. 2007. Developmental rates, structural asymmetry, and metabolic fingerprints of steelhead trout (*Oncorhynchus mykiss*) eggs incubated at two temperatures. *Fish Physiology and Biochemistry* 33(1):59–72.
- U.S. Bureau of Reclamation (USBR). 2018. NMFS Biological Opinion RPA IV.2.2: 201.1Six-Year Acoustic Telemetry Steelhead Study. Contributions by Buchanan, R., J. Israel, P. Brandes. E. Buttermore. Reclamation Bay-Delta Office, Mid-Pacific Region, Sacramento, CA. FINAL REPORT May 14, 2018, 144p. (<https://www.usbr.gov/mp/bdo/six-year-acoustic-telemetry-steelhead-study.html>)

- U. S. Fish and Wildlife Service. 2003. Flow-Habitat Relationships for Steelhead and Fall, Late-Fall and Winter-Run Chinook Salmon Spawning in the Sacramento River Between Keswick Dam and Battle Creek. Pages 79pp. in, Sacramento, California.
- U.S. Fish and Wildlife Service. 2006. Relationships Between Flow Fluctuations and Redd Dewatering and Juvenile Stranding for Chinook Salmon and Steelhead in the Sacramento River Between Keswick Dam and Battle Creek. Pages 94.
- U.S. Fish and Wildlife Service. 2007. Flow-Habitat relationships for Spring-run Chinook salmon and Steelhead/Rainbow Trout spawning in Clear Creek Between Whiskeytown Dam and Clear Creek Road.
- Voss, S. D., and W. R. Poytress. 2017. Brood year 2015 juvenile salmonid production and passage indices at the Red Bluff Diversion Dam. Report of U.S. Fish and Wildlife Service to U.S. Bureau of Reclamation, Sacramento, CA.
- Voss, S. D., and W. R. Poytress. 2018. Brood year 2016 juvenile salmonid production and passage indices at the Red Bluff Diversion Dam. Report of U.S. Fish and Wildlife Service to U.S. Bureau of Reclamation, Sacramento, CA.
- Voss, S. D., and W. R. Poytress. 2019. Brood year 2017 juvenile salmonid production and passage indices at the Red Bluff Diversion Dam. Report of U.S. Fish and Wildlife Service to U.S. Bureau of Reclamation, Sacramento, CA.
- Voss, S. D., and W. R. Poytress. 2020. Brood year 2018 juvenile salmonid production and passage indices at the Red Bluff Diversion Dam. Report of U.S. Fish and Wildlife Service to U.S. Bureau of Reclamation, Sacramento, CA.
- Voss, S. D., and W. R. Poytress. 2022. 2019 Red Bluff Diversion Dam Rotary Trap Juvenile Anadromous Fish Abundance Estimates. Report of U.S. Fish and Wildlife Service to U.S. Bureau of Reclamation, Sacramento, CA.
- Whitton, K. S., J. M. Newton, D. J. Colby, and M. R. Brown. 2006. Juvenile salmonid monitoring in Battle Creek, California, from September 1998 to February 2001. USFWS Data Summary Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Whitton, K. S., J. M. Newton, and M. R. Brown. 2007. Juvenile salmonid monitoring in Battle Creek, California, July 2001 through September 2002. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Whitton, K. S., J. M. Newton, and M. R. Brown. 2007. Juvenile salmonid monitoring in Battle Creek, California, October 2002 through September 2003. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Whitton, K. S., J. M. Newton, and M. R. Brown. 2007. Juvenile salmonid monitoring in Battle Creek, California, October 2004 through September 2005. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.

- Whitton, K. S., J. M. Newton, and M. R. Brown. 2007. Juvenile salmonid monitoring in Battle Creek, California, October 2003 through September 2004. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Whitton, K. S., J. M. Newton, and M. R. Brown. 2007. Juvenile salmonid monitoring in Battle Creek, California, October 2005 through September 2006. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Whitton, K. S., D. J. Colby, J. M. Newton, and M. R. Brown. 2008. Juvenile salmonid monitoring in Battle Creek, California, November 2007 through June 2008. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Whitton, K. S., D. J. Colby, J. M. Newton, and M. R. Brown. 2010. Juvenile salmonid monitoring in Battle Creek, California, November 2008 through June 2009. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- Whitton, K. S., D. J. Colby, J. M. Newton, and M. R. Brown. 2011. Juvenile salmonid monitoring in Battle Creek, California, November 2009 through July 2010. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.
- 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(3).
- Williams, J. G. 2010. DRERIP Delta Conceptual Model: Life History Conceptual Model for Chinook Salmon & Steelhead *Oncorhynchus tshawytscha* & *Oncorhynchus mykiss*. Department of Fish and Game Ecosystem Restoration Program.
- Williams, T. H., S. T. Lindley, B. C. Spence, and D. A. Boughton. 2011. Status review update for Pacific salmon and steelhead listed under the Endangered Species Act. National Marine Fisheries Service, Southwest Fisheries Science Center, Santa Cruz, CA.
- Williams, T. H., B. C. Spence, D. A. Boughton, R. C. Johnson, L. Crozier, N. Mantua, M. O'Farrell, and S. T. Lindley. 2016. Viability assessment for Pacific salmon and steelhead listed under the Endangered Species Act: Southwest. 2 February 2016 Report to National Marine Fisheries Service – West Coast Region from Southwest Fisheries Science Center, Fisheries Ecology Division 110 Shaffer Road, Santa Cruz, California 95060.
- Yuba County Water Agency. 2014. Draft Biological Assessment for Central Valley spring-run Chinook salmon, Central Valley steelhead, and North American green sturgeon and draft essential fish habitat assessment. Application for new license, major project – existing dam. Volume IV: exhibit E. Yuba River Development Project, FERC No. 2246. April 2014.
- Zaugg, W. S., B. L. Adams, and L. R. McLain. 1972. Steelhead Migration - Potential Temperature Effects as Indicated by Gill Adenosine-Triphosphatase Activities. *Science* 176(4033):415–416.

5.3 Models

Models support testing alternative operations and predicting environmental responses. The following models were available to Reclamation and relevant to addressing management questions:

5.3.1 Water Operations

CalSim II is a generalized reservoir-river basin simulation model that allows for specification and achievement of user-specified allocation targets, or goals (Draper et al. 2004). CalSim II represents the best available planning model for CVP and SWP system operations and has been used in previous system-wide evaluations of CVP and SWP operations (Bureau of Reclamation 2015). Reclamation and California Department of Water Resources (DWR) are advancing CalSim 3, but the model was not ready for these purposes.

5.3.2 Temperature

HEC_5Q is a reservoir routing and temperature model. Over the past 15 years, various temperature models were developed to simulate temperature conditions on the rivers affected by CVP and SWP operations (e.g., Sacramento River Water Quality Model [SRWQM] San Joaquin River HEC_5Q model) (Bureau of Reclamation 2008). Recently, these models were compiled and updated into a single modeling package referred to here as the HEC_5Q model. Further updates were performed under the LTO EIS modeling that included improved meteorological data and subsequent validation of the Sacramento and American River models, implementation of the Folsom Temperature Control Devices and low-level outlet, implementation of the Trinity auxiliary outlet, improved temperature targeting for Shasta and Folsom Dams, as well as improved documentation and streamlining of the models and improved integration with the CalSim II model (Bureau of Reclamation 2015). A summary of previous model calibration and validation details can be found at the following link: [DWR-1084 RMA 2003 SRWQM.pdf \(ca.gov\)](#). Reclamation is developing an updated water temperature modeling platform, but the model is not yet available for broad use.

6. Lines of Evidence

Reclamation's management questions for the formulation of an alternative include the following.

6.1 Habitat Suitability

Steelhead and fall-run Chinook salmon experience optimal flows for spawning at approximately 2000 cfs in the lower American River (USFWS 2003). However, close to 80% of the maximum spawning habitat is still available to these species at flows of 800 cfs to just over 3500 cfs. Below 800 cfs, spawning habitat availability drops off precipitously. Likewise, low flows may be problematic for rearing habitat. Yearling steelhead are found in bar complex and side channel areas characterized by habitat complexity in the form of velocity shelters, hydraulic roughness elements, and other forms of cover (Surface Water Resources Inc. 2001). At low flow levels, the availability of these habitat types becomes limited, forcing juvenile steelhead densities to increase in areas that provide less cover from predation. With high densities in areas of relatively reduced habitat quality, juvenile steelhead become more susceptible to predation as well as disease.

Not only is the magnitude of releases important to salmonid habitat, but fluctuations in flow in the lower American River have been documented to result in steelhead redd dewatering and isolation (American River Group 2017; American River Group 2018; Hannon and Deason 2008; Hannon et al. 2003; Water Forum 2005). Redd dewatering can affect salmonid eggs and alevins by impairing development and causing direct mortality due to desiccation, insufficient oxygen levels, waste metabolite toxicity, and thermal stress (Becker et al. 1982; Reiser and White 1983). Isolation of redds in side channels can result in direct mortalities due to these factors, as well as starvation and predation of emergent fry. Isolation of juvenile fish exposes individuals to warm water temperatures and fish and avian predation within habitats that are disconnected from the river, likely increasing their mortality risk. If the isolated habitat is not reconnected to the river with a subsequent increase in river stage, all steelhead in that habitat are assumed to die.

6.2 Temperature and Storage Levels

Modeling is under development.

The figures below show the degree days above a May through October temperature target of 65°F at Watt Avenue Watt Avenue as a function of Folsom end of April and end of September storage level.

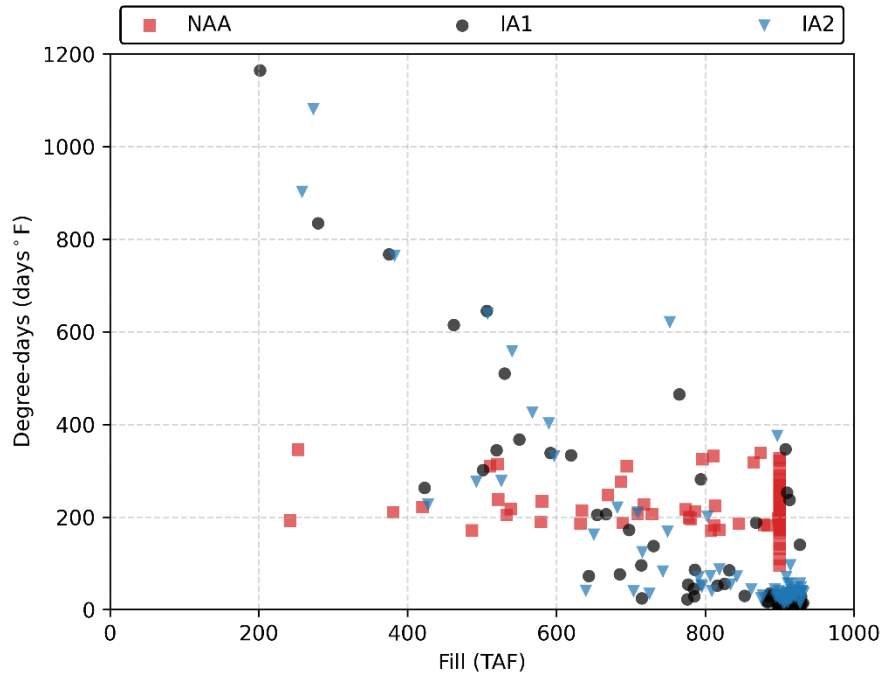


Figure 1. Degree Days above the Temperature Target as a function of Folsom End-of-April Storage

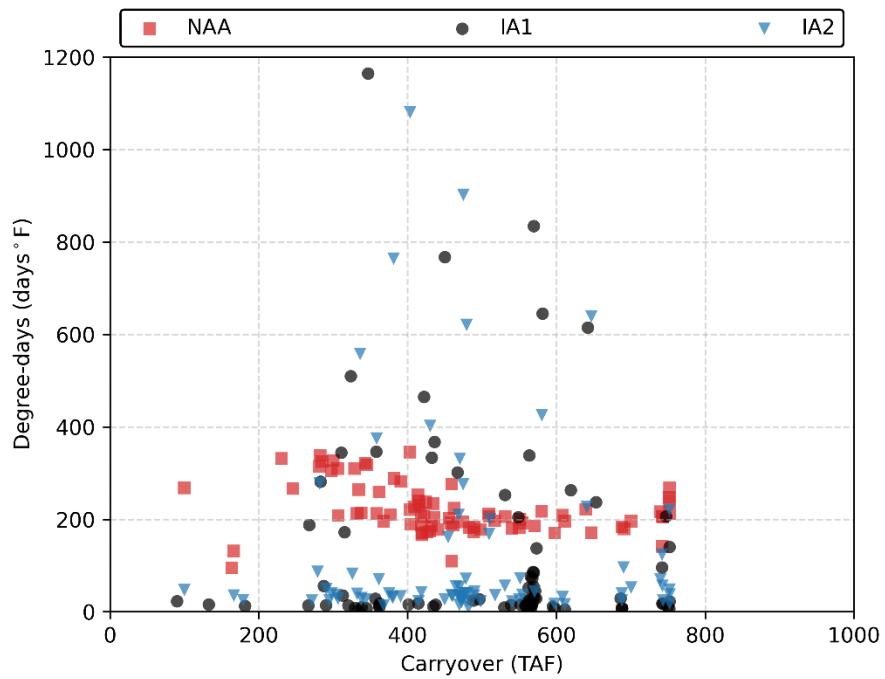


Figure 2. Degree Days above the Temperature Target as a Function of Folsom September Carryover Storage

6.3 Storage Planning Minimum and Coldwater Bypasses

Saving water over the summer until the fall period with implementation of planning minimums for end of September and end of December storage provides opportunity to provide cooler fall water temperatures. Cooler fall water temperature increases survival for juvenile steelhead rearing and for adult steelhead entering the river in the fall. Cooler water in the fall will reduce temperature related stress on holding Chinook salmon and increase survival for those eggs spawned prior to around the Thanksgiving time period. After about Thanksgiving, environmental cooling results in water temperature reaching and then dropping below 56 F. Egg survival is highest in water below 56 F at spawning time and then cooling through the winter period.

Cold water bypasses have occurred in the fall to reduce overall temperature of Folsom Dam releases. Cold water bypasses may (1) reduce prespawn mortality in fall-run Chinook salmon, (2) reduce fall-run Chinook salmon egg mortality, and (3) provide more suitable temperatures for hatchery operations. By releasing water from the lower river outlet at elevation approximately 210 feet (lowest elevation is 205.5 feet and highest elevation is 214.5 feet, average elevation is 210 feet) rather than through the powerplant penstocks, which pull from approximate elevation of 389 feet, it may reduce warm temperatures released into the lower American River. Fall releases of warmer water have been occurring more frequently since cold water accessed through the Folsom Shuttles is used primarily for summer cold water releases for fisheries benefit. Summer cold water releases occur to maintain suitable rearing habitat for juvenile Central Valley (CV) steelhead.

In water year 2021, Reclamation used a cold water bypass by bypassing up to 350 cfs through the lower river outlet rather than the powerplant to target downstream temperatures close to 60°F. This bypass started on October 11 and ended on December 5, when destratification resulted in similar temperatures across reservoir elevations. All cold water was used during the bypass.

In water year 2022, Reclamation used a cold water bypass by bypassing up to 500 cfs through the lower river outlet rather than through the Folsom powerplant to target downstream temperatures. This bypass lasted from October 11 through November 26, 2022, resulting in 28,711 acre-feet bypassed, \$641,852 daily weighted MWh hydropower not realized, and 5,180 tons of CO₂ production caused by replacement power.

The end of December storage planning minimum provides some insurance that in a critically dry winter there will be a level of storage left in the reservoir to provide operational flexibility to provide cooler water through the following summer than would otherwise be possible.

6.4 Planning Minimum and Water Supply Intakes in Folsom Reservoir

Modeling is under development.

At storage levels below 90,000 AF, the water level falls below the water supply intakes at Folsom Dam and El Dorado Hills, thereby preventing local water agencies from making critical water deliveries.

6.5 50% exceedance forecast early in the water year

See Attachment M.1 – Folsom Flow and Temperature Management Analysis

6.6 Effects of Releases on the American River to Shasta Reservoir, the Bay-Delta Water Quality Control Plan, and exports

See Attachment M.1 – Folsom Flow and Temperature Management Analysis

6.7 Historic Steelhead Redd Dewatering

Steelhead redd surveys were conducted in the American River and results reported in annual steelhead reports (Hannon et al. 2003; Hannon and Deason 2004, 2005, 2007; Chase 2010; Hannon 2013; Sellheim 2015, 2016, 2019, 2020; Sweeney 2017, 2021, 2022; Scrivin 2018). Steelhead redd dewatering was detected in the Sunrise side channel in 2003-2005, with 5 steelhead redds dewatered in each of 2003 and 2004 and 4 redds dewatered in 2005. Flow management and habitat modification completed in 2008 resolved the dewatering in that location, and dewatering has not been documented on the American River in subsequent reports.

6.8 Historic Steelhead Juvenile Stranding

Juvenile stranding surveys were conducted in the American River and results reported in annual reports in 2015 – 2022 (Sellheim 2015, 2016, 2019, 2020; Sweeney 2017, 2021, 2022; Scrivin 2018; Table 1). Cramer Fish Sciences conducted the stranding surveys under contract with Reclamation. The 2015 and 2016 surveys documented visual counts of juvenile salmonids stranded in disconnected pools and no attempts were made to move stranded fish back into the main channel. Surveys in 2017-2022 were conducted with assistance from California Department of Fish and Wildlife to include seining the isolated pools and the stranded fish were moved to the main river channel. During the seining surveys salmonids were identified to species (steelhead or Chinook) and counted before being released into the main channel. Mortalities were enumerated when observed during the surveys.

Table 1. Juvenile Salmonid Stranding Survey Results in the American River

Year	Species	Stranding events	Effort (survey days)	Stranding mortalities	Rescued	Notes
2022	Steelhead	1	6	233	8,164	
2021	Steelhead	2	4		25	
2020	Steelhead	2	5		35	
2019	Steelhead	5	9	1	273	
2018	Steelhead	6	8		370	
2017	Steelhead	7	14		22	
2016	Salmonids	3	5	1,595		mortalities not specified - no fish salvage attempts
2015	Salmonids	3	4	4,226		mortalities not specified - no fish salvage attempts

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7. Uncertainty

There are no identified LTO special studies to reduce uncertainty regarding CVP operations on the American River.

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8. References

Literature referenced for Folsom Reservoir Flow and Temperature Management are listed in Section 3 above. Additional references cited or used for informational material in the document are included below.

- American River Group. 2017. Annual Report of Activities October 1, 2016 to November 20, 2017.
- American River Group. 2018. Annual Report of Activities October 1, 2017 to October 22, 2018.
- Becker, C. D., D. A. Neitzel, and D. H. Fickeisen. 1982. Effects of Dewatering on Chinook Salmon Redds: Tolerance of Four Developmental Phases to Daily Dewaterings. Transactions of the American Fisheries Society 111(5):624-637.
- CalFish (2019). CalFish – A California cooperative anadromous fish and habitat data program. Middle Sacramento River salmon and Steelhead monitoring. Available: <https://www.calfish.org/ProgramsData/ConservationandManagement/CentralValleyMonitoring/SacramentoValleyTributaryMonitoring/MiddleSacramentoRiverSalmonandSteelheadMonitoring.aspx>.
- Chase, R. 2010. Lower American River Steelhead (*Oncorhynchus mykiss*) Spawning Survey - 2010. U.S. Bureau of Reclamation, and California Department of Fish and Game, editors., Sacramento, California.
- Draper, A.J., Munévar, A., Arora, S.K., Reyes, E., Parker, N I.L., Chung, F.I., and Peterson, L.E. 2004. CalSim: Generalized Model for Reservoir System Analysis. American Society of Civil Engineers, Journal of Water Resources Planning and Management, Vol. 130, No. 6
- Fortier, R., J. Nelson, R. Bellmer, and R. Nielson. 2014. Implementation Plan for the Central Valley Steelhead Monitoring Program. California Department of Fish and Wildlife, Fisheries Branch. July 2014.
- Hannon, J. 2012. American River Steelhead (*Oncorhynchus mykiss*) Spawning – 2012. U.S. Bureau of Reclamation, and California Department of Fish and Game, editors., Sacramento, California.
- Hannon, J. 2013. American River Steelhead (*Oncorhynchus mykiss*) Spawning– 2013. U.S. Bureau of Reclamation, and California Department of Fish and Game, editors., Sacramento, California.
- Hannon, J., and B. Deason. 2004. American River Steelhead (*Oncorhynchus mykiss*) Spawning 2001 – 2004. U.S. Bureau of Reclamation, and California Department of Fish and Game, editors., Sacramento, California.

- Hannon, J., and B. Deason. 2005. American River Steelhead (*Oncorhynchus mykiss*) Spawning 2001 – 2005. U.S. Bureau of Reclamation, and California Department of Fish and Game, editors., Sacramento, California.
- Hannon, J., and B. Deason. 2007. American River Steelhead (*Oncorhynchus mykiss*) Spawning 2001 – 2007. U.S. Bureau of Reclamation, and California Department of Fish and Game, editors., Sacramento, California.
- Hannon, J., and B. Deason. 2008. American River Steelhead (*Oncorhynchus mykiss*) Spawning 2001 – 2007. U.S. Department of the Interior, Bureau of Reclamation, Mid-Pacific Region.
- Hannon, J., M. Healey, and B. Deason. 2003. American River Steelhead (*Oncorhynchus mykiss*) Spawning 2001 – 2003. Pages 36 in U.S. Bureau of Reclamation, and California Department of Fish and Game, editors., Sacramento, California.
- National Marine Fisheries Service. 2019. Biological Opinion for the Reinitiation of Consultation on the Coordinated Operations of the Central Valley Project and State Water Project.
- Reiser, D. W., and R. G. White. 1983. Effects of Complete Redd Dewatering on Salmonid Egg Hatching Success and Development of Juveniles. *Transactions of the American Fisheries Society* 112(4):532-540.
- Scrivin, C., J.Sweeney, K.Sellheim, and J.Merz. 2018. 2018 Lower American River Monitoring 2022 Steelhead (*Oncorhynchus mykiss*) Spawning and Stranding Surveys Central Valley Project, American River, California Prepared for: United States Bureau of Reclamation. 51p.
- Sellheim,K., J.Merz, P.Haverkamp, and J.Sweeney. 2015. 2015 Lower American River Monitoring 2022 Steelhead (*Oncorhynchus mykiss*) Spawning and Stranding Surveys Central Valley Project, American River, California Prepared for: United States Bureau of Reclamation. 41p.
- Sellheim,K., J.Merz, D.Stroud, and J.Sweeney. 2016. 2016 Lower American River Monitoring 2022 Steelhead (*Oncorhynchus mykiss*) Spawning and Stranding Surveys Central Valley Project, American River, California Prepared for: United States Bureau of Reclamation. 50p.
- Sellheim, K., J.Sweeney, P.Colombano, and J.Merz. 2019. 2019 Lower American River Monitoring 2022 Steelhead (*Oncorhynchus mykiss*) Spawning and Stranding Surveys Central Valley Project, American River, California Prepared for: United States Bureau of Reclamation. 50p.
- Sellheim, K., J.Sweeney, P.Colombano, and J.Merz. 2020. 2020 Lower American River Monitoring 2022 Steelhead (*Oncorhynchus mykiss*) Spawning and Stranding Surveys Central Valley Project, American River, California Prepared for: United States Bureau of Reclamation. 53p.
- Surface Water Resources Inc. 2001. Aquatic Resources of the Lower American River: Baseline Report Draft.

- Sweeney, J., K.Sellheim, and J.Merz. 2017. 2017 Lower American River Monitoring 2022 Steelhead (*Oncorhynchus mykiss*) Spawning and Stranding Surveys Central Valley Project, American River, California Prepared for: United States Bureau of Reclamation. 49p.
- Sweeney, J., K.Sellheim, and J.Merz. 2021. 2021 Lower American River Monitoring 2022 Steelhead (*Oncorhynchus mykiss*) Spawning and Stranding Surveys Central Valley Project, American River, California Prepared for: United States Bureau of Reclamation. 57p.
- Sweeney, J., K.Sellheim, and J.Merz. 2022. 2022 Lower American River Monitoring 2022 Steelhead (*Oncorhynchus mykiss*) Spawning and Stranding Surveys Central Valley Project, American River, California Prepared for: United States Bureau of Reclamation. 57p.
- U.S. Bureau of Reclamation, 2008. Central Valley Project and State Water Project Operations Criteria and Plan Biological Assessment, Appendix E HEC5Q Model, May 2008.
- U. S. Bureau of Reclamation, 2015. Coordinated Long Term Operation of the CVP and SWP EIS, Appendix 5A CalSim II and DSM2 Modeling.
- U. S. Bureau of Reclamation, 2019. Final Environmental Impact Statement for Reinitiation of Consultation on the Long-Term Operation of the Central Valley Project and State Water Project.
- U.S. Fish and Wildlife Service (USFWS). 2003. Comparison of PHABSIM and 2 D Modeling of Habitat for Steelhead and Fall-Run Chinook Salmon Spawning in the Lower American River. Energy Planning and Instream Flow Branch.
- Water Forum. 2005. Lower American River State of the River Report.