BUREAU OF RECLAMATION

Long-Term Operation – Initial Alternatives Report

Appendix M – Folsom Reservoir Flow and Temperature Management

Central Valley Project, California

Interior Region 10 – California-Great Basin

U.S. Department of the Interior **September 2022**

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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1. Introduction

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

The Bureau of Reclamation (Reclamation)'s management questions for the formulation of an alternative include the following.

- 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 coldwater 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?

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2. Performance Metrics

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

2.1 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

2.2 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.

2.3 National Environmental Policy Act Resource Areas

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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3. 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.

3.1 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.aspx.

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

3.2 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. LaFaunce. 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 US 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.

3.3 Models

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

3.3.1 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 DWR are advancing CalSim 3, but the model was not ready for these purposes.

3.3.2 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.

4. Lines of Evidence

Analysis of the Long-Term Operation (LTO) relies on multiple lines of evidence from datasets, literature, and models.

Lines of Evidence section is currently under development and will be provided for the Public Draft Environmental Impact Statement (EIS).

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5. Initial Options Analysis

Reclamation's management questions for the formulation of an alternative for Folsom Reservoir flow and temperature management include:

- 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 coldwater 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 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?

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6. Conclusions

Folsom Reservoir flow and temperature management address the tradeoffs for minimum releases and the use of the available coldwater 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 Initial Alternative 1 (IA1), Initial Alternative 2 (IA2), and Initial Alternative 3 (IA3). The Calsim II and HEC-5Q models were used to conduct the analysis for the flows and temperature elements of coldwater 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 Initial 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.

What habitat is created for steelhead and fall-run Chinook salmon at different releases?

- 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.

What is the additional water temperature capability at different 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.

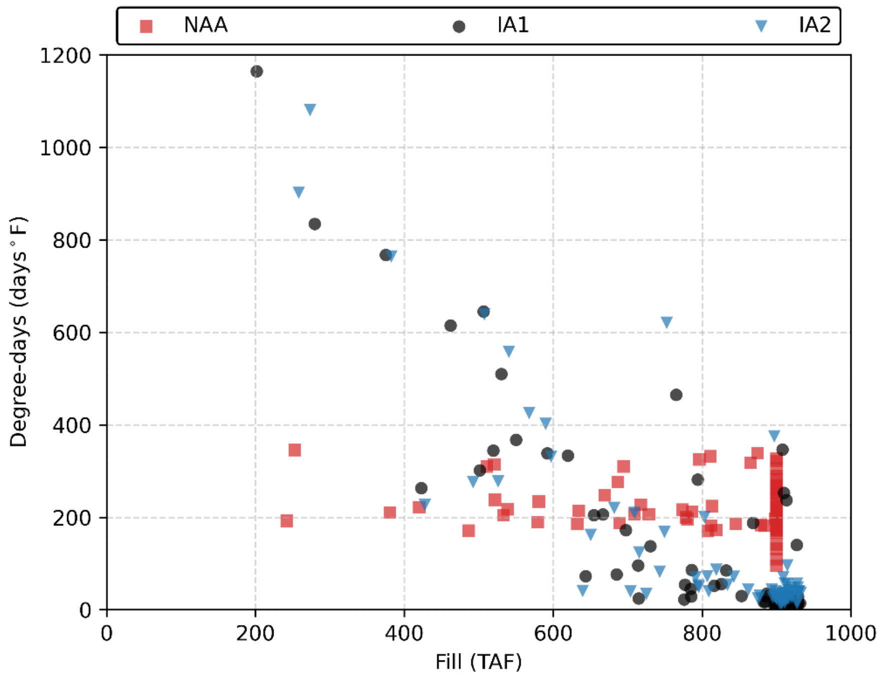

Figure 1. Degree Days above the Temperature Target as a function of Folsom End-of-April Storage

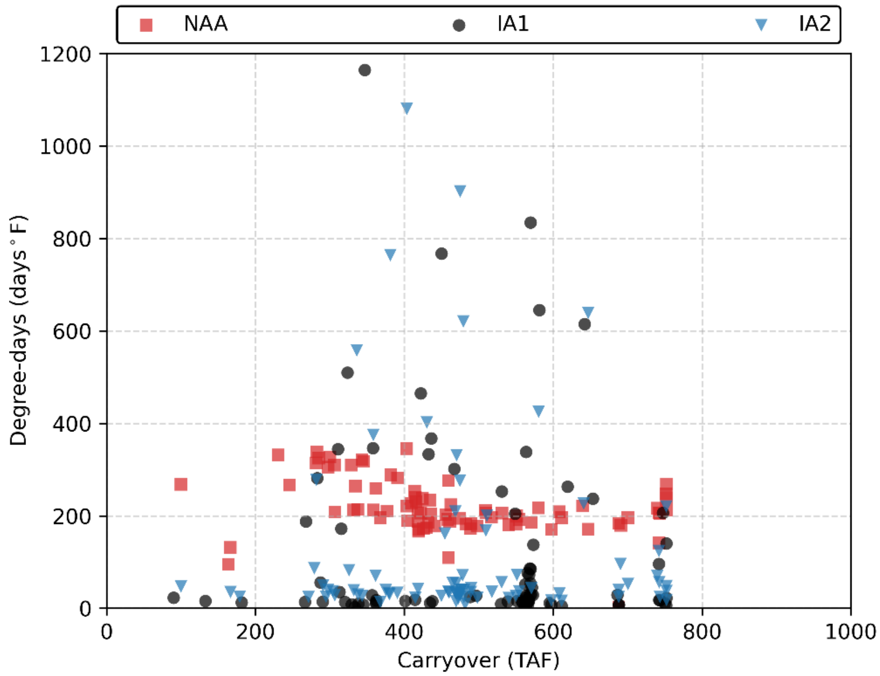

Figure 2. Degree Days above the Temperature Target as a Function of Folsom September Carryover Storage

How does planning minimum storage for both the end of September and the end of December improve potential coldwater habitat?

- Modeling is under development.
- 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.
- 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.

What planning-minimum reservoir storage maintains 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.

What risks occur from operating to a 50% exceedance forecast early in the water year?

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

What temperature targets are suitable for steelhead, while leaving sufficient cold water for fall-run Chinook salmon?

- See Attachment M.1 – Folsom Flow and Temperature Management Analysis
- The 65 F over-summer Watt Avenue temperature target provides suitable rearing temperatures for steelhead through much of the river in the years when Folsom can be operated to meet the target. In general the years when 65 F can be met over summer are the same years that the coolest water can be saved for fall-run Chinook salmon. Most years have insufficient coldwater in Folsom to meet the target temperature along with other operational objectives. Water temperature is a limiting factor to both steelhead and Chinook salmon in the American River and in most years temperatures are stressful for both species.

How do releases on the American River affect Shasta Reservoir, the *Bay–Delta Water Quality Control Plan* (Bay-Delta WQCP), and exports?

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

7. 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.

Draper, A.J., Munévar, A., Arora, S.K., Reyes, E., Parker, N 1 .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., 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.

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.

State Water Resources Control Board. 2018. Water Quality Control Plan for the San Francisco Bay/Sacramento–San Joaquin Delta Estuary. December 12.

Surface Water Resources Inc. 2001. Aquatic Resources of the Lower American River: Baseline Report Draft.

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. 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. Addendum to the Report Titled Impacts on the Lower American River Salmonids and Recommendations Associated with Folsom Reservoir Operations to Meet Delta Water Quality Objectives and Demands. September.

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

Folsom Reservoir flow and temperature management address the tradeoffs for minimum releases and the use of the available coldwater pool in Folsom Reservoir for water supply and steelhead and fall-run Chinook salmon in the American River. The following analysis compares the effects of American River operations in the No Action Alternative to Initial Alternative 1 (IA1), Initial Alternative 2 (IA2), and Initial Alternative 3 (IA3).

M.1.1 Alternatives

The Initial 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 (MRR).

M.1.1.1 No Action Alternative

The No Action Alternative is described as Revised Alternative 1 in Appendix F1 of the 2019 *Final Environmental Impact Statement for Reinitiation of Consultation on Long-Term Operation of the Central Valley Project and State Water Project* (Bureau of Reclamation 2019) with additional SWP operations for implementing the 2020 Incidental Take Permit. The No Action Alternative uses hydrology projected at year 2035 (2035 Central Tendency). Information about the updated modeling can be found on the CalSim Model Maintenance Management repository at github.com/usbr/cm3. In addition, full Sacramento River Settlement Contractors contract amounts were assumed, and there are no daily components to the Wilkin's Slough flow requirement.

Temperature management follows the Annual Temperatures Selection Procedure (ATSP), as determined by the NMFS 2019 *Biological Opinion for the Reinitiation of Consultation on the Coordinated Operations of the Central Valley Project and State Water Project* (NMFS 2019). This is a predetermined target-release temperature at Folsom Dam based on Folsom Reservoir storage and release.

In the No Action Alternative modeling, the "forecasted" 90% inflow was developed using 90th percentile of historic inflows for October through December; perfect foresight[1] was used in other months (forecast data is not available for CalSim II). The planning minimum of 275 thousand acre-feet (TAF) was used to model a 300-TAF planning minimum in real-time operations. The model was iterated several times to find the modeled target so that the 300-TAF planning minimum was met most of the years when hydrologically possible (91% of the years), with minimal overshooting to avoid impacts on Shasta storage.

M.1.1.2 Initial Alternative 1

IA1 includes additional release above the 2017 MFMS, downstream temperature targets, and an emphasis on storing water, rather than meeting Delta needs, with the following criteria.

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[1] *Perfect foresight* is the correct prediction of future events. If there is no uncertainty, then an agent can have perfect foresight if they know all relevant information and have a correct model to use for prediction. When there is uncertainty, it is not possible to have perfect foresight.

- MRR (increase by 10%)
    - Spring requested volumes
    - Fall requested volumes
    - Spring pulse (March 15–April 15)
- Coldwater Pool
    - ATSP-prioritized for listed species
        - Steelhead juvenile criteria (May–October), 65°F at Watt Avenue
        - Fall run–adult spawning criteria (May–September/October), 65°F at Watt Avenue
    - Bypasses as required
- Minimum storage planning goal
    - End-of-December 350 TAF in forecasts

M.1.1.2.1 CalSim Assumptions

CalSim assumptions for IA1 are the same as those for the No Action Alternative, except for American River Operations. On the American River, the assumptions are to increase MRR by 10% and December planning minimum to 350 TAF.

In the IA1 modeling, the October–December "forecasted" inflows in the No Action Alternative were multiplied by 0.90 to further reduce reliance on the high inflows to eliminate the "overshooting" observed in the No Action Alternative model. The December planning minimum target was modeled at 350 TAF to represent a 350-TAF planning minimum in real-time operations. The model was not iterated for IA1; however, model code and weights were updated to ensure that the planning minimum is reached 90% of the time.

M.1.1.2.2 HEC-5Q Assumptions

The IA1 model places a constant 65°F temperature target at Watt Avenue. To achieve this, the release temperatures at the dam begin cooler and are iteratively raised until the temperature at Watt Avenue convergences to within a 0.1% temperature change on average across the calendar year. Temperatures may be in excess of or less than the target temperature if there is insufficient cold water to maintain temperature or if the interaction of the water level with the intake elevations precludes temperature control.

The HEC-5Q model allows *power bypass*, which involves making releases through the lower outlets in the face of the dam, rather than through the power penstocks, between September 15–November 30 of each calendar year. The bypass can be up to the full release rate, if necessary for meeting the temperature target. This model is more aggressive in temperature control than actual operations, where power bypass is minimized in both volume and duration to maximize power production.

M.1.1.3 Initial Alternative 2

IA2 relies on other measures to meet species needs and relies on the 2017 MFMS, as described in the 2020 Record of Decision, with updates to temperature management to reflect dry-year conditions and no spring pulse.

- MRR
  - Spring volumes at 2019 Proposed Action (PA), which is the 2017 MFMS with modifications
  - Fall volumes at 2019 PA
- Coldwater pool
  - Steelhead juvenile criteria 65°F at Hazel Avenue
  - Fall run–adult spawning criteria 65°F at Hazel Avenue
  - No power bypass
- MRR storage planning goals
  - End-of-December storage of 300 TAF in forecasts

M.1.1.3.1 CalSim Assumptions

CalSim assumptions for IA2 are the same as those for the No Action Alternative; however, planning minimum target is modeled differently, as follows.

- In the IA modeling, the October–December "forecasted" inflows in the No Action Alternative were multiplied by 0.90 to further reduce reliance on the high inflows to eliminate the "overshooting" observed in the No Action Alternative model.
- The December planning minimum target was modeled at 300 TAF to represent a 300-TAF planning minimum in real-time operations. The model was not iterated for this IA alternative; however, model code and weights were updated to ensure that the planning minimum is reached 96% of the time.

M.1.1.3.2 HEC-5Q Assumptions

This model places a constant 65°F temperature target at Hazel Avenue. To achieve this, the release temperatures at the dam begin at cooler temperatures and are iteratively raised until the temperature at Hazel Avenue convergences is within a 0.1% temperature change on average across the calendar year. Temperatures may be in excess of or less than the target temperature if there is insufficient cold water to maintain temperature or if the interaction of the water level with the intake elevations precludes temperature control.

This model allows power bypass, which is making releases through the lower outlets in the face of the dam, rather than through the power penstocks, between September 15–November 30 of each calendar year. Bypass can be up to the full release rate, if it is necessary to meet the temperature target. This is more aggressive in temperature control than actual operations, where power bypass is minimized in both volume and duration to maximize power production.

M.1.1.4 Initial Alternative 3

IA3 incorporates real-time shaping of a spring pulse and fall dewatering adjustments with flexible temperature management and planning minimums.

- Minimum Release Requirement (MRR)
    - Spring volumes at 2019 MRR
    - Fall volumes at 2019 MRR
    - Spring pulse (March 15–April 15 in critically dry and dry years with possible reshaping of flows
    - Fall dewatering adjustments
- Coldwater pool
    - Flexible
- Steelhead juvenile criteria at Watt Avenue or Hazel Avenue
- Fall run–adult spawning criteria at Hazel Avenue
    - Bypass based on biological evaluation
- Minimum storage planning goals
    - End-of-December storage 275 to350 TAF in forecasts

M.1.1.4.1 CalSim Assumptions

- CalSim assumptions for IA2 are the same as those for the No Action Alternative. Reshaping of flows is not captured in the monthly model. Planning minimum target is modeled differently, as follows. In the IA modeling, the October–December "forecasted" inflows in the No Action Alternative were multiplied by 0.90 to further reduce reliance on the high inflows to eliminate the "overshooting" observed in the No Action Alternative model.
- The December planning minimum target was modeled at 300 TAF to represent a 300-TAF planning minimum in real-time operations. The model was not iterated for this IA alternative; however, model code and weights were updated to ensure that planning the minimum is reached 96% of the time.

M.1.1.4.2 HEC-5Q Assumptions

Temperature cannot be determined for this case because the temperature targets are defined in real time by Reclamation in consultation with participating agencies.

Table M.1-1. Operational Assumptions for Folsom Initial Alternatives

Assumption	No Action Alternative	IA1	IA2	IA3
Minimum Flow below Nimbus Dam	American River Flow Management Standard, per 2017 Water Forum Agreement with a planning minimum end-of-December storage target of 275 TAF (representing a planning minimum of 300 TAF)	American River Flow Management Standard increased by 10%, per 2017 Water Forum Agreement with a planning minimum end-of-December storage target of 350 TAF	American River Flow Management Standard, per 2017 Water Forum Agreement with a planning minimum end-of-December storage target of 300 TAF	Same as IA2
Minimum Flow at H Street Bridge	SWRCB D-893	Same as No Action Alternative	Same as No Action Alternative	Same as No Action Alternative
American River: Folsom Dam Flood Control	Variable 400/600 flood control diagram (without outlet modifications)	Same as No Action Alternative	Same as No Action Alternative	Same as No Action Alternative
Temperature	2019 BiOp schedule	65°F at Watt Avenue	65°F at Hazel Avenue	Not modeled

IA1 = Initial Alternative 1; IA2 = Initial Alternative 2; IA3 = Initial Alternative 3; MRR = minimum required release; TAF = thousand acre feet; SWRCB = California State Water Resources Control Board; BiOp = Biological Opinion; °F = degrees Fahrenheit.

M.1.2 Reservoir Storage

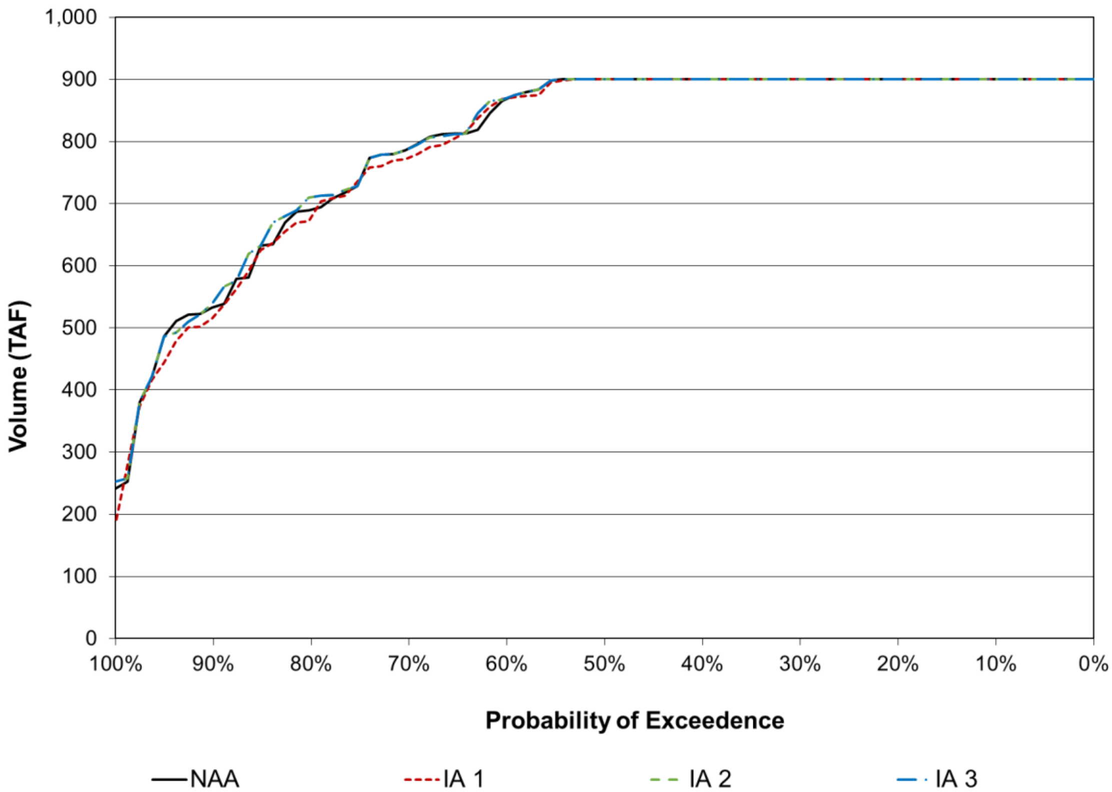


Figure M.1-1. Folsom End-of-April Storage (TAF) Exceedance

Due to Folsom Reservoir's large inflow relative to storage, refill at the end of April) is similar to the No Action Alternative in all of the Initial Alternatives. The MFMS pulse flow is simulated in March, so a small drawdown can be seen in IA1, which increases the MRR by 10%.

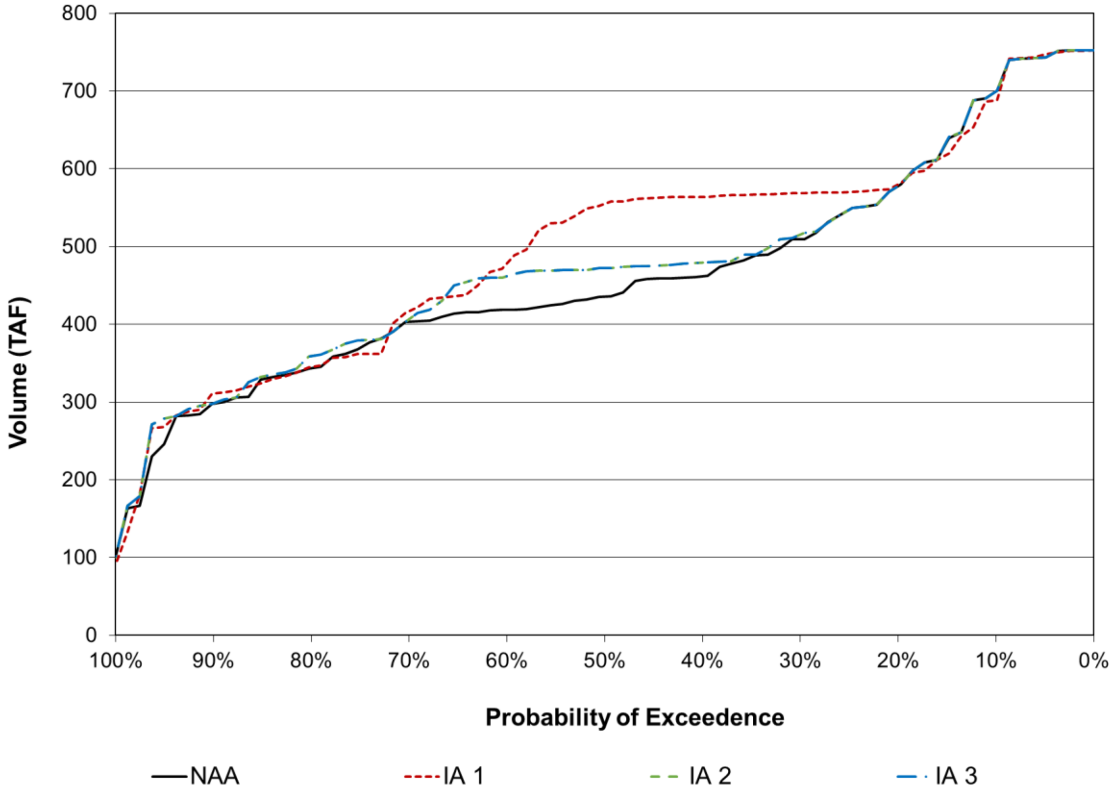


Figure M.1-2. Folsom End-of-September Storage (TAF) Exceedance

End-of-December storage-planning thresholds affect modeled Folsom results throughout the year because CalSim calculates the level of release needed to preserve that December target and dissuades anything higher. This can affect end-of-September storage. IA1, which has the highest end-of-December Folsom storage target, shows the largest increase in end-of-September storage, most notably in the 20% to 70% exceedance range. The driest 5% of years in IA1 have lower end-of-September storage, due to the overall impact on storage of the increased MRR releases. IA2 and IA3 have a higher end-of-December storage target than the No Action Alternative; the increased storage is most notable in the 40% to 70% exceedance range.

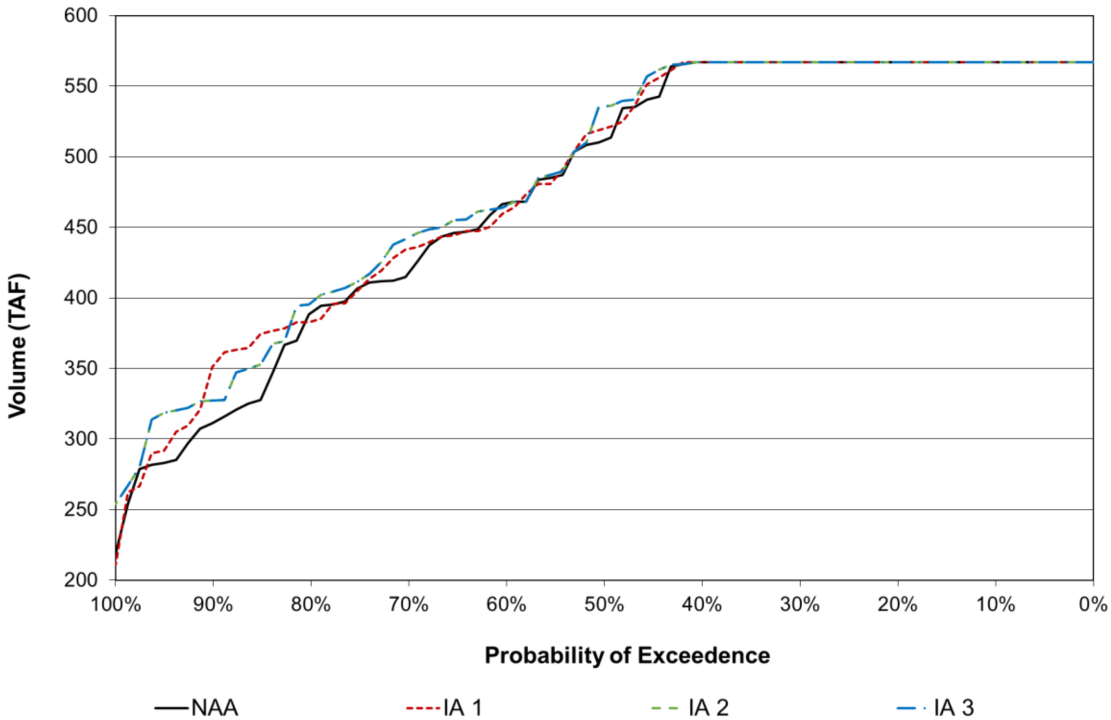


Figure M.1-3. Folsom End-of-December Storage (TAF) Exceedance

IA1, which targets a 350-TAF end-of-December target, results in end-of-December Folsom storage at or above 350 TAF 6% more often than the No Action Alternative (90% in IA1 compared to 84% in No Action Alternative), despite the increased flows in IA1, as compared to the No Action Alternative. IA2 and IA3, which target a 300-TAF end-of-December target, result in end-of-December Folsom storage at or above 300 TAF 5% more often than the No Action Alternative (98% in IA2 and IA3 compared to 93% in the No Action Alternative).

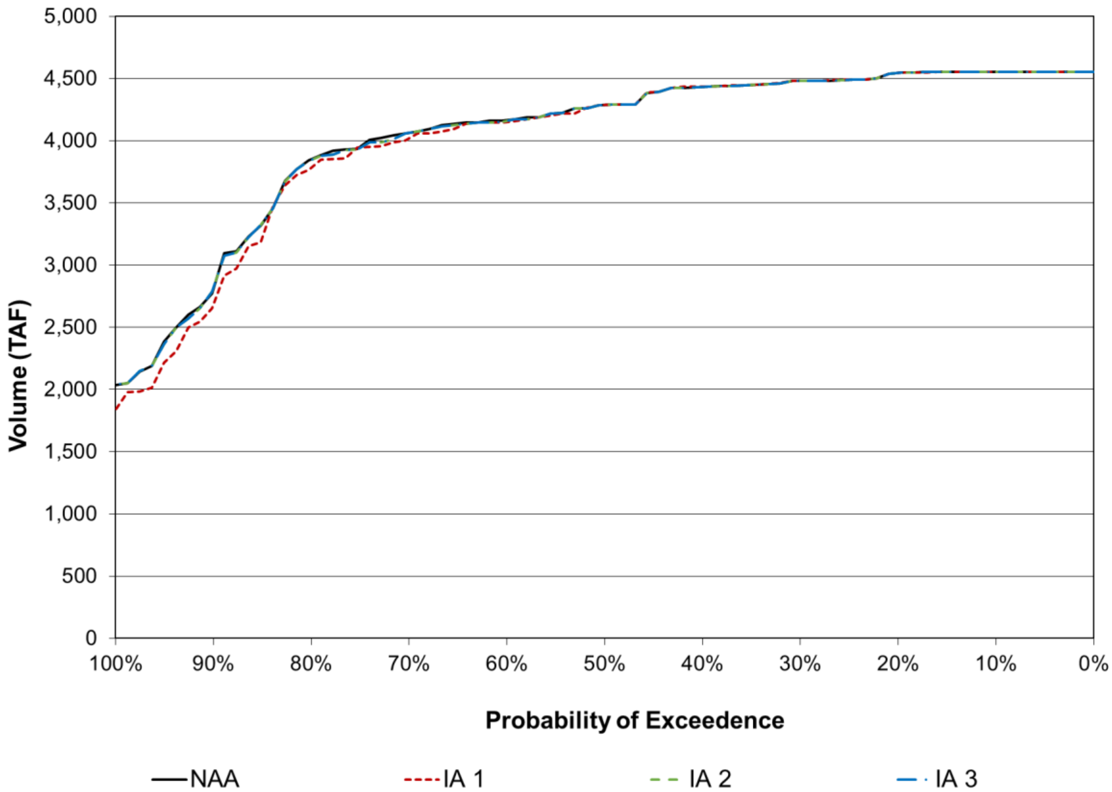


Figure M.1-4. Shasta End-of-April Storage (TAF) Exceedance

IA2 and IA3, which slightly increase the Folsom December carryover target, do not affect Shasta Reservoir's ability to fill. IA1 requires more releases from Folsom, while targeting more end-of-December storage, which limits Folsom's ability to contribute to other system needs. IA1 can result in other reservoirs needing to release additional water, while Folsom hedges its releases to meet its December target, particularly in drier years. IA1 has lower fill at Shasta. These changes are highlighted in Figure M.1-5, which charts the exceedance of the difference between the IAs and the No Action Alternative.

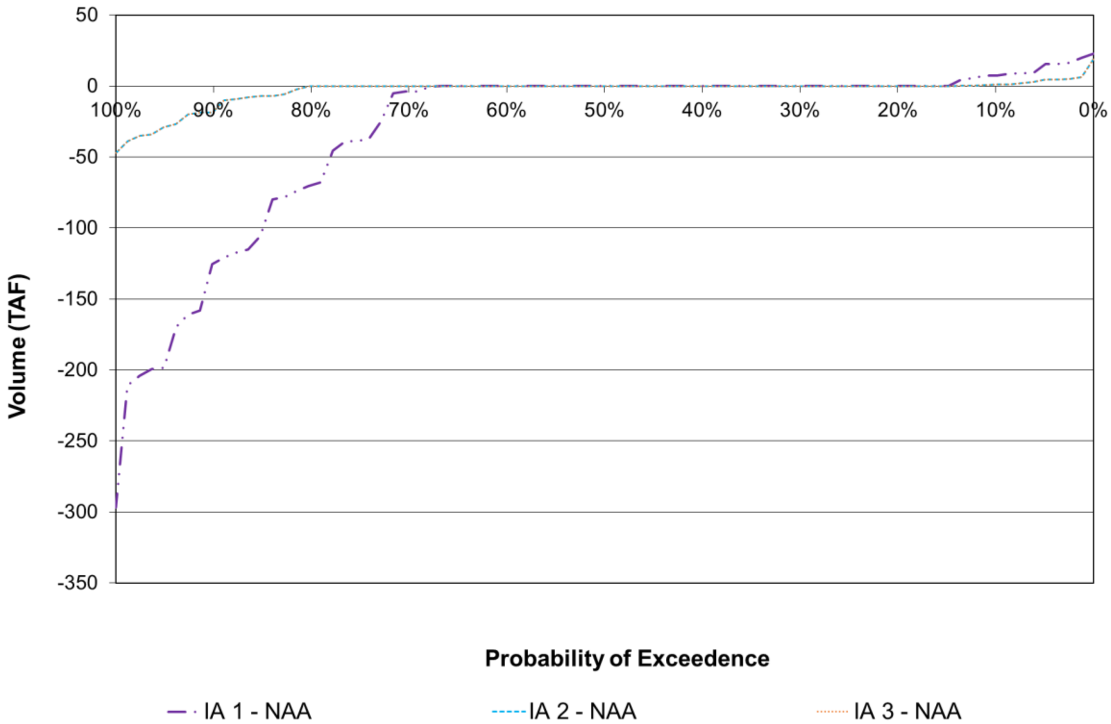


Figure M.1-5. End-of-April Shasta Storage (TAF) Initial Alternative’s Difference from No Action Alternative

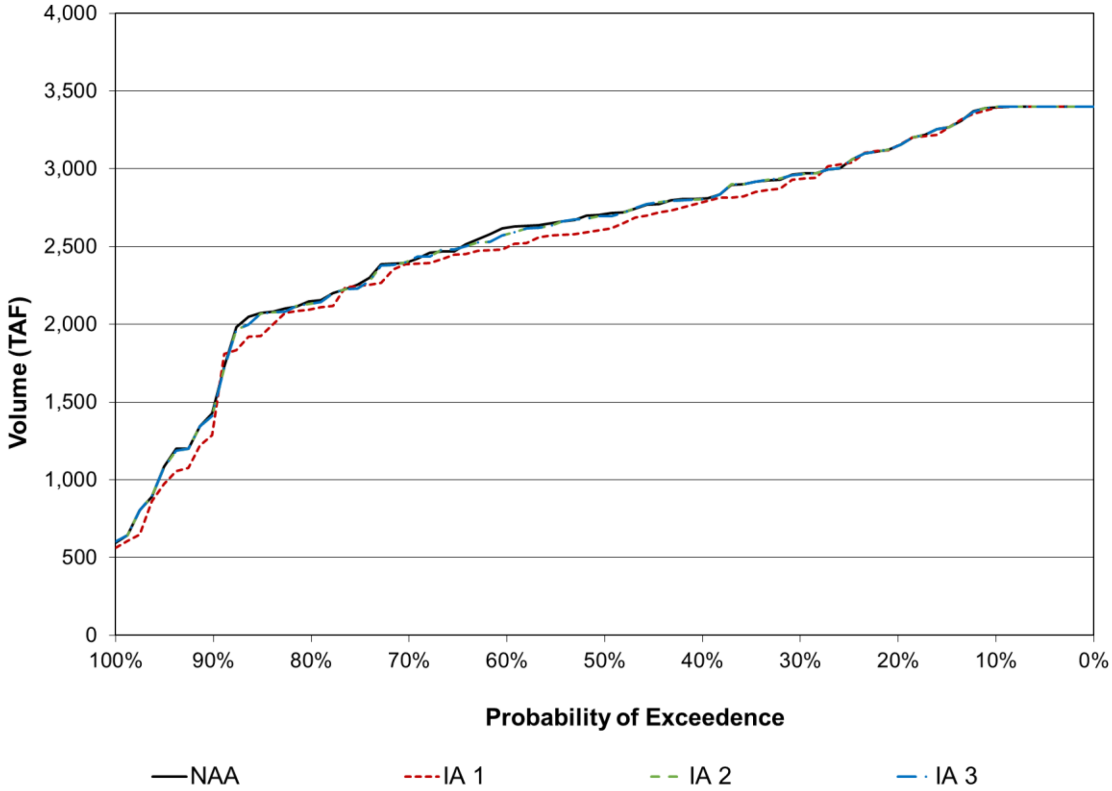


Figure M.1-6. Shasta End-of-September Storage (TAF) Exceedance

Due to IA1's limits on Folsom contribution to system-wide requirements, IA1 shows lower carryover storage at Shasta Reservoir. The small change in Folsom end-of-December carryover target in IA2 and IA3, compared to the No Action Alternative, produces very limited effects to storage. These changes are highlighted in Figure M.1-7, which charts the exceedance of the difference between the IAs and the No Action Alternative.

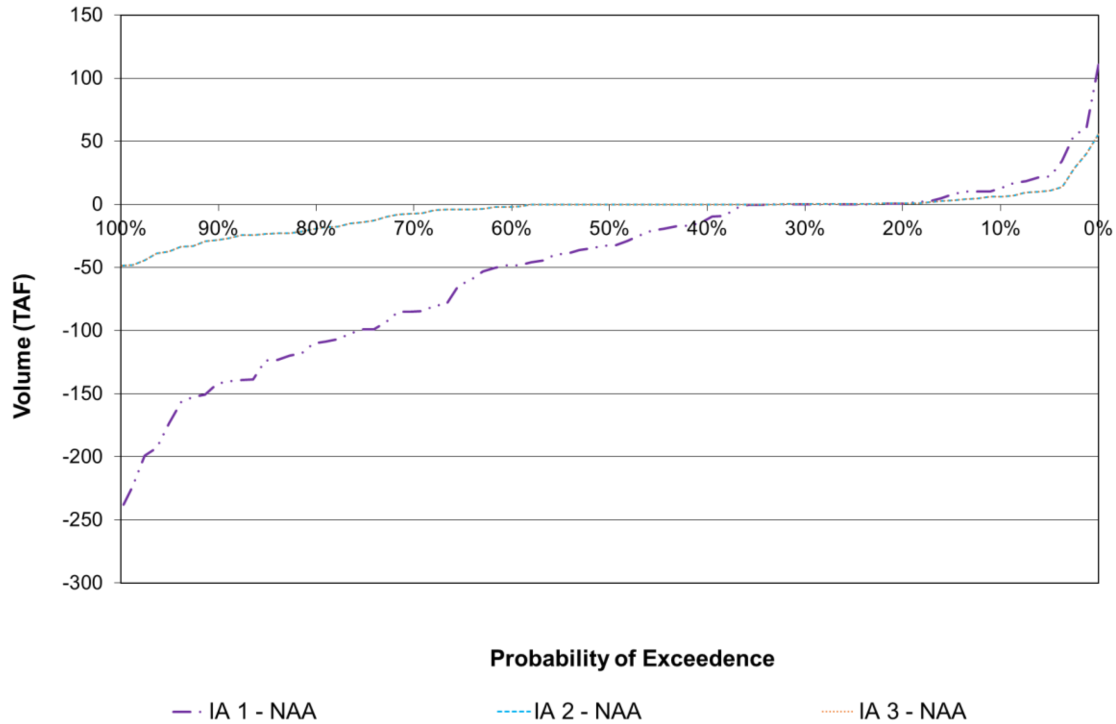


Figure M.1-7. End-of-September Shasta Storage (TAF) Initial Alternative’s Difference from No Action Alternative

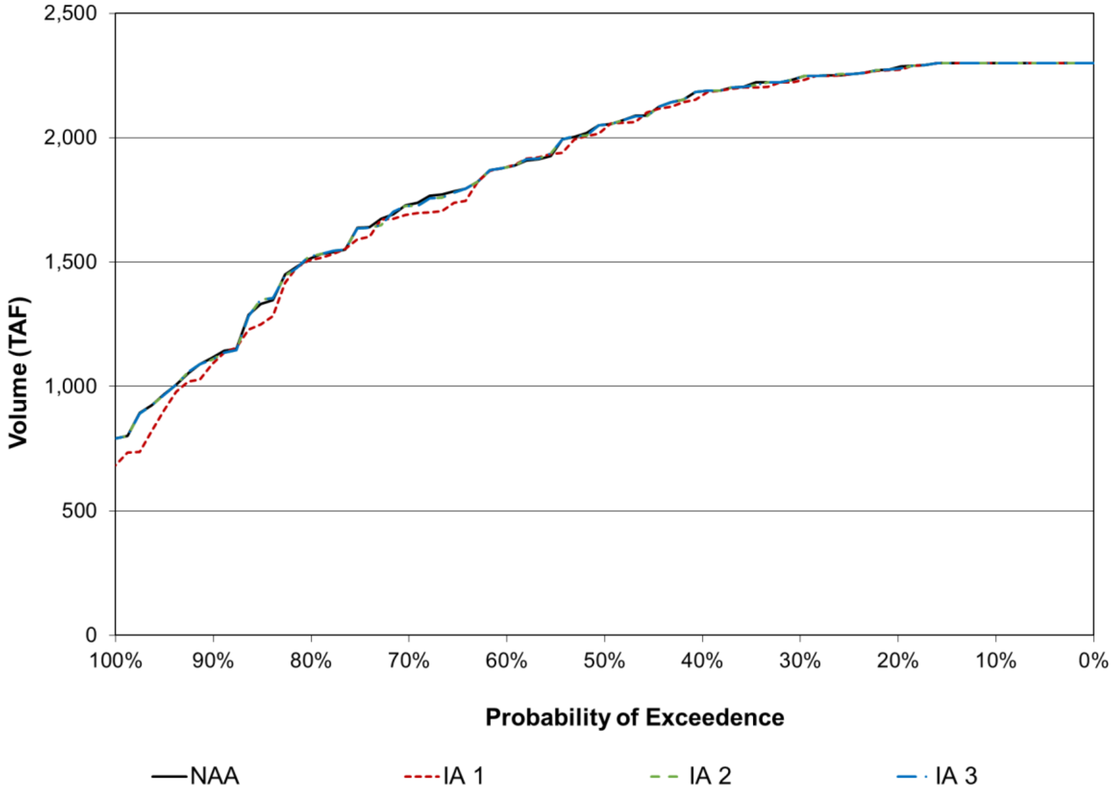


Figure M.1-8. Trinity End-of-April Storage (TAF) Exceedance

Similar to Shasta (Figure M.1-4), Trinity has lower fill storages in IA1, but only small changes in IA2 and IA3.

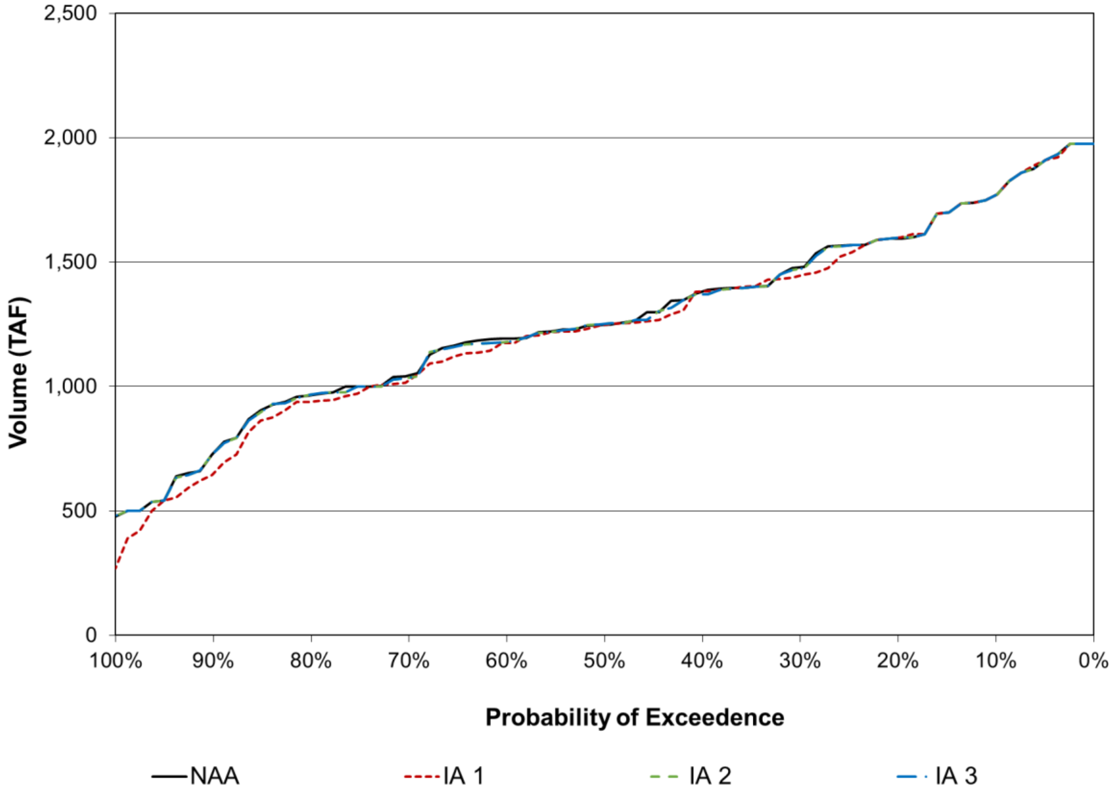


Figure M.1-9. End-of-September Trinity Storage (TAF) Exceedance

Similar to Shasta (Figure M.1-6), Trinity has lower carryover storages in IA1, but only small changes in IA2 and IA3.

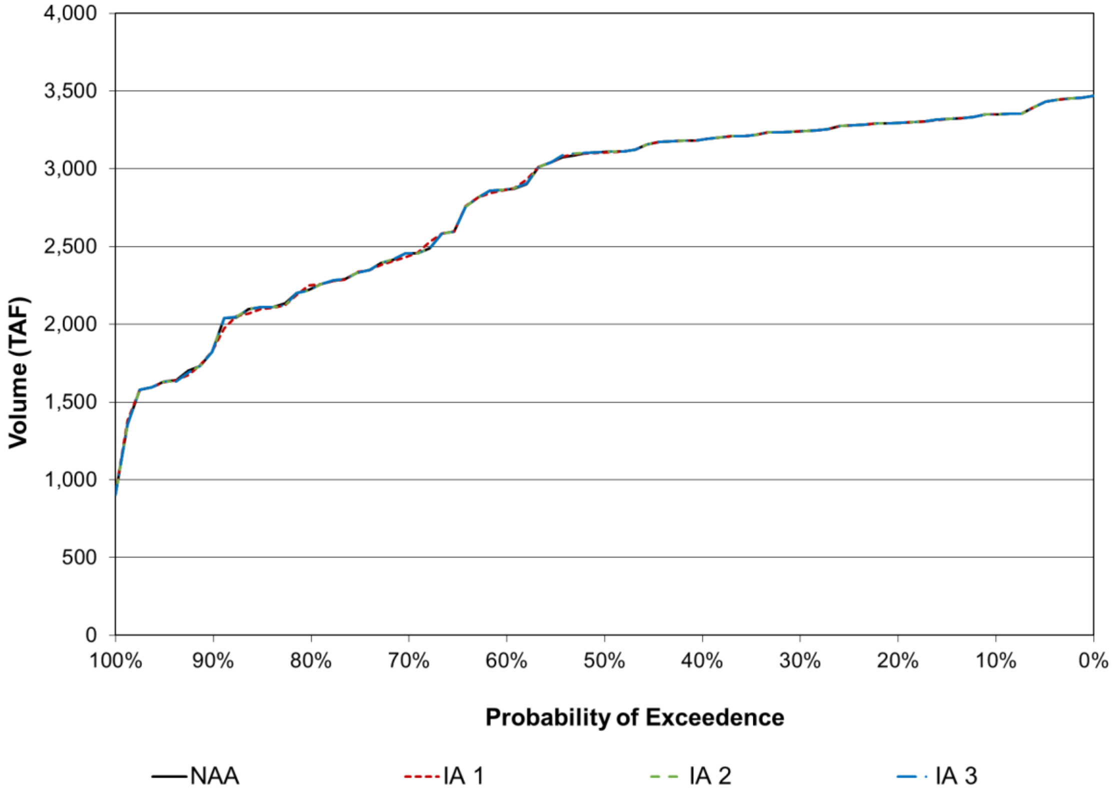


Figure M.1-10. End-of-April Oroville Storage (TAF) Exceedance

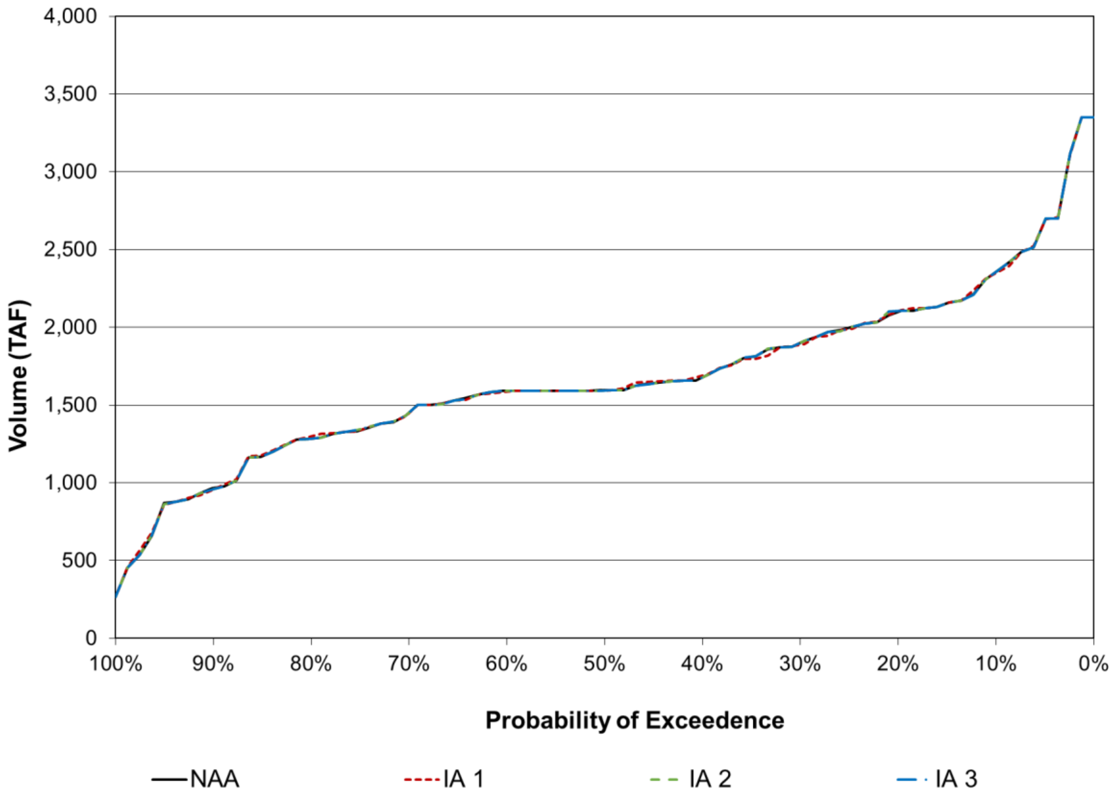


Figure M.1-11. End-of-September Oroville Storage (TAF) Exceedance

As seen in Figure M.1-10 and Figure M.1-11, Folsom operation does not have a great effect on Oroville storage in IA1, IA2, or IA3, as compared to the No Action Alternative. SWP obligations under Conditions of Approval would not change as a result of the Folsom Initial Alternatives.

M.1.3 Flows

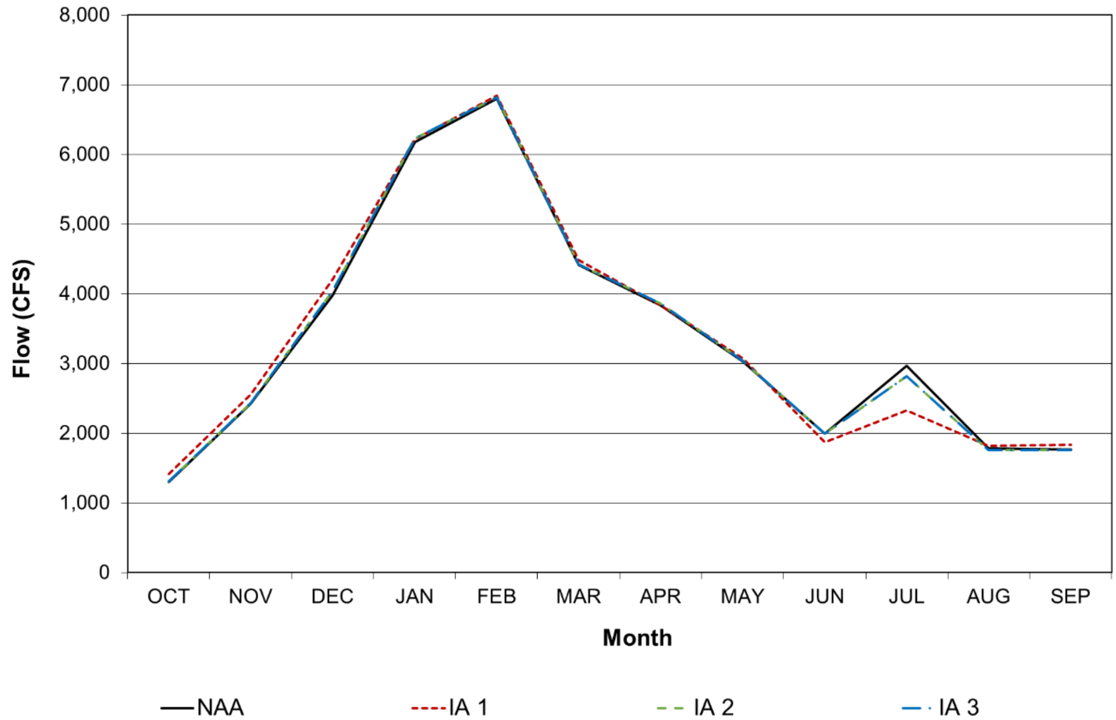


Figure M.1-12. Average Monthly Flow below Nimbus Dam (cfs)

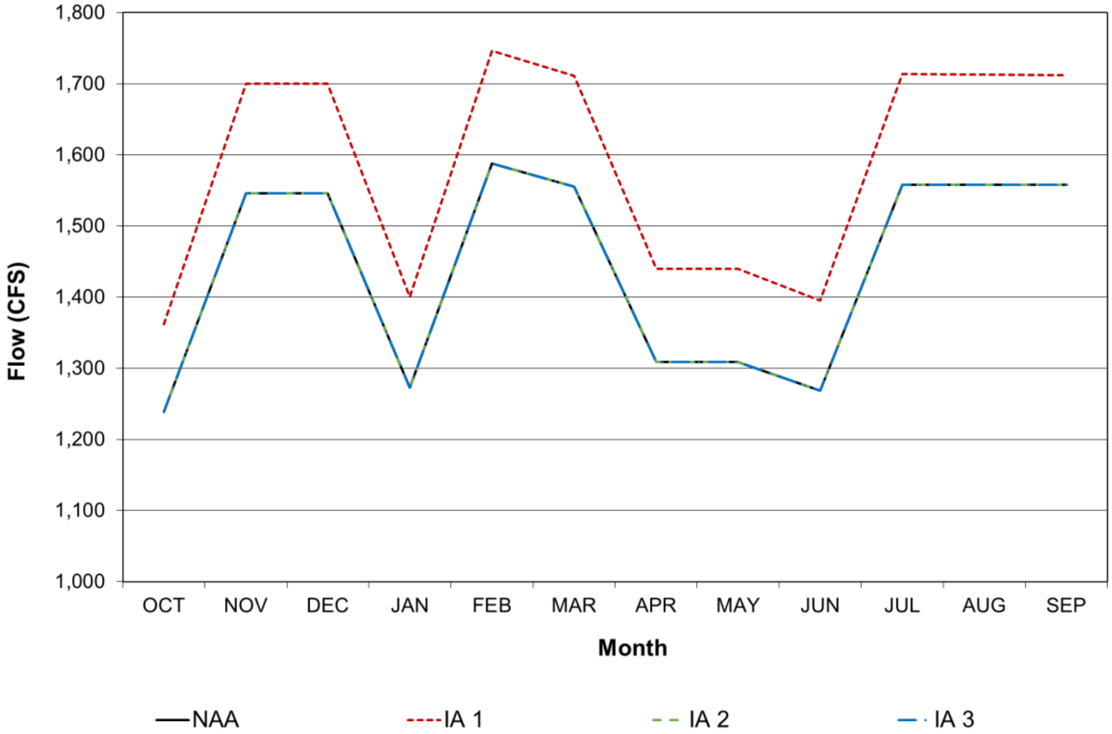


Figure M.1-13a. Average Monthly MRR (cfs)

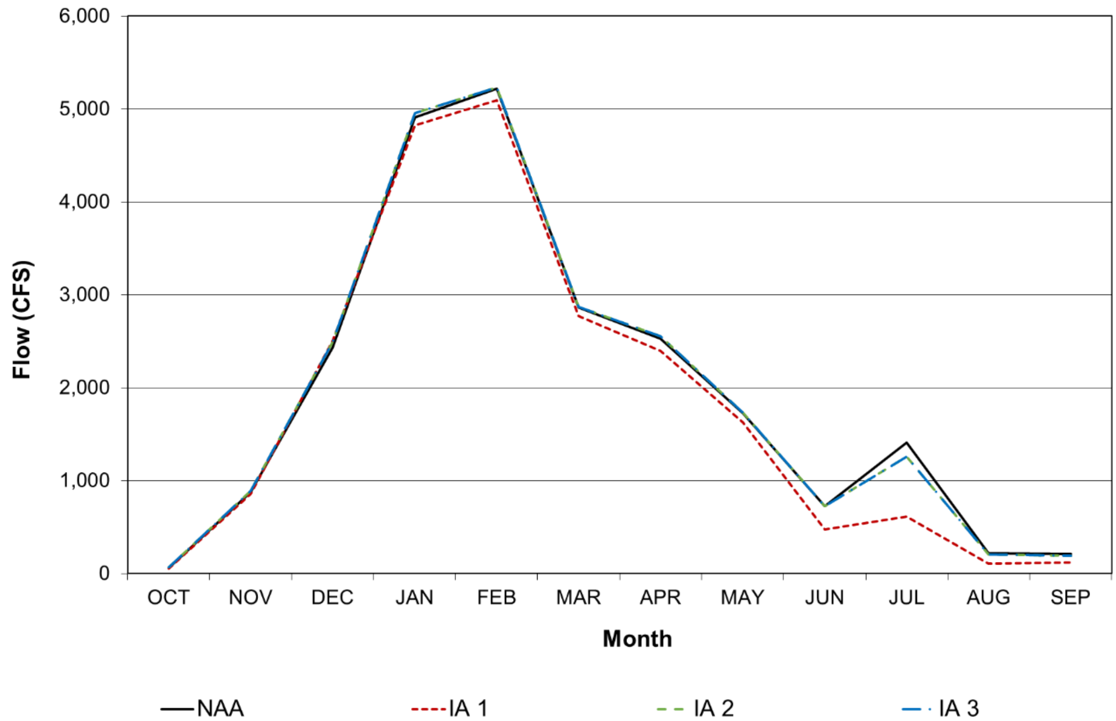
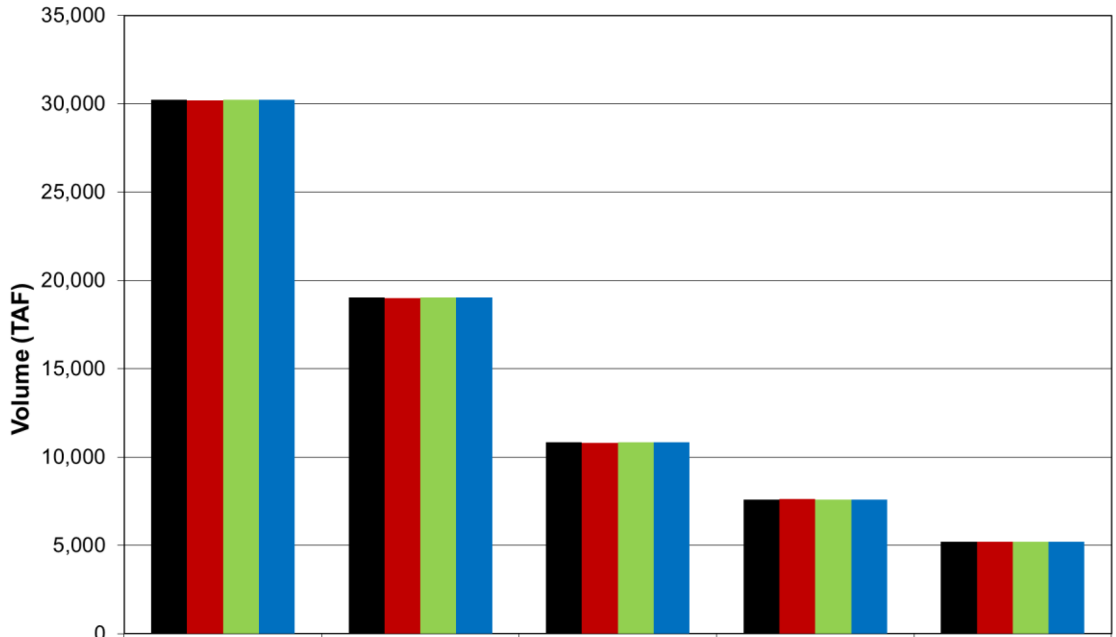


Figure M.1-13b. Average Monthly "Excess" Flow below Nimbus (Flow above MRR) (cfs)

MRRs at Nimbus are between 500 cubic feet per second (cfs) and 2,000 cfs, varying by month and hydrologic condition. Average monthly total flow, seen in Figure M.1-12, indicates that Nimbus releases often exceed the minimums when releases are made for flood control and support of local deliveries, Delta obligations, and exports. CalSim discourages flows above the minimum if there is any likelihood that these additional releases could compromise ability to meet the end-of-December carryover target for Folsom storage.

In IA1, MRR is set 10% higher than its normal values, seen clearly in Figure M.1-13a and noted in Figure M.1-12 in September through December, where the red-dashed line is slightly above the No Action Alternative values. MRR controls releases frequently in these months, so the higher minimums have a notable effect on average flow. In January through May, average flows are similar among all runs—even though the MRR component of flow in IA1 is higher, these flows have less excess, resulting in similar overall flows. This is echoed in Figure M.1-13b, which shows excess flows are now slightly less in IA1 relative to the No Action Alternative in January–May. June and July show the main influence of IA1 on Nimbus releases. Even with the 10% increase in minimum flow, total flow is reduced because excess flows are discouraged as CalSim tries to preserve storage ahead of the December target.

IA2 and IA3 have more limited effects on flows at Nimbus. The higher December carryover storage target results in less release because of less excess, with the largest differences seen in July.



	Wet	Above Normal	Below Normal	Dry	Critically Dry
NAA	30,206	19,018	10,824	7,585	5,206
IA 1	30,186	19,011	10,819	7,619	5,216
IA 2	30,218	19,017	10,826	7,604	5,206
IA 3	30,218	19,017	10,826	7,604	5,206

Figure M.1-14. Annual (Oct–Sep) Total Delta Outflow (TAF) by Water Year Type (40-30-30)

The Folsom Initial Alternatives have only a small effect on Delta outflow.

M.1.3.1 Exports and American River Deliveries

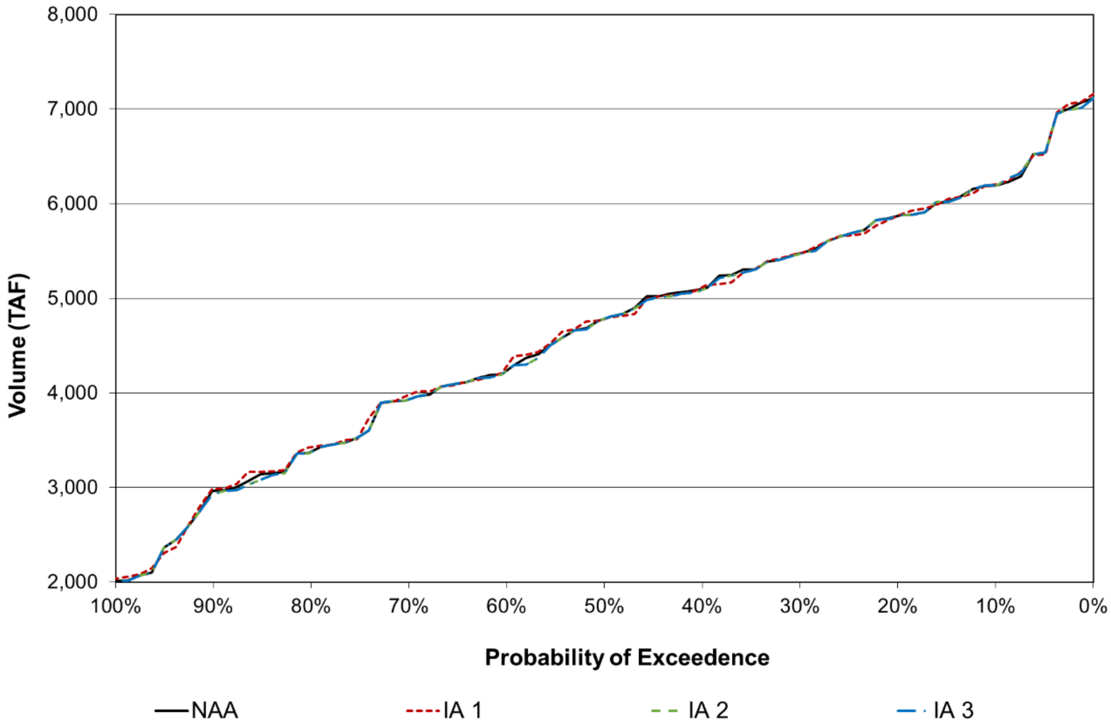
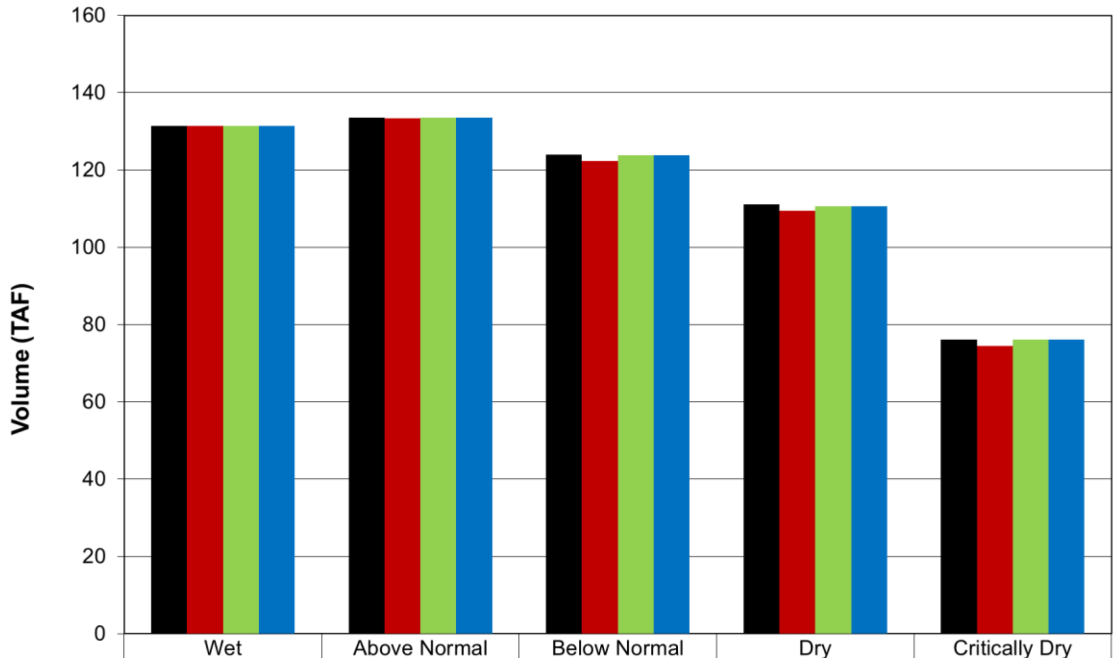


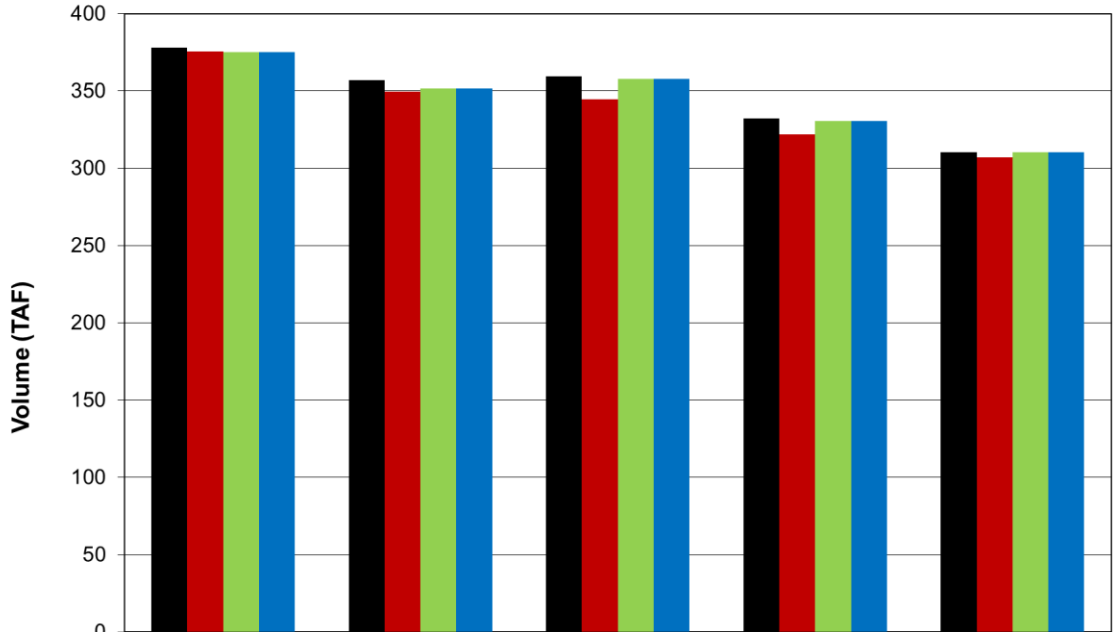
Figure M.1-15. Annual (Oct–Sep) Exceedance of Total Project Exports (TAF)

The Folsom Initial Alternatives have only a small effect on project exports.



	Wet	Above Normal	Below Normal	Dry	Critically Dry
NAA	131	134	124	111	76
IA 1	131	133	122	109	74
IA 2	131	133	124	111	76
IA 3	131	133	124	111	76

Figure M.1-16a. Average Annual (Mar–Feb) American River CVP Deliveries (TAF) by Water Year Type



	Wet	Above Normal	Below Normal	Dry	Critically Dry
NAA	378	357	360	332	310
IA 1	375	349	345	322	307
IA 2	375	352	358	331	310
IA 3	375	352	358	331	310

Figure M.1-16b. Average Annual (Mar–Feb) American River Non-Project Deliveries (TAF) by Water Year Type

Figure M.1-16a and Figure M.1-16b present the American River deliveries. Small reductions to the CVP deliveries can be seen in IA1 in the drier water year types, but CVP deliveries under IA2 and IA3 are very similar to the No Action Alternative. The American River non-project deliveries show reductions under IA1 in all water year types. IA2 and IA3 also see reductions to non-project deliveries, but at much smaller levels.

M.1.4 Analysis

Reclamation’s management questions for the formulation of a Folsom Reservoir alternative include the following:

M.1.4.1 What risks occur from operating to a 50% exceedance forecast early in the water year?

A sensitivity study was performed to analyze changes to the MFMS flows if different forecast exceedances were used. The MFMS uses the American River Index (ARI) to set flows in most months; the ARI is unimpaired inflow to Folsom, minus spills, so forecast sensitivities use different forecast exceedances (50% and 90%) for unimpaired inflow to Folsom.

M.1.4.1.1 Step 1: Calculating the New Forecast

Creating forecasted, unimpaired inflows to Folsom was built on the approach used in creating the CalSim input table "American_Runoff_Forecast.table." This table uses increasing confidence (i.e., February uses the 99% exceedance, whereas May uses the 50% exceedance) to estimate the runoff that will occur in the rest of the water year. This was modified to create a constant exceedance (50% or 90%) and reflect forecasted, unimpaired inflow for the full water year.

Using the climate-change precipitation values for February through September, precipitation that has already fallen is summed; precipitation that will fall through the end of the water year is summed separately. For example, in March, October through February precipitation amounts are added together, and March through September precipitation amounts are added together.

To determine the forecast of precipitation that has not yet fallen, for each calendar month, take all of the summed precipitation through the end of the water year for that month, and calculate the exceedance level for the forecast that will be used. For example, for the April 50% forecast, using summed April through September precipitation for all years, calculate the 50% exceedance. These forecasted precipitation values are then added to the summed precipitation total that has already fallen to create the full water year precipitation forecast. Continuing the example above, in calculating the 1923 April 50% forecast, the 50% exceedance April through September precipitation would be added to the summed October 1922 through March 1923 precipitation.

The precipitation forecast is then converted to unimpaired inflow, using a regression between full water year precipitation and full water year unimpaired inflow.

M.1.4.1.2 Step 2: Applying the New Forecast

Forecasted unimpaired flows are calculated for February through September at the 50% and 90% exceedance level. October through January uses the full unimpaired flow for the previous water year. These values are then added to an input timeseries that replaces the perfect foresight lookup table in the MFMS code.

M.1.4.1.3 Results

Using the exceedance values, some years would be expected to overestimate the amount of inflow and some years to underestimate it. At the 90% exceedance, this method seems to overestimate inflow. With 82 years in the sequence, about 8 years would be expected with inflow higher than the 90% exceedance; these results show 13 years when inflow in the 90% forecast is higher than the actual, resulting in higher flows than the No Action Alternative. This approach also misses high inflows, but causes less effects because most MRR flows are constant when the ARI reaches approximately 2-million acre feet.

Flows generally follow the trend of higher forecasted unimpaired inflow results in higher MRR. The exception seems to be in some Marchs, where a lower forecast drops an MRR above 1,500 cfs to below 1,500 cfs, triggering a pulse flow.

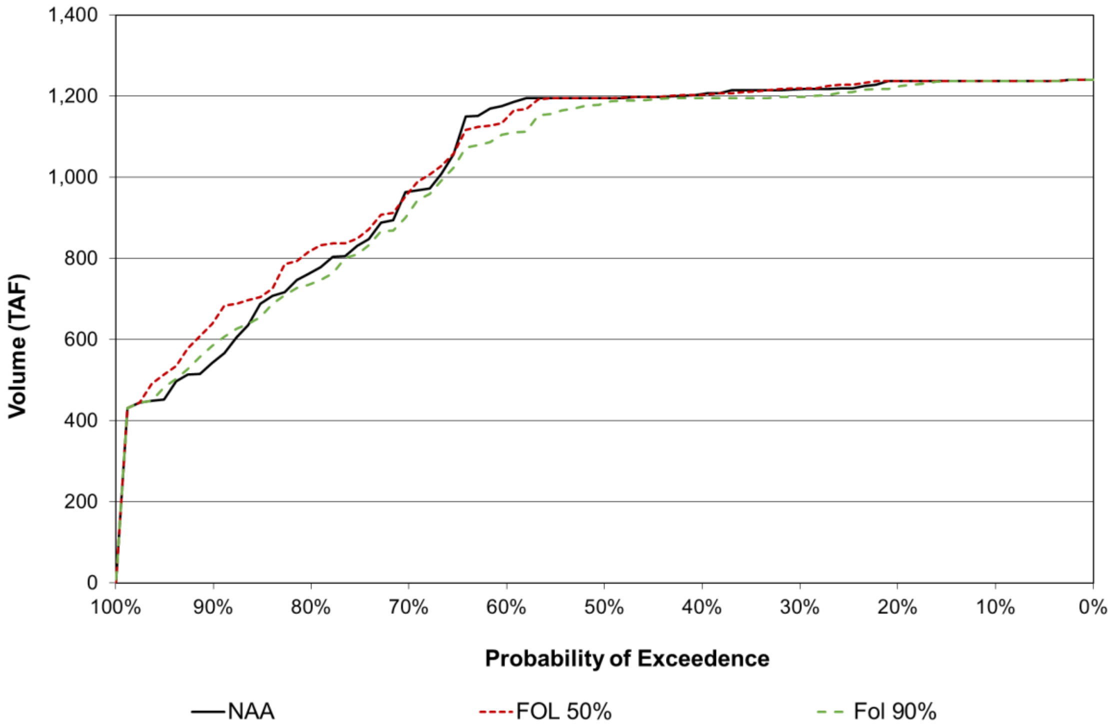


Figure M.1-17. Annual (Mar–Feb) MRR Flows

Figure M.1-17 shows the annual MRR flows. With the 50% exceedance forecast, it is expected that the forecast would underestimate the higher unimpaired flow and overestimate the inflow in drier years. This is seen in the releases where the 50% forecast results in higher MFMS releases than the perfect foresight used in the No Action Alternative in the drier 65% of years. Similarly, the 90% forecast would be expected to overestimate the inflow in the 10% driest years (although the 90% overestimates the perfect foresight of the No Action Alternative in the driest 12% of years). The 90% forecast is usually lower than the perfect foresight the rest of the time (except in the wettest years, when the model releases the highest MFMS flows).

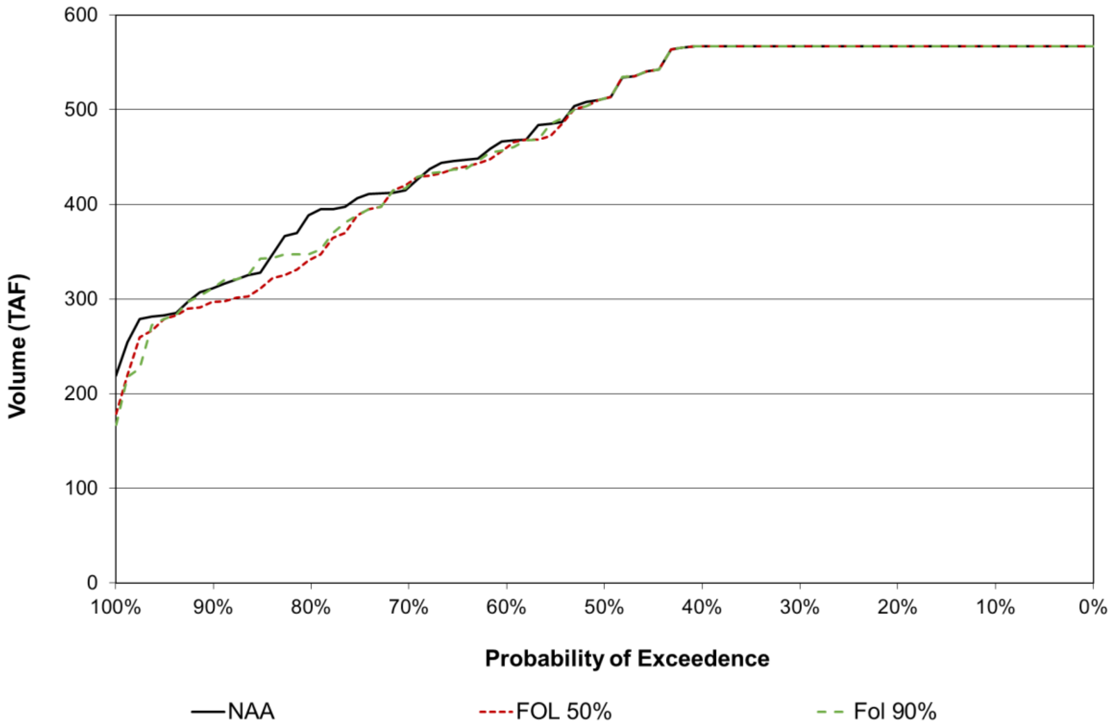


Figure M.1-18. End-of-December Folsom Storage (TAF)

The Folsom storage signal is somewhat lost because the forecast is also used to set the carryover targets. Using a lower forecast (e.g., the 90%), the model calculates release limits that are intended to meet the carryover target using lower MFMS demands, allowing storage to draw down further. If unimpaired inflow is higher than the forecast, then MFMS flows are likely to increase, but storage may have already drawn down to the point where it cannot meet both the higher MFMS flows and the carryover target.

M.1.4.2 What temperature targets reasonably protect steelhead, while leaving sufficient cold water for fall-run Chinook salmon?

IA1 provides a May through October temperature target of 65°F at Watt Avenue, with bypasses, as necessary, beginning September 15. As modeled, bypasses can be up to the full release rate if sufficient cold water exists, and it is necessary to meet the temperature target.

IA2, as described, provides a temperature target of 65°F at Hazel Avenue, with no bypass. However, power bypass is a necessary portion of the Folsom HEC-5Q model logic that cannot be readily disabled. Bypass conditions were therefore maintained as described in IA1 to give a consistent comparison between alternatives.

IA3 was not modeled.

The No Action Alternative was modeled using ATSP following the 2019 Biological Opinion. Values are reported referenced to Watt Avenue. The coldwater pool was not reported for the No

Action Alternative because the version of the model with the ATSP logic does not output reservoir temperatures.

Figures M.1-19 and M.1-20 give degree days above the temperature target for each alternative as a function of end-of-April storage (i.e., fill) and end-of-September storage (i.e., carryover). Although temperature-dependent mortality models do not exist for the American River, degree days above the target can be used as a predictor for anticipated mortality, with higher degree days generally corresponding to increasing mortality. Temperature compliance is a strong function of fill, with both IA1 and IA2 showing a decrease in mortality with increasing storage. The correlation is less strong for carryover from the previous water year, indicating that winter hydrology and inflows are the determining factors in temperature-target compliance.

Both alternative conditions perform worse than the No Action Alternative in years with low fill, but have equal or better performance than the No Action Alternative in years with greater than 600 TAF of fill. As a function of carryover storage, No Action Alternative performance is almost constant as a function of carryover. By contrast, the performance of both alternatives is bifurcated, with many years having better temperature performance and a small number having worse performance.

Use of the coldwater pool by the model within both alternatives was generally good, as indicated by Figure M.1-21, which counts the frequency of coldwater volume less than or equal to 52°F on October 31 across water years. Bins are given in 25 TAF increments. IA1 skews strongly toward having minimal cold water remaining, with nearly 50 of the 81 modeled years occurring in the first bin, with less than 25 TAF. However, both alternatives have more than 50 of the 81 modeled years having less than 50 TAF of 52°F remaining. IA2 does have a somewhat larger fraction of years with more coldwater volume remaining, indicating that there may be additional thermal capacity remaining in the system to further lower temperatures.

Power bypass is utilized with different frequency between the No Action Alternative and the initial alternatives. Although the No Action Alternative employs power bypass in just a handful of years, the initial alternative scenarios use power bypass in at least a third of years with IA1 using bypass more frequently than not. The bypass logic within the initial alternative scenarios allows unlimited use of bypass during the allowed window, if necessary to meet temperature. The No Action Alternative scenario utilizes a different release logic that does not allow bypass as readily. Unfortunately, the specific logic causing this difference is unknown because the source code for the 2019 Biological Opinion logic is not available.

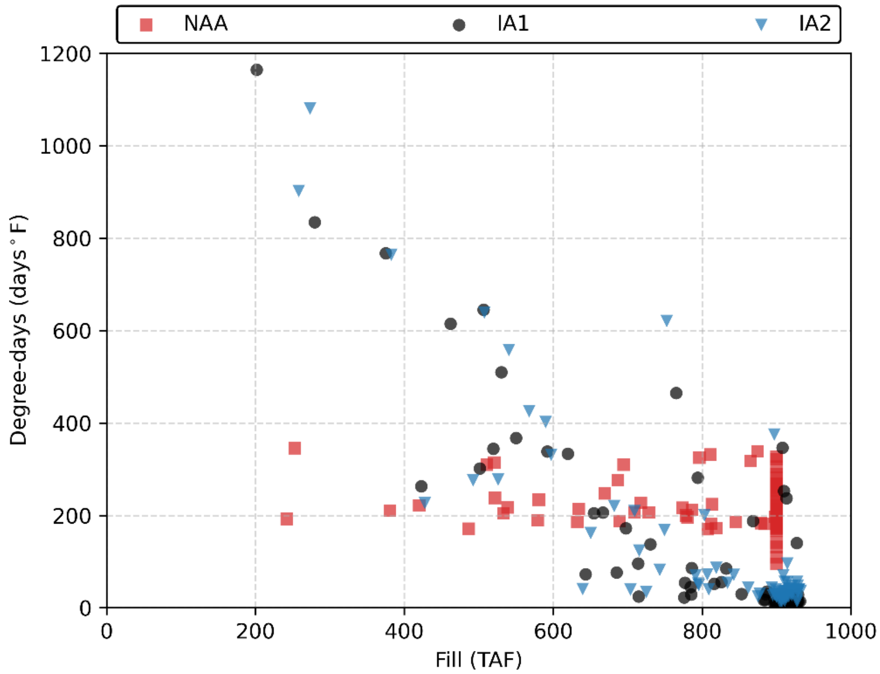


Figure M.1-19. Degree Days above the Temperature Target as a function of Folsom End-of-April Storage

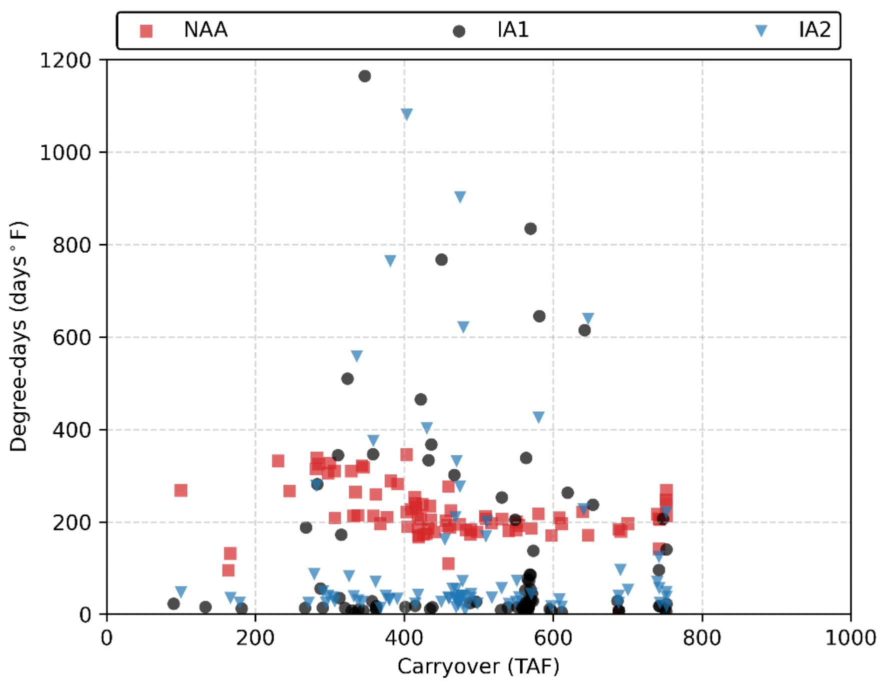


Figure M.1-20. Degree Days above the Temperature Target as a Function of Folsom September Carryover Storage

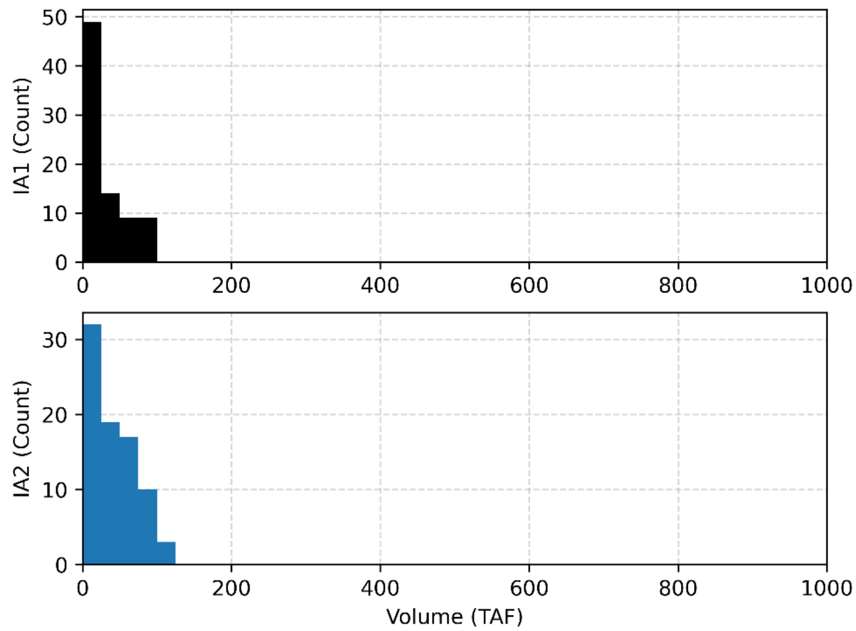


Figure M.1-21. Histogram of the Coldwater Volume at or less than 52°F on October 31 for each Alternative, Given in 25 TAF Increments

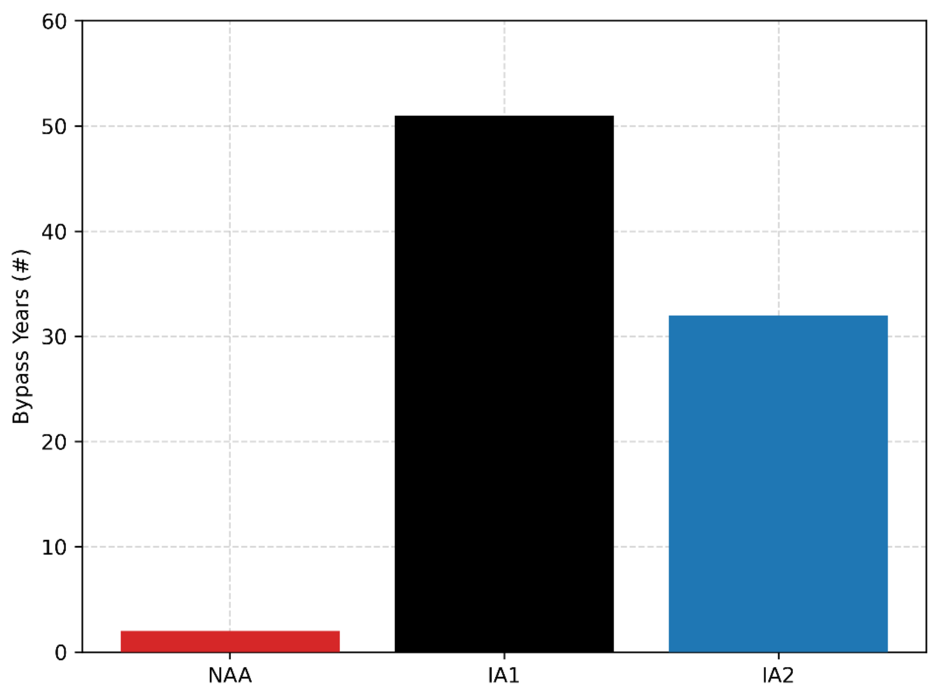


Figure M.1-22. Number of Years with an active Power Bypass for each Alternative

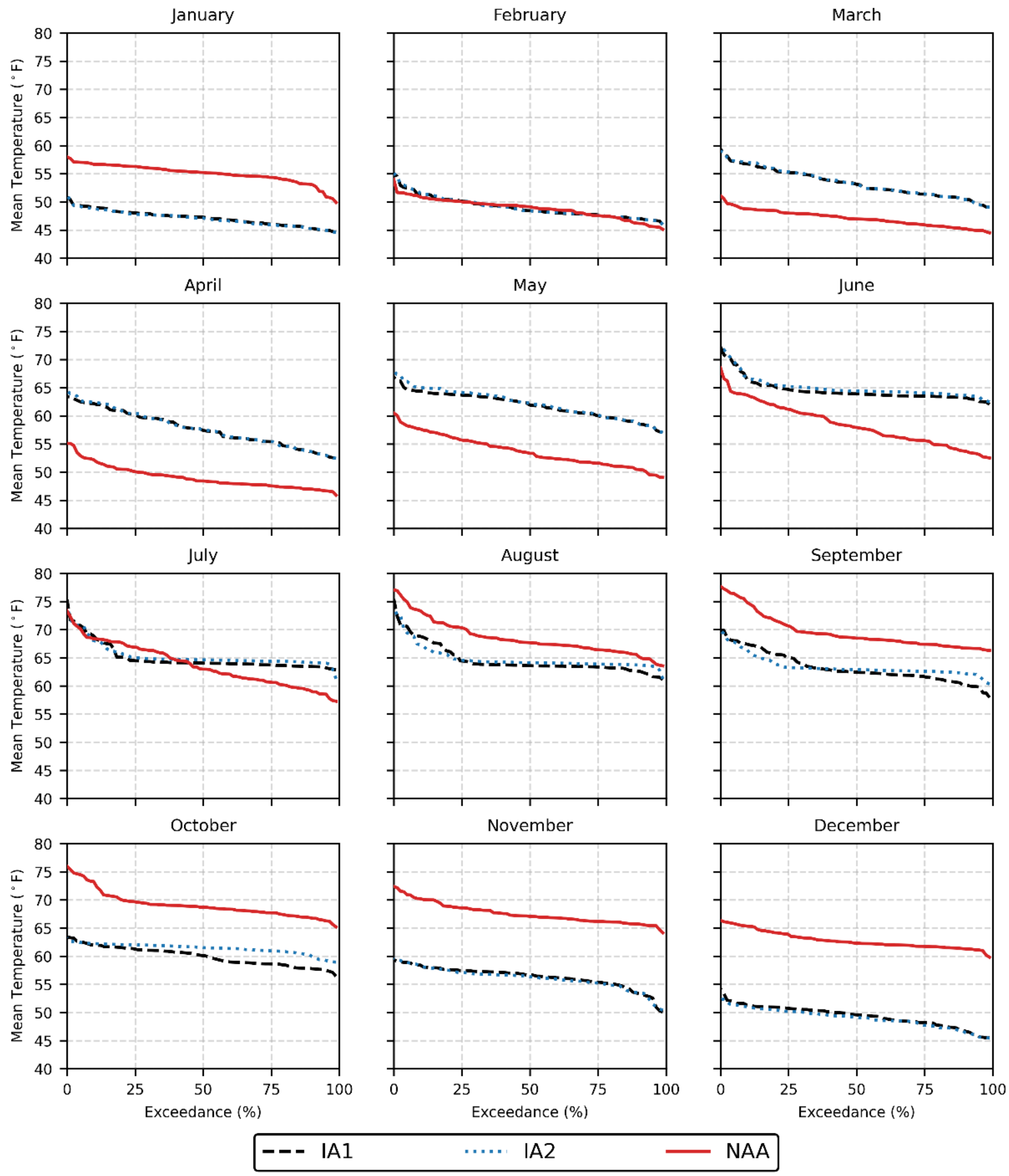


Figure M.1-23. Monthly Temperature Exceedance at Watt Avenue for the No Action Alternative and each Initial Alternative

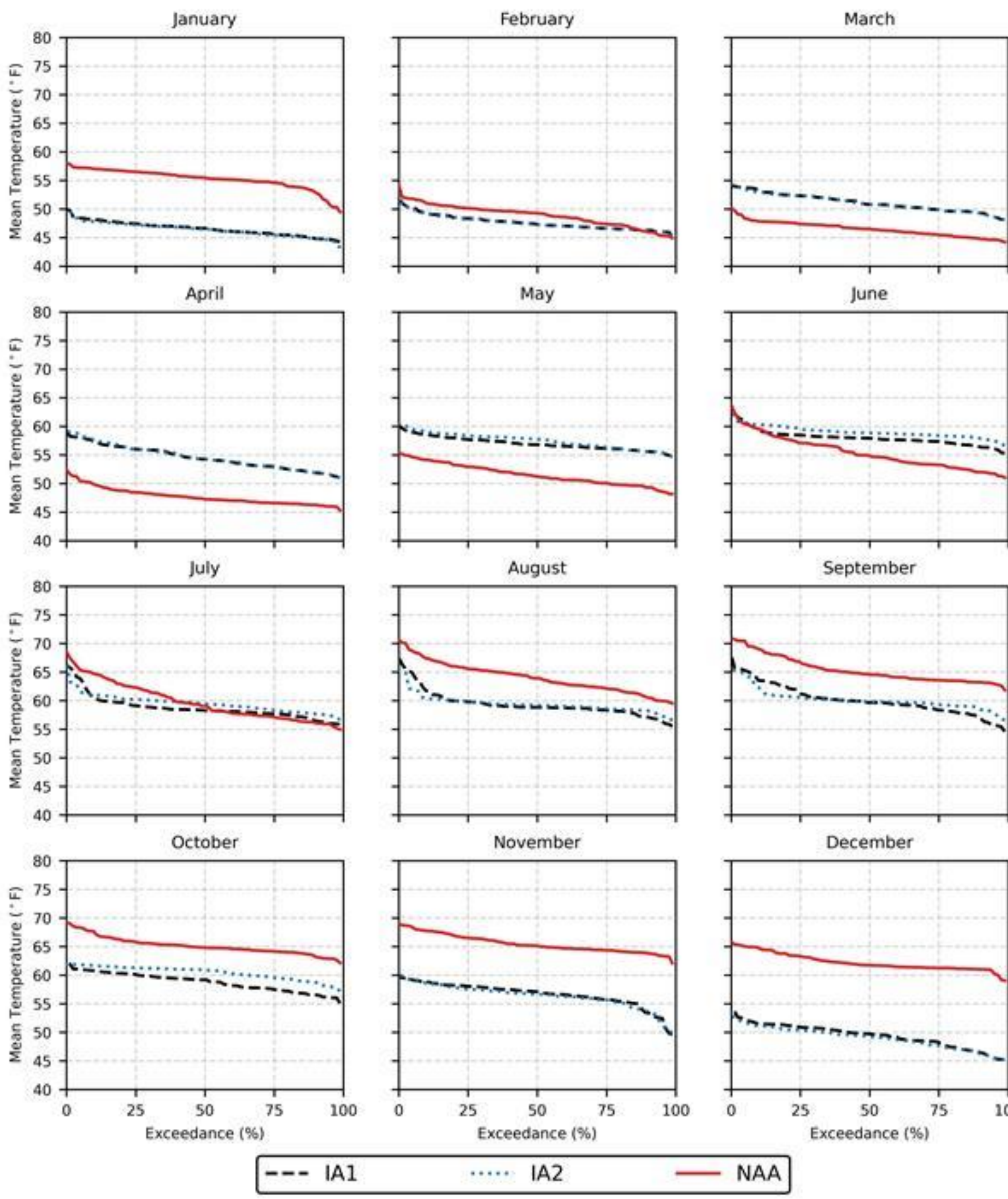


Figure M.1-24. Monthly Temperature Exceedance at Hazel Avenue for the No Action Alternative and each Initial Alternative

M.1.4.3 How do release on the American River affect Shasta Reservoir, Bay-Delta WCQP, and exports?

M.1.4.3.1 Shasta Reservoir

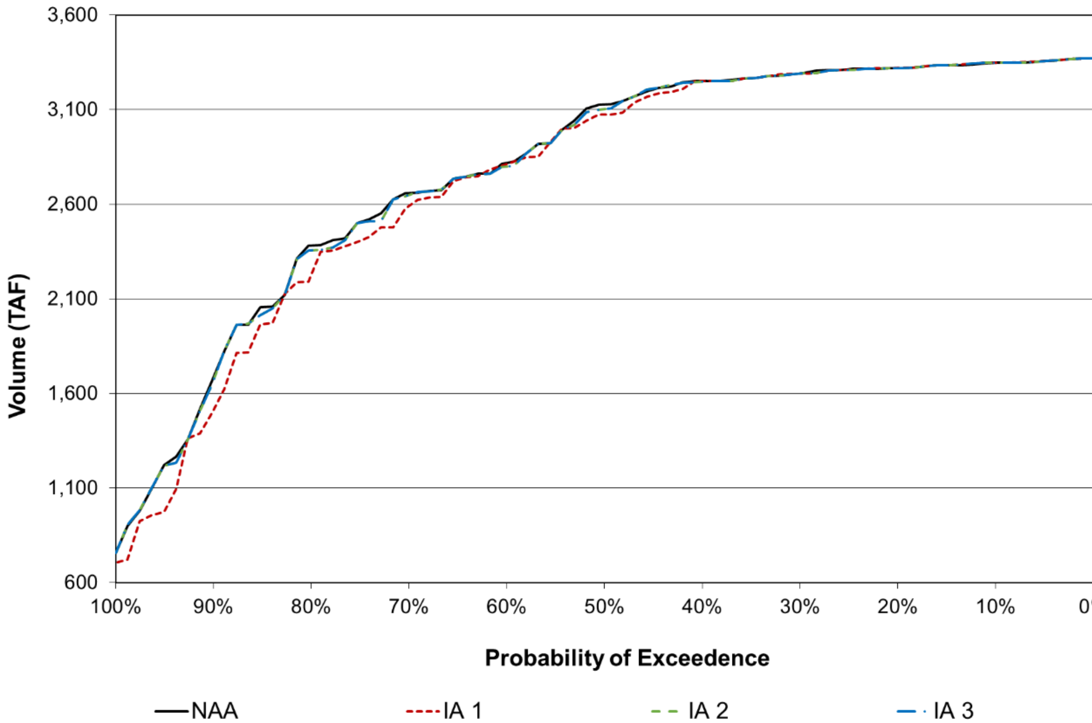


Figure M.1-25. Shasta End-of-December Storage (TAF) Exceedance

IA1 requires more releases from Folsom, while targeting more end-of-December storage, which limits Folsom's ability to contribute to other system needs. IA1 can result in other reservoirs needing to release additional water to replace the water that Folsom keeps in storage. IA1 shows lower storages at Shasta. The small change in IA2 and IA3, compared to the No Action Alternative, only results in small changes to other system operations, resulting in small changes to storage.

M.1.4.3.2 Water Quality Control Plan

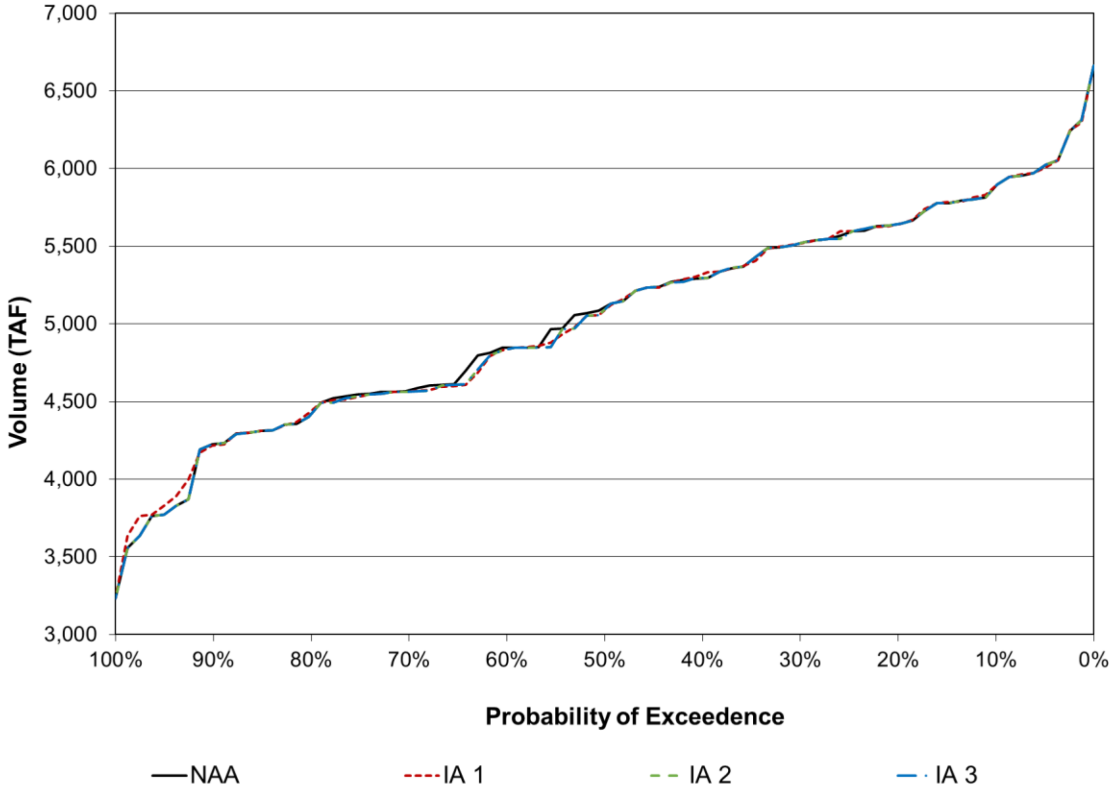
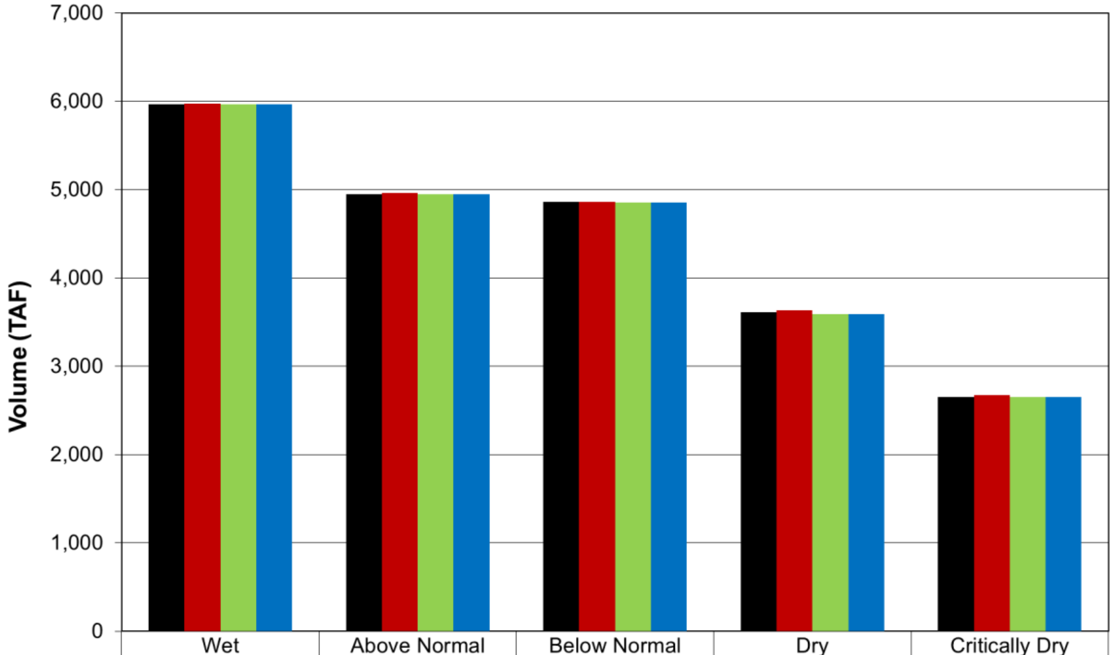


Figure M.1-26. Annual (Oct–Sep) Minimum Required Delta Outflow (TAF) Exceedance

Requirements in the Delta are not expected to change as a result of the Folsom Initial Alternatives. Folsom may contribute less in order to meet end-of-December carryover targets, but the CVP obligation to the Delta will remain very similar.

M.1.4.3.3 Exports



	Wet	Above Normal	Below Normal	Dry	Critically Dry
NAA	5,969	4,950	4,862	3,611	2,652
IA 1	5,970	4,960	4,858	3,632	2,673
IA 2	5,964	4,945	4,857	3,593	2,651
IA 3	5,964	4,945	4,857	3,593	2,651

Figure M.1-27. Annual (Oct–Sept) Total Project Exports by Water Year Type (40-30-30)

The Folsom Initial Alternatives result in small changes in exports