Public Comment
Bay-Delta Phase II Working Draft Report
Deadline: 12/16/16 12:00 noon

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NCWA
Northern California Water Association

To advance the economic, social and environmental sustainability of Northern California
by enhancing and preserving the water rights, supplies and water quality.

December 16, 2016

Felicia Marcus, Chair
Members of the Board
State Water Resources Control Board
P.O. Box 100
Sacramento, CA 95812

Re: Scientific Basis Report, Phase II WQCP Update

Dear Chair Marcus and Members of the Board:

The Northern California Water Association (NCWA) and the Sacramento Valley Water Users (SVWU) provide the following comments on the draft Phase II scientific basis report (Draft SBR). We appreciate the State Water Board circulating this as an initial "working draft" and we provide our comments in this vein—to help develop a more robust next draft of the report. In addition to our comments, we will follow up with the State Water Board to provide this information in more detail and we also stand ready to provide any additional information upon the request by the State Water Board staff.

In sum, we strongly believe that California needs a more progressive approach to water management than one simply based on some selected percentage of "unimpaired flows." The following summarizes why an "unimpaired flow" approach would not work for 21st century California, while also proposing a "functional flow" approach for the Sacramento Valley that more closely reflects the need to efficiently serve multiple beneficial uses of water in a state with 39 million people. We also believe that a close review of recent science surrounding the Delta suggests the State Water Board should evolve and offer a different approach that relies upon the current science supporting "functional flows."

I. The unimpaired flow approach would not work for 21st century California.

The "unimpaired flow" approach would not be practical as a regulatory approach nor would it help foster or serve as a good measure for the success of negotiated resolutions or voluntary agreements as called for in the California Water Action Plan. Water suppliers in every part of California expressed concerns with this approach last July 25 for this reason. (*see* letter, Appendix 1.)

The "unimpaired flow" approach is a variation of an old and tired dogma where redirecting water for instream flows was the objective, rather than focusing on how water can best serve multiple beneficial purposes such as fish, birds, cities and farms, as required by Water Code §13000 *et seq*. The "unimpaired flow" approach also belies 21st century water management that is necessary to serve 39 million people with a highly diverse landscape in California. This simplistic approach would provide little, if any, benefit for the environment in the Bay-Delta water system, and would adversely affect the environment in upstream areas such as the Sacramento Valley by depleting cold water reservoir supplies that are needed for salmon, by reducing available water supplies for birds and the Pacific Flyway, and by limiting food production throughout the Sacramento Valley that is necessary for healthy fish and birds.

Importantly, redirecting wholesale blocks of water into the Delta without clear scientific benefits would undermine the state's co-equal goals and would be a waste and unreasonable use of water in California.

A. An unimpaired flow objective would not be likely to benefit fish in the Delta.

- California has tried a highly flow-centric approach in the Delta for the past several decades, with agencies re-directing more than **1.3 million acre-feet more water per year for Delta outflow** over the past several decades. (*See* MBK Engineers and HDR "Retrospective Analysis of Changed Central Valley Project and State Water Project Conditions Due to Changes in Delta Regulations," January 2013; see Appendix 2.) This has <u>not</u> improved fisheries in the Delta and it appears that there have been further declines in pelagic fisheries with these additional flows. Now is the time to try a different approach, as described below.

- Modern science has shown that **dedicating large blocks of water** to a sterile and inhospitable channelized river provides **little or no benefit to fisheries** in the Delta. For example, the Delta Independent Science Board in "Flows and Fishes in the Sacramento-San Joaquin Delta" (August 2015) presented a report that highlighted this dynamic. The Lead Scientists for the program have also presented this information to the State Water Board on several occasions over the past several years, explaining that adding water to a clear, inhospitable channel, such as those in the Delta, would not improve fisheries unless other issues are addressed.

- The State Water Board held a series of **workshops in 2012** to bring good modern science to the process. The October draft scientific basis report has completely ignored the entire 2012 process. In that process, **ICF presented a formal report** to the SWRCB that raised some serious questions about the "unimpaired flow" approach. The draft scientific basis report also has completely ignored peer-reviewed and published scientific reports that question the relationship between Delta flows and Delta fish abundance. Instead, the Draft SBR relies on old, outdated reports.

- A snapshot of the current and evolving science surrounding the Delta can be seen in the recent **Delta Science Program report** "The Delta on Fast Forward: Thinking Beyond the

Next Crisis" (November 2016), where there is a focus on various priority stressors that do not include unimpaired flows into the Delta.

- For **salmon,** Dave Vogel, a leading expert on salmonid species who presented and submitted important biological information and analyses during the 2012 workshops, has undertaken a detailed review of the Draft SBR sections pertaining to anadromous salmonids. A copy of Mr. Vogel's report is attached as Appendix 3, and his key conclusions and recommendations are summarized as follows:

  - The best available science concerning anadromous salmonids was not used in preparing the Draft SBR--relevant science on anadromous salmonids, previously provided for the 2012 Workshops, was overlooked or ignored.

  - Information regarding Sacramento River basin anadromous salmonids presented in the Draft SBR is incomplete and largely out-of-date.

  - Many statements in the Draft SBR regarding anadromous salmonids are unsubstantiated with no supporting scientific basis.

  - The Draft SBR does not address major scientific uncertainties or highly complex variables affecting salmonids.

  - There are numerous conflicting and confusing statements concerning unimpaired flows and natural flows.

  - The draft SBR frequently recommends "mimicking the natural hydrograph" for purported benefits to anadromous salmonids, but then also recommends artificially "sculpting" flows that would not reflect natural hydrologic conditions.

  - The Draft SBR lacks descriptions of alleged flow-related problems in the Sacramento River and its tributaries on a specific spatial and temporal basis.

  - The Draft SBR is severely deficient in not providing any meaningful details on non-flow measures that could be implemented to benefit salmonids.

  - The Draft SBR does not adequately describe the specific biological mechanisms that would result from the flow recommendations, and does not quantify how those mechanisms would benefit anadromous salmonids.

  - The Draft SBR provides no meaningful discussion of the redirected impacts on other species and life stages that would result from the flow recommendations – e.g., major reductions in water storage in the large reservoirs (Shasta, Oroville, Folsom).

  - The Draft SBR is severely deficient in the section concerning other stressors on anadromous salmonids, and additional management actions which could be implemented to benefit salmonids.

- For **pelagic fish,** Dr. Robert Latour, an expert on the use of biostatistics in fishery management and who also presented important information during the 2012 workshops, has reviewed the Draft SBR's sections concerning pelagic fish in the Delta. A copy of Dr. Latour's comments is attached as Appendix 4. His comments include the following:

  - The Draft SBR does not consider peer-reviewed, published scientific reports that demonstrate that statistical analyses based on Fall Midwater Trawl indices on which the Draft SBT is based are flawed.[1]

  - By relying strictly on survey indices, the Draft SBR disregards a very large amount of instructive information concerning the relationship between fish behavior and condition and environmental variables. The basis for a much more robust analysis would be readily available in existing data if the analysis instead were to be based on the raw survey data, rather than only on the indices, as is the currently dominant approach.

  - The Draft SBR does not account for known and significant scientific uncertainty with current fish abundance indices. Failing to account for that uncertainty significantly detracts from the value for policymaking of any analysis based on those indices.

  - As a result of these problems with the current method of analysis of the relationship between environmental variables and Delta fish populations, including the analysis reflected in the Draft SBR, the Draft SBR does not meet the scientific standards applied by, among other agencies in the United States, NOAA Fisheries in developing policy for other fish-management programs, such as setting acceptable levels of commercial fish harvest.

- Although the "unimpaired flow" approach is suggested as a way to **mimic natural flow patterns**, this would not be the case in the Sacramento Valley. The term "natural" flows describe the flows that would have occurred absent all anthropogenic influences and is considered to represent flows during the period before significant landscape changes in the Delta and Sacramento River basin. Since then, there have been substantial changes in land use, including the clearance and drainage of wetlands and constructions of levees for flood control, which have ended the natural cycle of bank overflows and detention storage. These influences have dramatically affected Central Valley and Delta flows. For this reason, **unimpaired flows do <u>not</u> represent natural conditions** in the Sacramento Valley and Delta. Instead, they simply are calculations that adjust historical flows for upstream reservoir operations and current water use practices. Under natural conditions, the Sacramento Valley was inundated by high flows in most years. The consumptive use of these areas and the functions they provide must be considered if flow requirements are meant to mimic natural flows. (*Estimates of Natural and Unimpaired Flows for the Central Valley of California: WY 1922-2014,* DWR, March 2016). The functional flow

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[1] See Newman, K. 2008. Sample design-based methodology for estimating delta smelt abundance. San Francisco Estuary & Watershed Science 6(3); Latour, R.J. 2016. Explaining patterns of pelagic fish abundance in the Sacramento-San Joaquin Delta. Estuaries and Coasts 39:233-247. Copies of these peer-reviewed, published papers are enclosed with this letter, see Appendix 4.

approach described below more closely resembles and can serve as a surrogate for more natural flow paths in a state with a flood and water system designed for 39 million people.

B. An unimpaired flow approach would have significant impacts on <u>every</u> beneficial use of water in the upstream areas in the Sacramento Valley.

- An unimpaired flow approach would significantly impact reservoir storage necessary to serve cities, rural communities, farms, fish, birds and recreation, particularly during dry years. Most notably, unimpaired flows would have **significant impacts on reservoir storage**, which would impact every one of these beneficial uses of water in the Sacramento Valley and throughout California. As discussed in MBK's September 2012 material presented to the State Water Board (MBK, *Evaluation of Potential SWRCB Unimpaired Flow Objectives – April 25, 2012; see* Appendix 5), if a 50% unimpaired flow requirement were to be imposed impacts to the cold-water pools of Shasta, Oroville, and Folsom Reservoirs would be impacted in 80% of the years. In addition, these reservoirs would reach their dead pools in 20 to 40% of the years. In addition to such reductions in storage, increases in spring time releases also would deplete cold water supplies needed to protect salmon spawning downstream from reservoirs. Importantly, such an approach would further limit California's ability to be prepared for future dry years, such as those we saw in 2014-15. This includes reducing cold water pools and management flexibility for salmon, reduced deliveries for birds along the Pacific Flyway (ricelands, refuges), and reduced deliveries and reliability for cities, rural communities and farms. By **drawing so heavily on reservoir storage**, this approach also would significantly limit California's ability to prepare for drought conditions such as we have seen the past five years. Because flow requirements based on a percent of unimpaired flow would require increased reservoir releases in the spring before the irrigation season begins, it would not be possible to simply reduce agricultural diversions to satisfy these requirements.

- The **draft SBR lacks details** about the potential activities that will be "further evaluated," including any coordinated actions concerning cold water habitats on the major tributaries. This deficiency, in addition to the lack of detail relative to the overall plan for implementation, prevents any meaningful evaluation of the potential benefits or impacts to, or trade-offs for, fisheries, birds, and water supply that would occur with such activities.

- The unimpaired flow approach would be **counter to** the recent state policies and direction regarding **sustainable groundwater management**, which will rely upon groundwater recharge and the conjunctive management of surface and groundwater resources to achieve these objectives. (*see* Water Code §§10720.1(g); 10727.4(e) and (f).) The unimpaired flow approach clearly would lead to significant additional groundwater pumping, which according to the Nature Conservancy's 2014 report, *Groundwater and*

Stream Interaction in California's Central Valley: Insights for Sustainable Groundwater Management (*see* Appendix 6)*,* would result in less recharge opportunities, could impact groundwater-supported ecosystems, and could have negative impacts on stream flows that are not fully developed for years or even decades. This would be counter to the Sustainable Groundwater Management Act (SGMA).

II. California should pursue functional flows for multiple beneficial purposes.

California needs a 21st century water management approach that focuses on functional flows tailored for specific beneficial purposes. In California, every drop of water must have a specific purpose. Modern science is revealing that spreading water across the bypasses and the landscape in the Sacramento Valley and Delta (as a surrogate for natural system functions) will likely benefit fish and other species through food production and habitat. Importantly, the functional flow approach depends upon the special interactions between the water and the landscape. This approach already is underway and can be expanded in the Sacramento Valley.

- The California Water Action Plan section on water flows describes a goal to "ensure sustainable river and estuary habitat conditions for a healthy, functional Bay-Delta ecosystem." (*See* page 12.)

- The Delta Stewardship Council (DSC) in its approved Delta Plan provides a solid overview of the functional flow approach in Chapter 4.

- The past two Lead Scientists for the Delta Science Program were co-authors in a recent published report that found that in highly modified riverscapes (such as the Sacramento Valley), functional flows are a "more effective approach to identify and restore aspects of the flow regime that support key ecosystem functions and drive geomorphological and ecological processes." (Yarnell et al., "Functional Flows in Modified Riverscapes: Hydrographs, Habitats and Opportunities (2015); *see* Appendix 7.)

- Local agencies in every part of the Sacramento Valley and its river systems already have re-managed flows for the benefit of salmon and steelhead in the past several decades. (*"*Re-managing the Flow;" see Appendix 8.) These include actions on the American, Bear, Feather, Sacramento and Yuba Rivers, as well as Mill Creek and various smaller watercourses. These flows all have been tailored for salmon and steelhead. These arrangements all began to be implemented after the last major update of the Water Quality Control Plan.

- On the Sacramento Valley floor, water spread out and slowed down more closely mimics natural conditions and this water will serve multiple beneficial uses in a flow through system—cities and rural communities, farms, birds along the Pacific Flyway, food for fish, recreation. A recent example is the program in the Sacramento Valley during the summer to implement the 2016 North Delta Food Web Action as part of the Delta Smelt Resiliency Strategy (July 2016) (*see* Appendix 9).

- Recent energetics models for birds and the Pacific Flyway have shown the value and importance of functional flows for food production and habitat along the Pacific Flyway, which includes ricelands and refuges. Recent actions for Delta smelt food production in the Yolo Bypass have shown the same promise and various efforts to grow and nurture small salmon on ricelands have suggested better salmon survival than in the sterile channelized river. (The Sacramento Valley and Waterfowl; *see* Appendix 10; and Duck's Unlimited comments submitted to the State Water Board, incorporated by reference.)

We will follow up and provide more detail on all the functional flows that have already been implemented since the last major update of the Water Quality Control Plan and others that are currently being developed.

III. Listen to the new science regarding opportunities for functional flows.

The State Water Board and other state and federal agencies should continue to enlist the Delta Science Program and the Independent Science Board, a leading group of scientists, to provide guidance to state and federal agencies with respect to Delta science. Water suppliers across the state on July 19, 2016 sent a letter to the SWRCB suggesting a new approach is necessary and encouraging the SWRCB and other agencies to listen to the new science surrounding flows. (S*ee* Appendix 11.) We strongly encourage the State Water Board to listen closely to the Lead Scientist and the Independent Science Board comments and incorporate modern science into the scientific basis. In this regard, we recommend and request that the SWRCB issue and pose the listed questions set forth in Appendix 12 to any independent review of the draft scientific basis report, including in particular, the peer review to be conducted pursuant to California Health & Safety Code §57004.

IV. Negotiated resolutions can lead to effective functional flow approaches.

Regulatory solutions do not seem to be working well for any beneficial uses that depend on water in the Sacramento Valley or the Delta. Moreover, further regulatory actions will generally take decades to implement. On the other hand, the California Water Action Plan calls for a coordinated and collaborative approach that encourages negotiated voluntary agreements. (Page 18.) The Resources Secretary and you exchanged letters in November 2015 reiterating your mutual commitment to voluntary agreements. On September 19, 2016, the Governor again directed agencies to pursue negotiated agreements. For this administration to be successful in the water arena, negotiated resolutions (not regulatory actions) that pursue functional flows and other measures will be essential and will lead to more sustainable outcomes. The Sacramento Valley Water Users are committed to a negotiated resolution and voluntary agreements for the Sacramento Valley and the Delta.

We appreciate the opportunity to provide comments on your working draft.

Sincerely yours,

David Guy
President, NCWA

Dustin Cooper
Minasian Law Firm

Andy Hitchings
Somach, Simmons and Dunn

Dan Kelly
Placer County
Water Agency

Alan Lilly
Bartkiewicz, Kronick
and Shanahan

Kevin O'Brien
Downey Brand

cc: Tom Howard
Eric Oppenheimer
Michael Lauffer
Michael George
Jeanine Townsend (per SWRCB notice)

Appendix 1

THE METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA
SAN JOAQUIN TRIBUTARIES AUTHORITY
NCWA Northern California Water Association
KERN COUNTY WATER AGENCY
OID OAKDALE IRRIGATION DISTRICT
CENTRAL COAST WATER AUTHORITY
RWA Regional Water Authority BUILDING ALLIANCES IN NORTHERN CALIFORNIA
CASTAIC LAKE WATER AGENCY
Santa Clara Valley Water District
SAN LUIS & DELTA-MENDOTA WATER AUTHORITY
SWC STATE WATER CONTRACTORS Served by the State Water Project FOUNDED IN 1982
TLBWSD
LIVERMORE-AMADOR VALLEY ZONE 7 19 57 WATER SUPPLY • FLOOD PROTECTION
MID Modesto Irrigation District Water and Power
TID WATER & POWER Serving Central California since 1887
Westlands Water District
MID MERCED IRRIGATION DISTRICT WATER & POWER
SSJID SOUTH SAN JOAQUIN IRRIGATION DISTRICT
Mojave Water Agency

July 23, 2015

Ms. Felicia Marcus, Chair
Members of the Board
State Water Resources Control Board
P.O. Box 100
Sacramento, CA 95812-0100

Re: Unimpaired Flows

Dear Chair Marcus and Members of the Board:

The broad coalition of undersigned public water agencies and water companies in every part of California call on the State Water Resources Control Board to abandon its effort to advance an “unimpaired flow” or similar approach to water management in the Sacramento-San Joaquin Delta and San Francisco Bay, including the Water Quality Control Plan process.

Our coalition supports and is implementing progressive and innovative 21st century water management for 39 million people within the stable framework of California’s well-established water rights system. Four consecutive dry years have revealed the fallacy of attempting to mimic “unimpaired flows” to protect beneficial uses in present-day California. In fact, if the “unimpaired flow” approach was in place over the past five years, precious water resources would have already been drained from reservoirs throughout California before we entered these past several dry years. As a result, there would be even less water available in 2015 for the benefit of all beneficial uses, which includes cities and rural communities, fire suppression, cold water to sustain salmon, farms, birds and the Pacific Flyway, and recreational opportunities. Stated another way, an “unimpaired flow” approach would create greater risk for all beneficial uses during dry years. This dynamic would be further exacerbated under the various climate change scenarios evaluated by your administration. We cannot afford to go back in time and rely on defunct measures like an “unimpaired flow” approach for a system that has been highly altered over time. This type of approach will not improve the highly altered system and will only prove to deplete upstream reservoirs that all of California relies on.

We instead urge you and the administration to pursue a different and more practical approach--as called for in your California Water Action Plan--to improve flow regimes that will increase and sustain native fish populations through programs of implementation. This will include both strategic re-managed flows and other non-flow measures such as addressing the predation of native species by invasive species, which appears to be the largest factor that negatively affects salmon in the Central Valley. California needs a progressive approach that will empower 21st century water resources management to support a vibrant economy and environment.

We look forward to discussing new approaches with you in more detail at your earliest convenience.

Sincerely yours,

Jeff Kightlinger

Jeff Kightlinger
Metropolitan Water District

Steve Knell
San Joaquin River Tributaries Authority

Stefanie Morris

Stefanie Morris
State Water Contractors

Dan Masnada
Castaic Lake Water Agency

Thomas W Birmingham

Tom Birmingham
Westlands Water District

John Sweigard

John Sweigard
Merced Irrigation District

Steve Knell
Oakdale Irrigation District

Jill Duerig
Zone 7 Water Agency

Roger Van Hoy

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Modesto Irrigation District

Steven P. Emrick

Steve Emrick
South San Joaquin Irrigation District

Beau Goldie
Santa Clara Valley Water District

David Guy
Northern California Water Association

John Woodling
Regional Water Authority

Dan Nelson
San Luis & Delta Mendota Water Authority

Ray A Stokes

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Central Coast Water Authority

Jim M. Beck

Jim Beck
Kern County Water Agency

Kirby Brill

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Mojave Water Agency

Mike Gilkey
Tulare Lake Basin Water Storage District

Art Godwin
Turlock Irrigation District

cc: Tom Howard
Michael Lauffer
Michael George
Natural Resources Agency

Appendix 2

Water and Power Policy Group

Retrospective Analysis of Changed Central Valley Project and State Water Project Conditions Due to Changes in Delta Regulations

January 2013

MBK ENGINEERS
CONSULTING ENGINEERS

HDR

Member Organizations of the Water and Power Policy Group

*** State and Federal Contractors Water Agency**

*** San Joaquin River Group**

*** Western Area Power Authority**

*** Pacific Gas and Electric Company**

*** Sacramento Municipal Utilities District**

*** Redding Electric Utility**

*** Association of California Water Agencies**

*** Placer County Water Agency**

Northern California Power Agency

California Municipal Utilities Association

Yuba County Water Agency

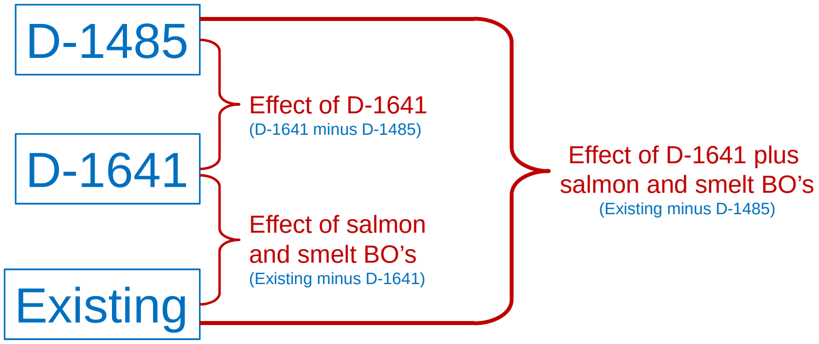
*** Member Organizations helping to fund the effort.**

BACKGROUND

The purpose of this analysis is to demonstrate how conditions affecting the Central Valley Project (CVP) and State Water Project (SWP) have been, and are being affected by changes in regulations governing Delta operations. Specifically, these projects have been affected by the early implementation of the standards contained in D-1641 and the Central Valley Project Improvement Act (CVPIA) in the mid-1990's. They have also been affected to even a greater extent by implementation of the most recent Biological Opinions (BiOps) beginning in 2008 and 2009. Although there have been significant changes in regulations governing upstream operations, addition of new facilities, and increases in water demands, this analysis solely addresses changes in Delta regulations. The analysis keeps the regulatory conditions that currently exist upstream in place in all the scenarios and only "rolls back" the regulatory conditions in the Delta that have been changed in the last 30 plus years.

Due to the relatively short hydrologic periods that these requirements have been in place, it is not possible to understand how these changes have affected the system by reviewing historical conditions. Also, regulatory requirements have changed over the years both upstream and in the Delta so an historical analysis cannot isolate the impacts due solely to the regulatory changes in Delta. Hydrology is a dominate factor when comparing historical periods, because of this it is difficult to determine effects to due to changes in regulatory conditions by comparing relatively short historical periods. Therefore, modeling over a common long-term hydrologic period is the best way to discern effects of new projects or changes in regulatory requirements.

To perform this analysis, three modeling scenarios were developed and compared to demonstrate changes to the system. The first scenario contains Delta regulatory requirements of the Existing Biological Opinions (BiOps) adopted in 2008 and 2009 together with those of D1641. The second scenario is Delta regulatory requirements of D-1641 by itself (these requirements were implemented early by the December 1994 Bay/Delta Accord). The third scenario is the Delta regulatory requirements of D-1485 (adopted in August 1978). The Figure below demonstrates how these modeling scenarios are compared to demonstrate effects.



For the purpose of this analysis, the "Existing BiOps" model scenario is used to represent how the CVP/SWP currently operates. This scenario includes reasonable and prudent alternatives ("RPAs") in the BiOps. While court orders have prevented some parts of the BiOps from being implemented in some years since those BiOps were issued, those BiOps' terms remain the best representation of how the CVP and the SWP currently operate, and may operate for the foreseeable future. The RPAs contained in the 2008 Delta smelt BiOp may be found at pages 329-379 of that BiOp and include six actions: (i) Adult Migration and Entrainment (First Flush), (ii) Adult Migration and Entrainment, (iii) Entrainment Protection of Larval Smelt, (iv) Estuarine Habitat During Fall, (v) Temporary Spring Head of Old River Barrier (HORB) and the Temporary Barrier Project (TBP), and (vi) Habitat Restoration. The RPAs contained in the 2009 salmon BiOp may be found at pages 587-654 of that BiOp.

Among the salmon and smelt BiOps there are five RPAs that have significantly modified water system operations. Those RPAs are: (i) Action IV.1.2 DCC [Delta Cross Channel] Gate Operation, which is described at pages 635-640 of the Salmonid BiOp; (ii) Action IV.2,1 San Joaquin River Inflow to Export Ratio, which is described at pages 641-645 of the Salmonid BiOp; (iii) Action 2: Adult Migration and Entrainment, which is described at pages 352-356 of the Delta smelt BiOp; (iv) Action 3: Entrainment Protection of Larval Smelt, which is described at pages 357-368 of the Delta smelt BiOp; and (v) Action 4: Estuarine Habitat During Fall, which is described at pages 369-376 of the Delta smelt BiOp. This scenario is referred to in this document and accompanying exhibits as the “Existing BiOps” scenario.

To represent how the system operated prior to the implementation of the BiOps, the Existing BiOps scenario is modified by removing the RPAs in the salmon and smelt BiOps that are specific to governing Delta operations; this scenario is referred to as the “D-1641” scenario. The only RPAs, specific to upstream operations, which were removed, are for Clear Creek pulse flows. Others were not removed from the Existing BiOps scenario and remain in the D-1641 modeling scenario. For this analysis, there is no attempt to remove the effects of RPAs specific to upstream operations, because these effects are difficult to distinguish from the effects of actions to implement section 3406(b)(2) of the CVPIA, which were already occurring in the mid-1990’s. Moreover, the RPAs that are specific to Delta operations are much more important drivers of water system changes than the upstream RPAs. Therefore, the main difference in regulatory requirements between the Existing BiOps and D-1641 model simulations are the Delta RPAs.

To represent system operation under D-1485 conditions, the D-1641 model scenario was modified by removing 3406(b)(2) operating constraints and replacing D-1641 criteria with D-1485 criteria. Although there are numerous changes, the more significant changes are removal of Vernalis Adaptive Management Plan (VAMP) export restrictions, E/I ratio, and spring X2 Delta outflow requirements. As with the D-1641 scenario, upstream flow requirements remain the same as the Existing scenario, with the exception of Clear Creek flows.

In addition to changes in Delta operating criteria, there have been significant changes in regulations governing upstream operations, addition of new facilities, and increases in water demands. The Trinity River Decision requires significantly more flow to remain in the Trinity River system; therefore, water that was used to satisfy Sacramento River flow and temperature requirements, Delta requirements, and water demands is no longer available. There have also been changes in the operation of the Yuba River pursuant to the Yuba Accord, and the Feather River pursuant to the settlement agreed to as part of Federal Energy Regulatory Commission (FERC) relicensing. There have been increases in water demands, particularly in urban areas such as the American River Basin, Bay Area, and Southern California. Under CVPIA, a portion of CVP supply is dedicated to refuges, this has led to a decrease in agricultural water supply; this dedication of water is kept in place and therefore its impacts are not addressed in this analysis. In addition to changes in regulation and water demands, new facilities have been constructed. For the purpose of this analysis, existing infrastructure is assumed to be in place in all the scenarios.

The primary analytical tool used for this effort is the latest publically-available version of the CalSim II model. The CalSim II model simulation used to support the 2011 State Water Project Delivery Reliability Report (SWP DRR) is the best available modeling tool and latest public release of the model. The DRAFT Technical Addendum to SWP DRR 2011, titled January 2012 of the SWP DRR, describes the CalSim II modeling assumptions. For this analysis, CalSim II was used to assess changes in CVP / SWP storage, river flows, water deliveries, and Delta conditions. The SWP DRR may be found at the following web location: http://baydeltaoffice.water.ca.gov/swpreliability/2011DraftDRR012612.pdf. The following is the most current public version of the CalSim II model used by the California Department of Water Resources (DWR) to develop its 2011 SWP reliability study. This model is available for download from DWR's website at:
http://baydeltaoffice.water.ca.gov/modeling/hydrology/CalSim/Downloads/CalSimDownloads/CalSim3
IIStudies/SWPReliability2011/index.cfm.

ANALYTICAL RESULTS

This analysis shows that, on average, D-1641 has resulted in approximately 300,000 acre feet (AF)/year of additional Delta outflow relative to D-1485, and the BiOps have resulted in approximately 1 million AF/year of additional Delta outflow over the levels required in D-1641. There is also an increased reliance on water stored in upstream reservoirs to satisfy Delta flow requirements and other beneficial uses of water. Increases in Delta flow requirements imposed by D-1641 and the BiOps have further constrained CVP and SWP operations, resulting in decreases in operational flexibility and increases in vulnerability to adverse dry year conditions for the environment and water supply, primarily due to reduced carryover storage. There have been changes in flow patterns in all major tributaries in the Central Valley that have affected beneficial uses of water. There have been reductions in project reservoir storage and water deliveries and water supply reliability.

Flow Changes

For both the CVP and the SWP, implementation of D-1641 and the BiOps has resulted in reduced opportunities to capture uncontrolled flows into the Delta with an increased reliance on upstream storage to satisfy both environmental requirements and water supply needs. Under the D-1485 scenario, the CVP and the SWP could divert more water during periods of high flow (excess conditions) than under the D-1641 scenario. This ability to divert more water during periods of high flow has been reduced to a greater extent under the Existing BiOps scenario; this is because terms in the RPAs impose significantly more Delta export restrictions during late winter and spring periods when flows are typically the highest. D-1641, and to a greater extent the RPAs, also result in increased reservoir releases to comply with Delta outflow requirements during the fall period when natural flows are typically the lowest. Increased Delta outflow has caused the CVP and the SWP to increase their reliance on stored water. This effect has, in turn, altered the flow regimes in upstream tributaries and changed the pattern of Delta export water diversions.

Delta Outflow

Exhibit 1 contains a summary of Delta outflow changes. As previously mentioned, together both D-1641 and the BiOps has increased average annual Delta outflow by approximately 1,300,000 AF. Delta outflows are generally higher under the D-1641 scenario relative to the D-1485 scenario, but are less at times; decrease in June outflow is due to the removal of an export restriction for June that was in place under D-1485. Delta outflows are generally higher under the Existing BiOps scenario relative to the D-1641 scenario; the main exception is when reservoirs refill during wet conditions to recover from the additional drawdown triggered by the BiOps.

Sacramento River Flow below Keswick

Exhibit 2 depicts changes in Sacramento River flow below Keswick. There is fluctuation when comparing D-1641 to D-1485, this is due to how Shasta releases react to changes in system requirements. Under the Existing BiOps scenario, Sacramento Basin river flows are generally lower than under the D-1641 scenario during winter and spring months, December through June, because, during those months, the CVP and SWP recover from lower storage and try to conserve water for future use.

Under the Existing BiOps scenario, September reservoir releases and tributary flows are higher than under the D-1641 scenario in wet and above normal years, to satisfy the Delta smelt BiOp's Fall X2 requirement. This condition also occurs in November for the Sacramento and American Rivers. For both the CVP and the SWP, the need to release additional water to meet the Fall X2 requirement causes lower carryover storage, and thus has reduced CVP and SWP carryover storage that could be used during drier years to support both fisheries and consumptive uses.

Changes in tributary flows during July and August vary depending on the characteristics of each tributary. Sacramento River flows below Keswick Dam are lower for this period in the existing BiOps scenario compared to the D1641 scenario. This reduction in flows due to the BiOps may result in warmer water temperature at the Sacramento River temperature compliance point located between Balls Ferry and Bend Bridge in most years.

Feather River Flows

Exhibit 3 demonstrates changes in the Feather River below Thermalito. Under D-1641 there are often increases in July and August flows relative to D-1485 to support project demands. Flows in the Feather River are higher in July through September under the Existing scenario relative to the D-1641 scenario to satisfy needs in the Delta.

American River Flow below Nimbus

Exhibit 4 contains charts showing changes in American River flow. Changes in American River flows are variable depending on numerous conditions and how Folsom responds to changing requirements. Flows in June tend to be more in D-1641 relative to D-1485; this is due the removal of the D1485 June export constraint by D-1641. Flows in D-1641 tend to be lower in July and August relative to D-1485. Flows in June are less under Existing conditions relative to D-1641 due to export restrictions, and flows in the fall period are higher to satisfy Fall X2.

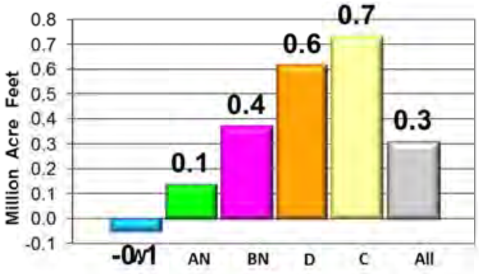
San Joaquin River at Vernalis

Exhibit 5 displays average changes in the San Joaquin River by water year type. Flows in April and May are higher in the D-1641 scenario compared to the D-1485 scenario due to VAMP requirements specified in D-1641 The lower flows in most other months are due to the VAMP requirements in April and May. Since upstream RPA’s in the Stanislaus and San Joaquin River remain unchanged for this analysis, there is little or no difference between the Existing BiOps and D-1641 scenarios.

Exhibit 1 - Change in Delta Outflow

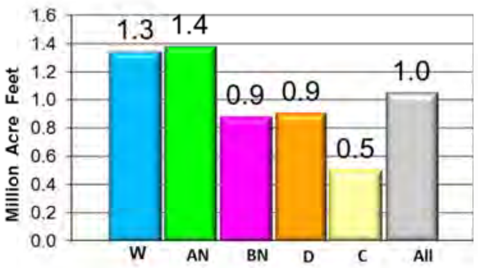
D-1641 minus D-1485

Average annual changes by year type



Average monthly changes by year type

Existing BiOps minus D-1641



Existing BiOps minus D-1485

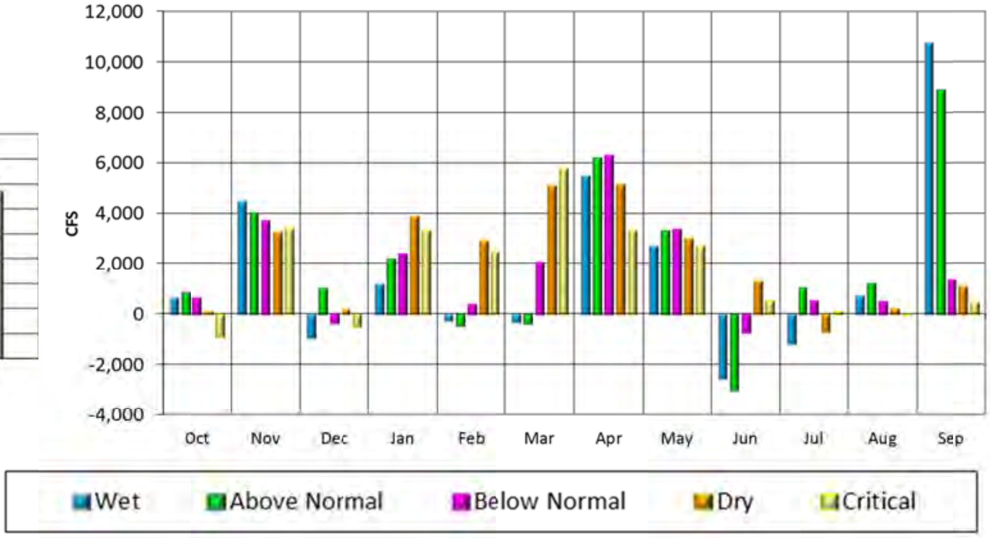
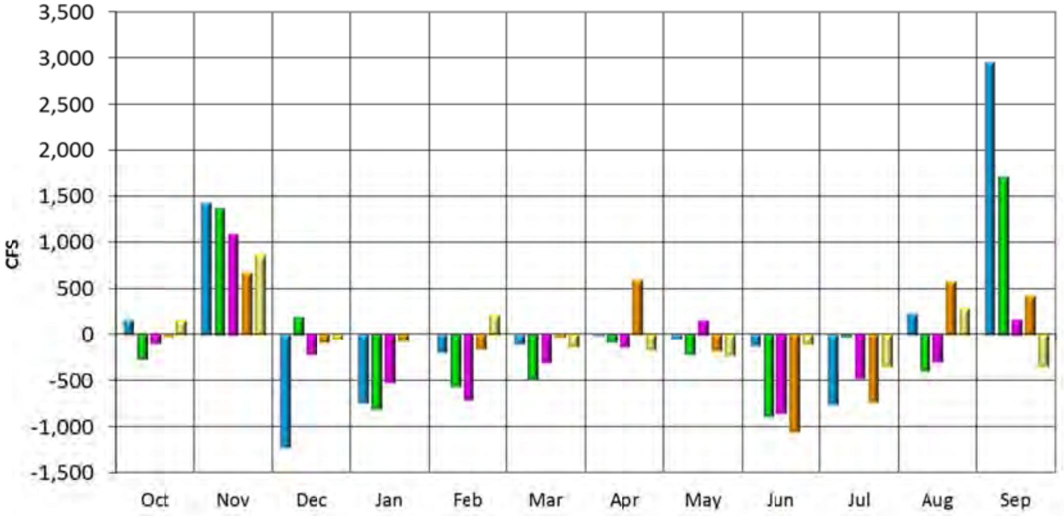


Exhibit 2 – Average Change in Sacramento River Flow below Keswick by Water Year Type

D-1641 minus D-1485

Existing BiOps minus D-1641



Existing BiOps minus D-1485

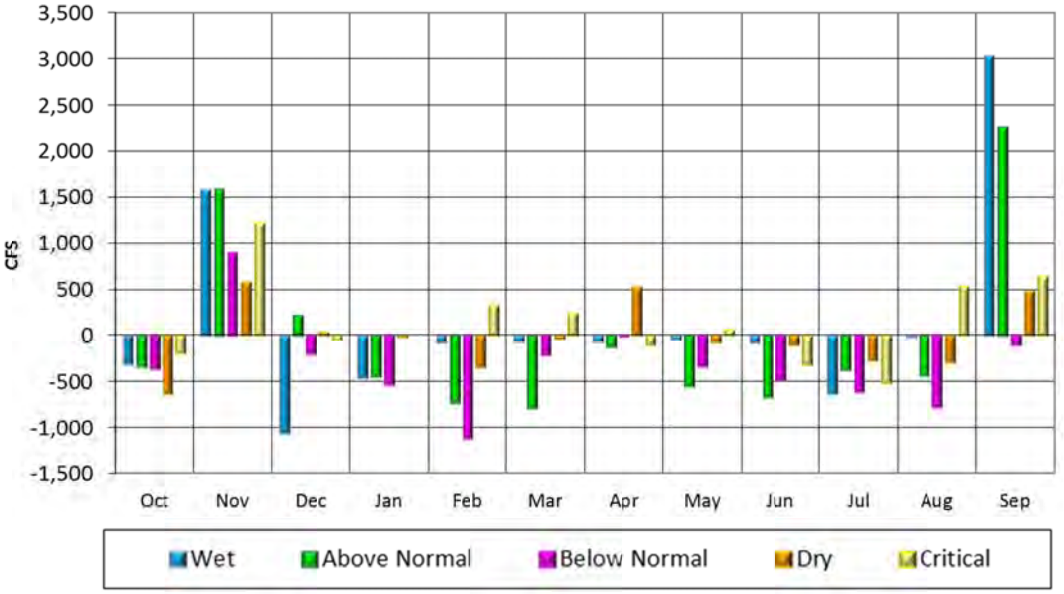
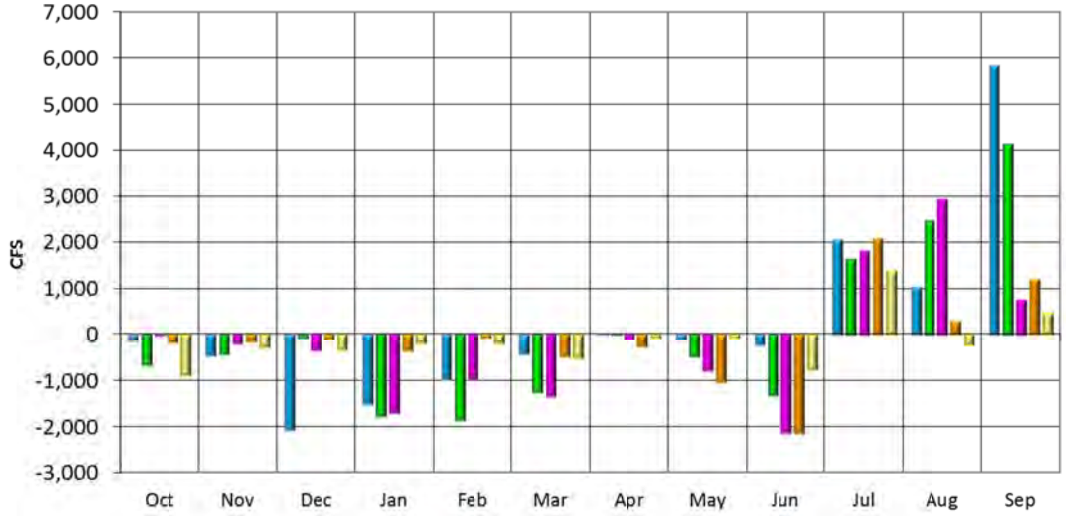


Exhibit 3 – Average Change in Feather River Flow below Thermalito by Water Year Type

D-1641 minus D-1485

Existing BiOps minus D-1641



Existing BiOps minus D-1485

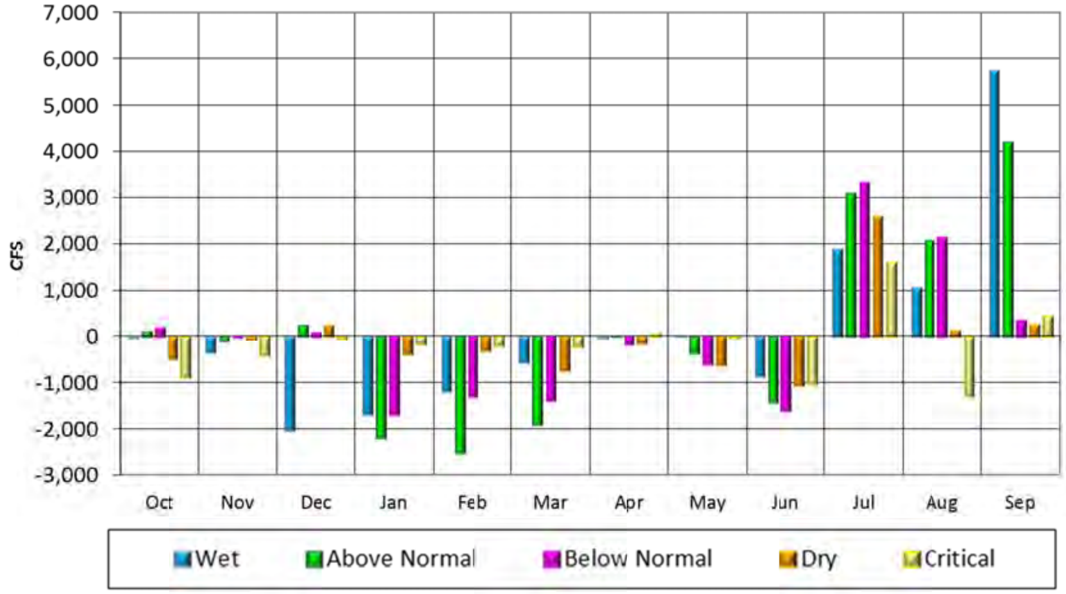
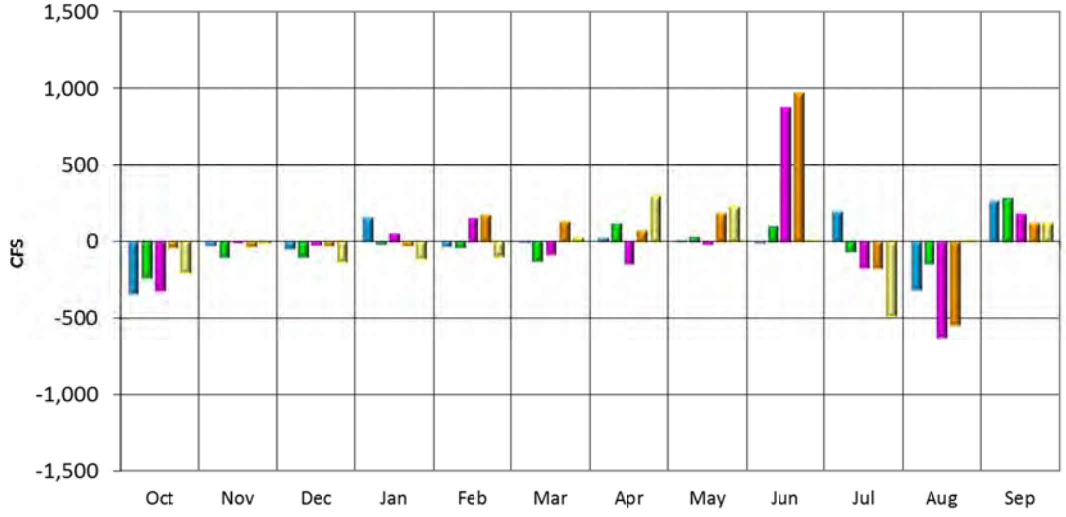
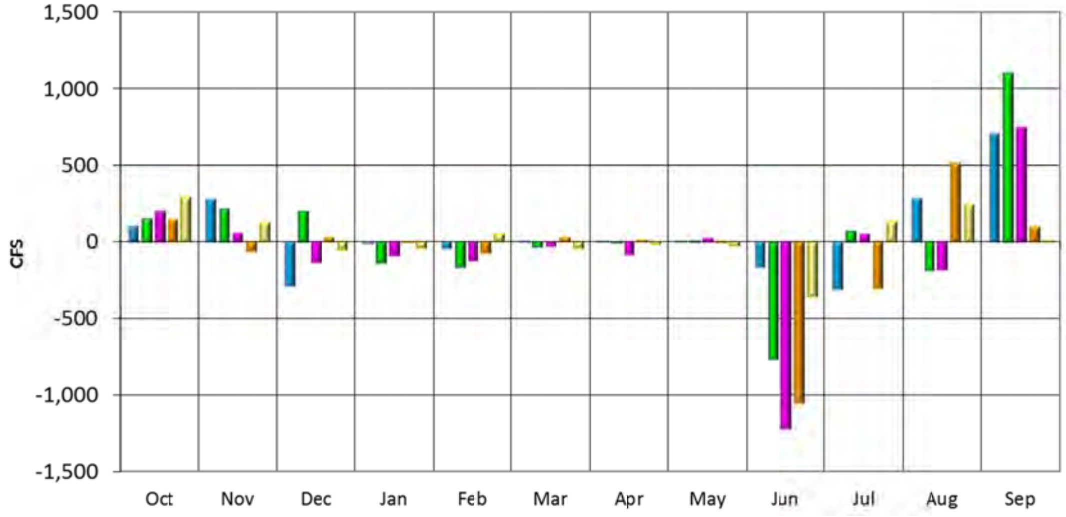


Exhibit 4 – Average Change in American River Flow below Nimbus by Water Year Type

D-1641 minus D-1485



Existing BiOps minus D-1641



Existing BiOps minus D-1485

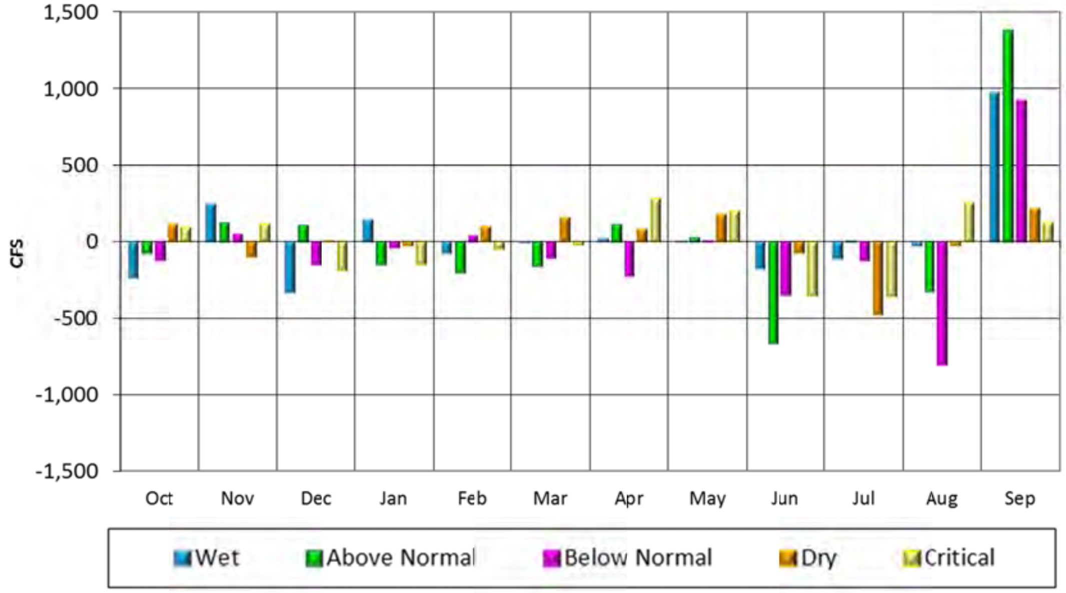
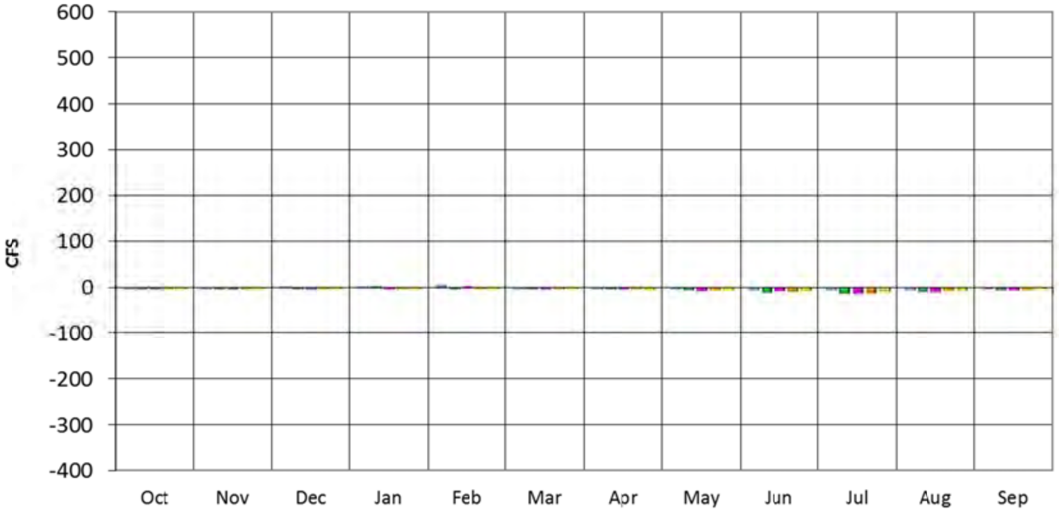


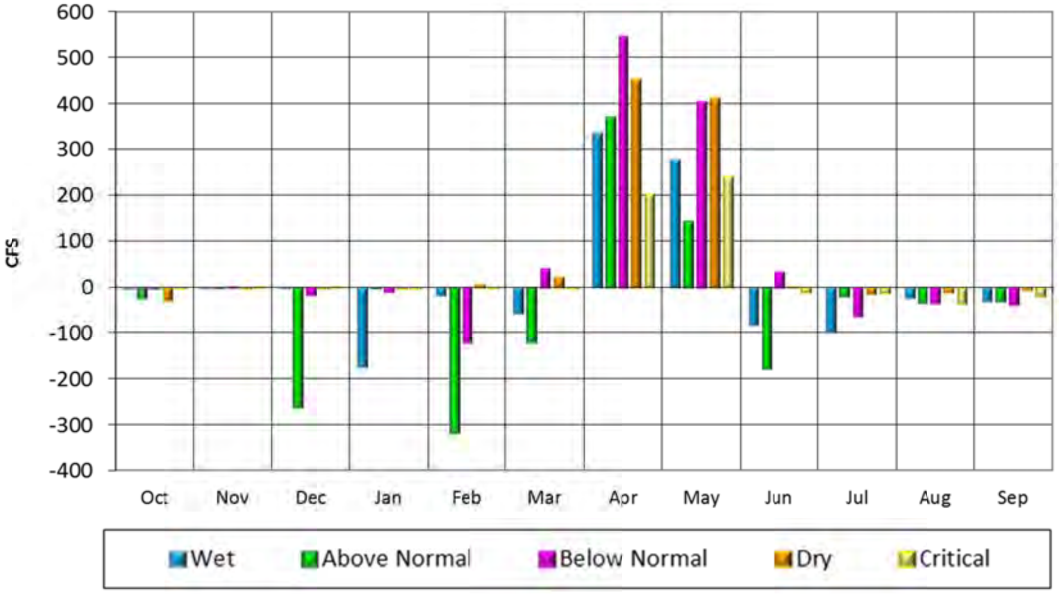
Exhibit 5 – Average Change in San Joaquin River Flow at Vernalis by Water Year Type

D-1641 minus D-1485

Existing BiOps minus D-1641



Existing BiOps minus D-1485



Reservoir Storage Changes

Exhibit 6 depicts exceedance probability plots for key upstream CVP/SWP reservoirs for the D-1485, D-1641, and Existing scenarios. For each of these reservoirs, there have been reductions in storage resulting from both D-1641 and the RPAs. These reductions in storage have reduced water supply reliability for water users throughout the CVP/SWP system, and reduced water supply and habitat reliability for fish. The following summarizes D-1641 and BiOps' effects on CVP and SWP reservoirs' storage.

Trinity Reservoir
Trinity Reservoir average carryover storage is about 15,000 AF lower in the D-1641 scenario relative to the D-1485 scenario, and 30,000 AF lower in the Existing BiOps scenario relative to the D-1641 scenario. Trinity Reservoir is affected the most in critical years. Exhibit 7 contains storage for each month of the simulation for all three scenarios; note that during periods of low storage there tends to be greater reductions in storage.

Shasta Reservoir
Shasta Reservoir average carryover storage is about 60,000 AF lower in the D-1641 scenario relative to the D-1485 scenario, and 95,000 AF lower in the Existing BiOps scenario relative to the D-1641 scenario. The most significant issue regarding effects to Shasta storage occurs in critical years where there is about 260,000 AF reduction in the D-1641 scenario relative to the D-1485 scenario, and 230,000 AF reduction in the Existing scenario relative to the D-1641 scenario BiOps . When comparing the Existing BiOps scenario critical year carryover to the D-1485 scenario, there is about a half million acre-foot reduction in storage.

CalSim modeling of the BiOps' effects show Shasta storage declining to dead pool more often; this reduces the CVP's ability to comply with upstream flow and temperature requirements that have been established to support salmon in the upper Sacramento River. Because Shasta is a reservoir that has multiple years' worth of storage capacity; during extended dry conditions it can take several years to recover from these types of additional drawdown. Exhibit 8 contains storage for each month of the simulation for all three scenarios. The effects on Shasta are the most significant during extended droughts such as the 1928-1934 and 1987-1992 periods when Shasta falls below the salmon BiOp RPA level.

Oroville Reservoir
Oroville Reservoir average carryover storage is about 60,000 AF lower in the D-1641 scenario relative to the D-1485 scenario, and 355,000 AF lower in the Existing BiOps scenario relative to the D-1641 scenario. When comparing the Existing BiOps scenario critical year carryover to the D-1485 scenario, there is about a 400,000 acre foot reduction in storage. Exhibit 9 contains Oroville storage for each month of the simulation for all three scenarios. Under the D-1641 scenario, Oroville storage is drawn down to a greater extent than in the D-1485 scenario, and in the Existing scenario the storage is drawn down to an even greater extent.

Folsom Reservoir
Folsom Reservoir average carryover storage is about 11,000 AF lower in the D-1641 scenario relative to the D-1485 scenario, and 8,000 AF lower in the Existing BiOps scenario relative to the D-1641 scenario. When comparing the Existing BiOps scenario critical year carryover to the D-1485 scenario, there is about a 20,000 acre foot reduction in storage. Exhibit 10 contains Folsom storage for each month of the simulation for all three scenarios.

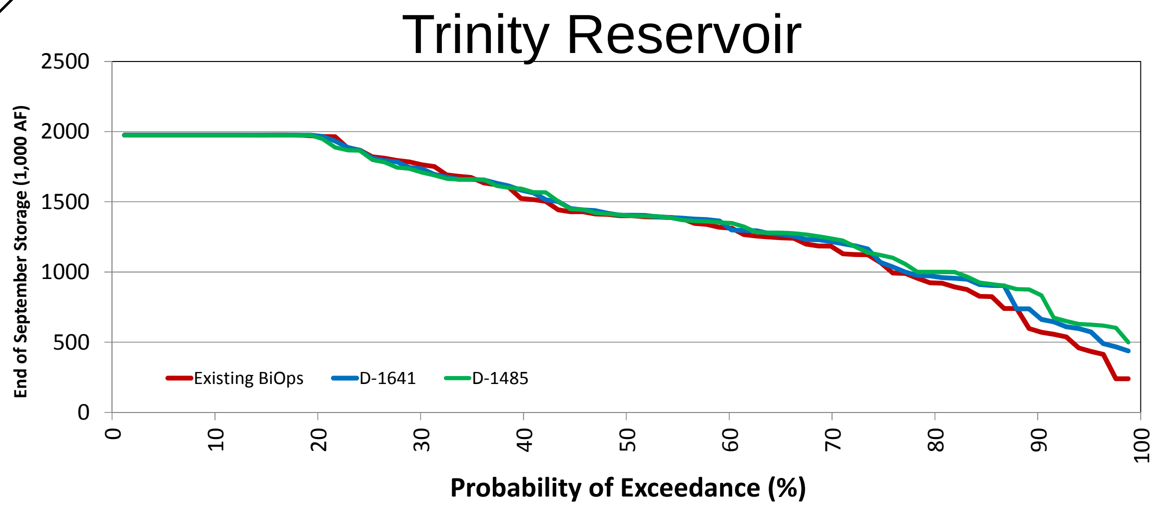
The characteristics of Folsom are different than other CVP and SWP reservoirs; this is primarily due to highly variable nature of its inflow and susceptibility to droughts. Because Folsom 's storage capacity (about 1,000,000 AF) is small relative to its watershed's yield, it has much less ability to store water from year to year than Shasta or Oroville. Indeed, in critical years, natural flows in the American River are less than combined environmental and consumptive demands, which means that water users and fish must rely on stored water. A number of major urban water suppliers, however, depend on the American River and Folsom and have few, if any, other water sources. As the State Water Rights Board recognized in Decision 893, these water suppliers are "naturally dependent" on the American River. Without storage in Folsom, dry year reliability in this region is a main concern and reductions in dry year reliability in Folsom storage puts American Basin urban areas at risk. The Folsom Reservoir carryover chart in Exhibit 6 shows Folsom reaching dead pool one time in the D-1485 scenario and about 5% of the time in both the D-1641 and Existing scenarios.

San Luis Reservoir

Exhibit 11 contains exceedance probability plots for the annual maximum and annual minimum storage in combined San Luis reservoir. Under the D-1485 and D-1641 scenarios, San Luis reservoir fills, or nearly fills, in about 80% of years, this was reduced to about 20% in the Existing BiOps scenario. The reduced ability to capture excess Delta flows prevents San Luis Reservoir from filling in most years when it previously would have filled. San Luis Reservoir operation has changed due to the timing of available export capacity and water availability, therefore, the low point has also changed. The BiOps have resulted in low point being lower than in the D-1641 scenario, this could have implications to urban water quality.

Exhibit 6 - Project Reservoir Carryover Storage Summary

	Year Type	D1641 minus D1485	Existing minus D1641	Existing minus D1485
Trinity	W	7	0	7
	AN	-27	-18	-45
	BN	-39	-12	-51
	D	1	-42	-42
	C	-43	-104	-147
	All	-15	-29	-44



	Year Type	D1641 minus D1485	Existing minus D1641	Existing minus D1485
Shasta	W	-3	-135	-138
	AN	-27	-42	-69
	BN	-43	42	0
	D	-42	-90	-132
	C	-257	-231	-488
	All	-59	-95	-154

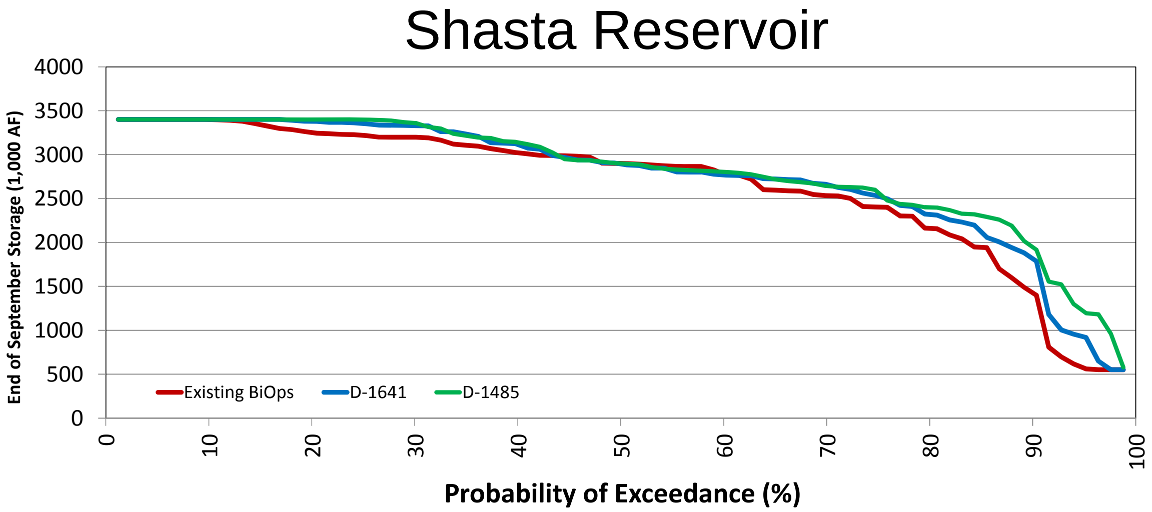
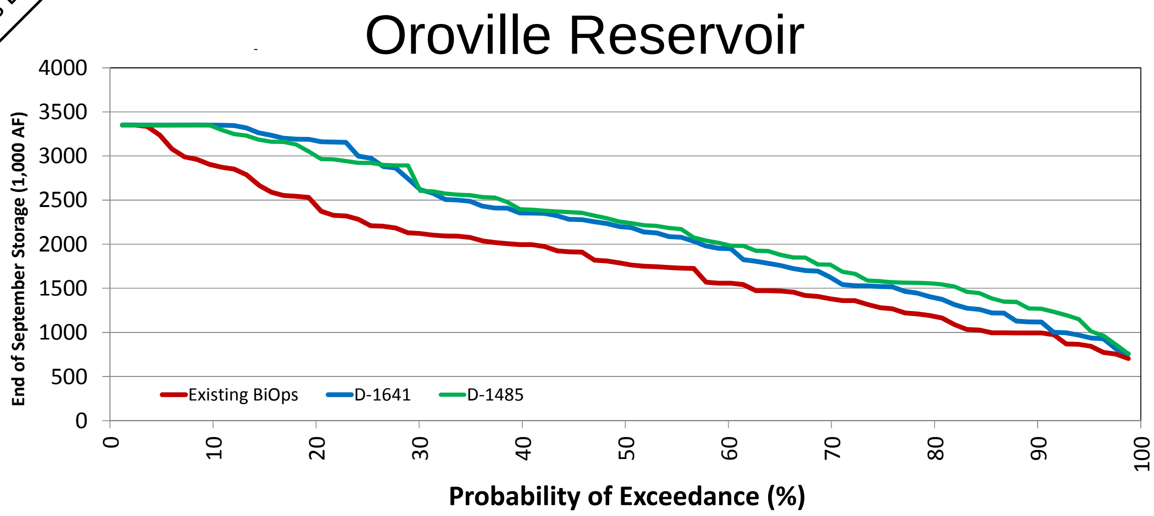


Exhibit 6 - Project Reservoir Carryover Storage Summary (continued)

	Year Type	D1641 minus D1485	Existing minus D1641	Existing minus D1485
Oroville	W	46	-509	-463
	AN	-83	-394	-477
	BN	-99	-317	-416
	D	-96	-259	-355
	C	-140	-150	-291
	All	-56	-352	-408



	Year Type	D1641 minus D1485	Existing minus D1641	Existing minus D1485
Folsom	W	-8	-32	-39
	AN	-10	-14	-24
	BN	-9	32	23
	D	-25	18	-7
	C	-2	-38	-40
	All	-11	-8	-20

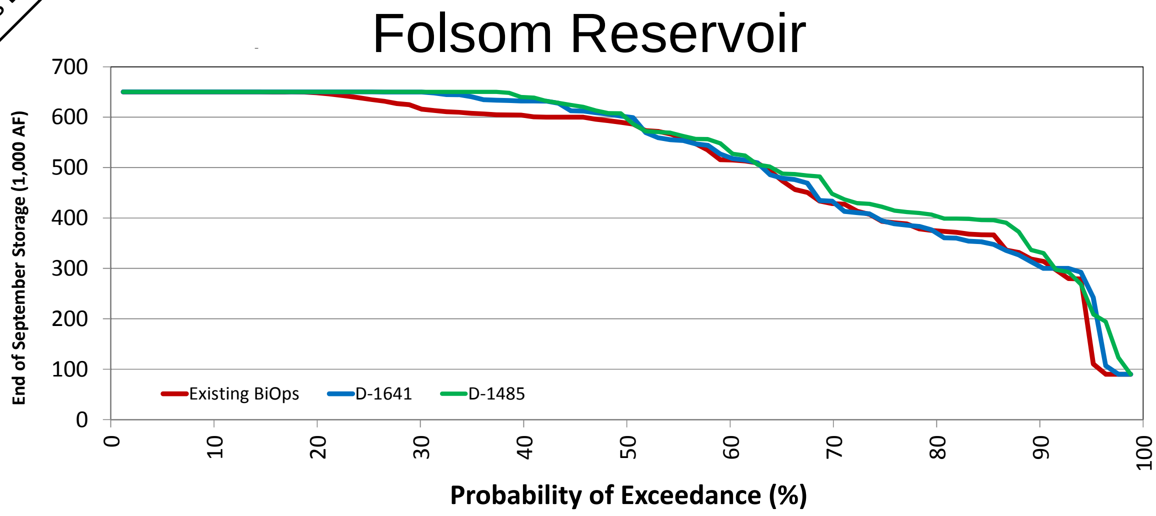


Exhibit 7 - Trinity Reservoir Monthly Storage for Entire Model Period

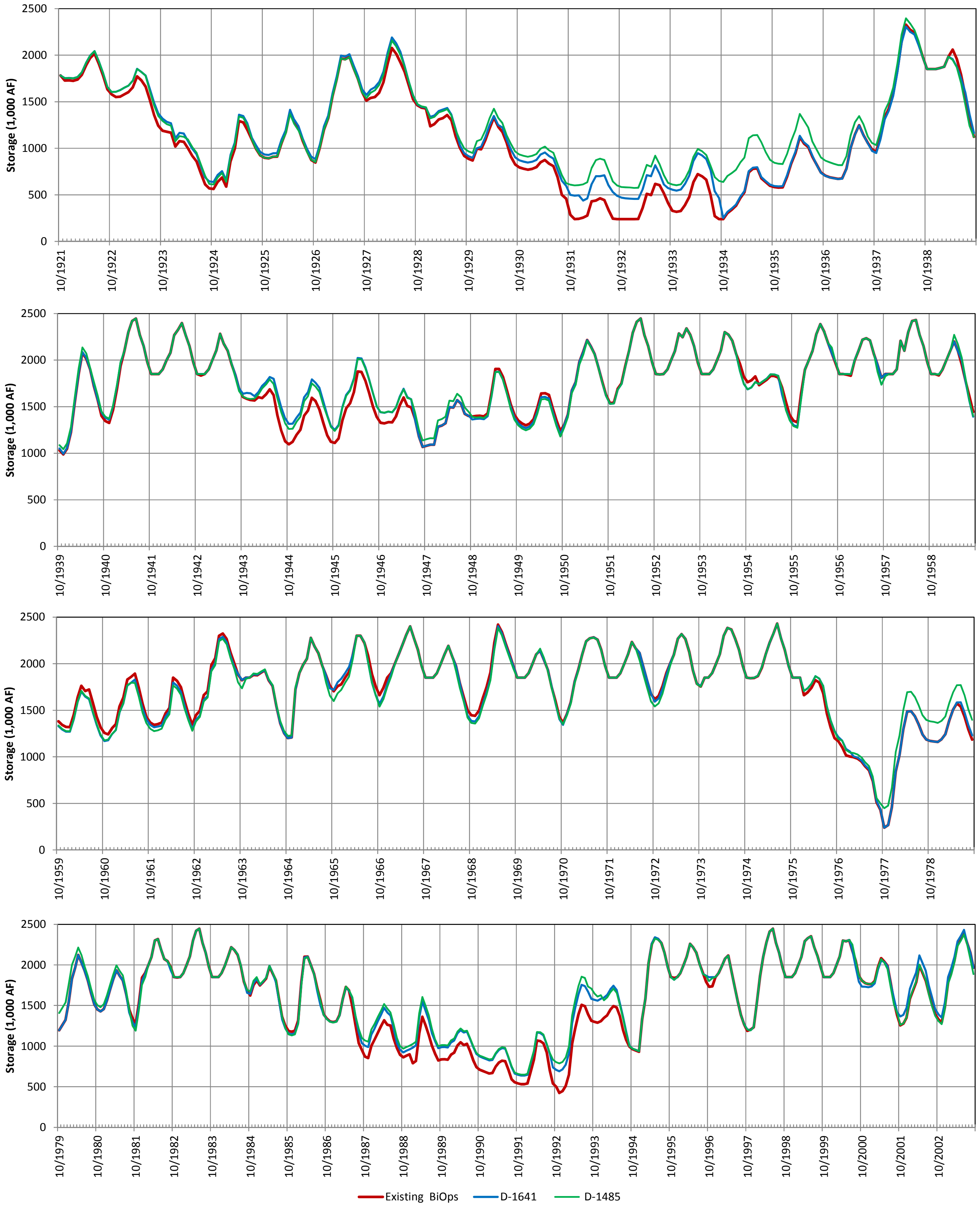


Exhibit 8 - Shasta Reservoir Monthly Storage for Entire Model Period

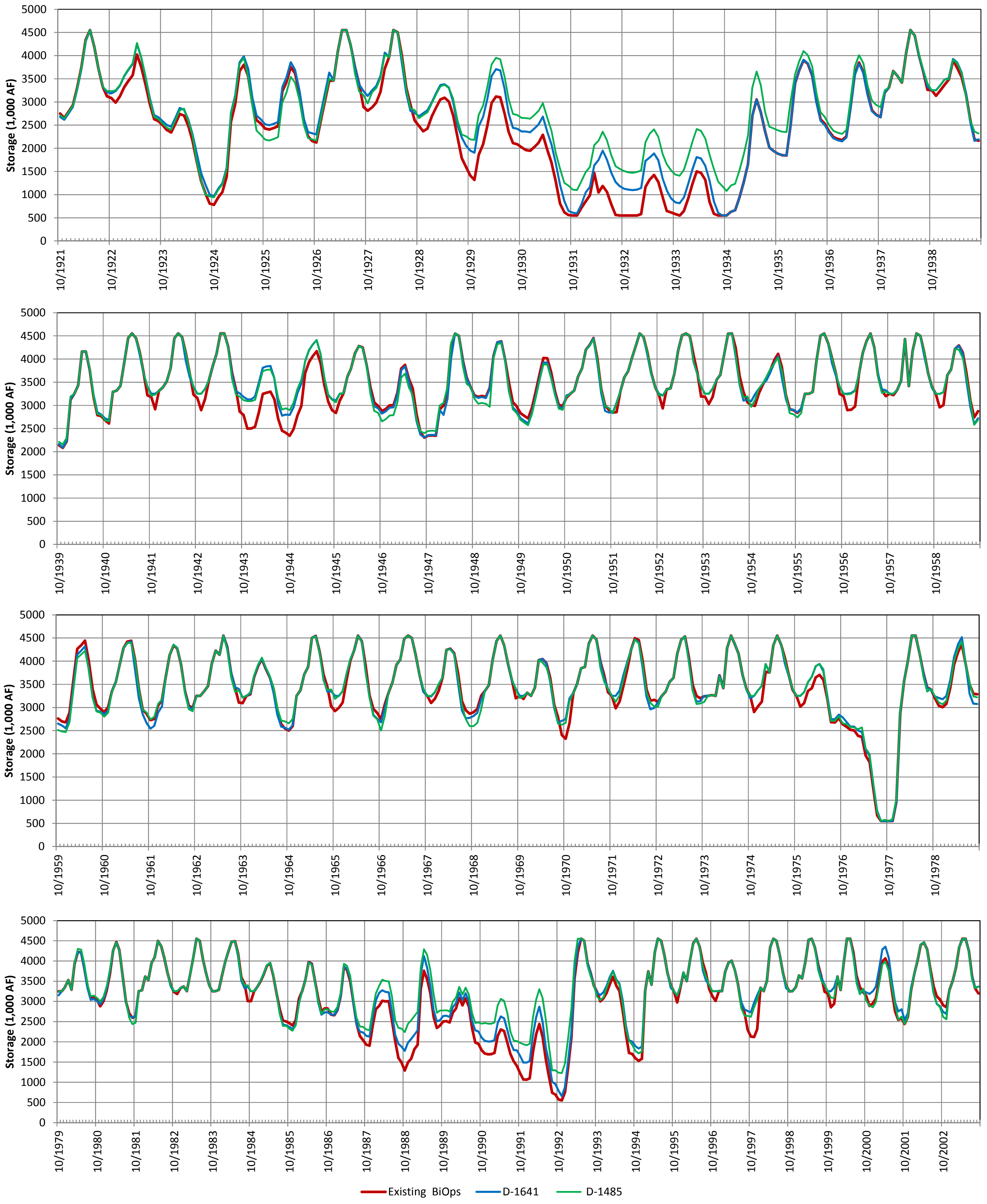


Exhibit 9 - Oroville Reservoir Monthly Storage for Entire Model Period

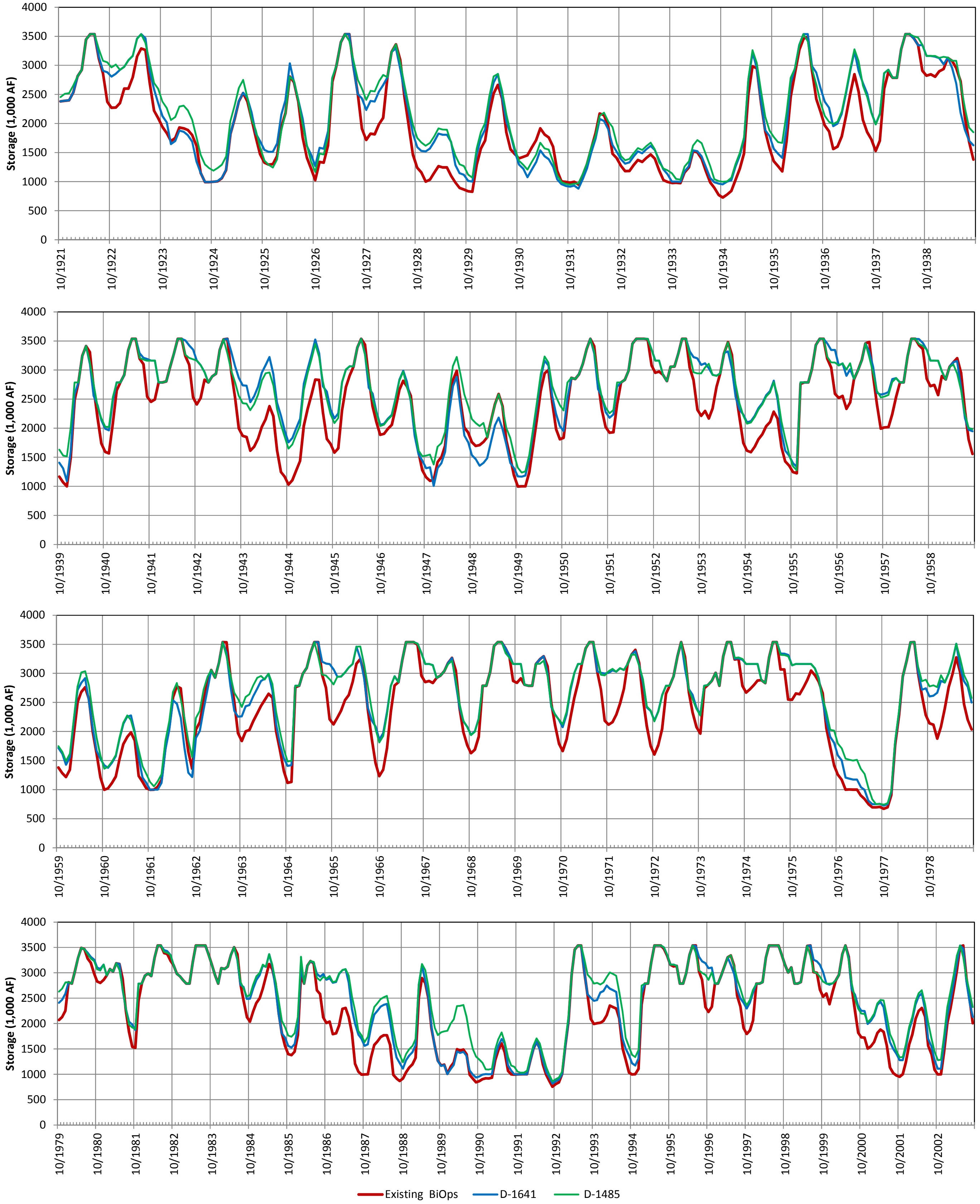


Exhibit 10 - Folsom Reservoir Monthly Storage for Entire Model Period

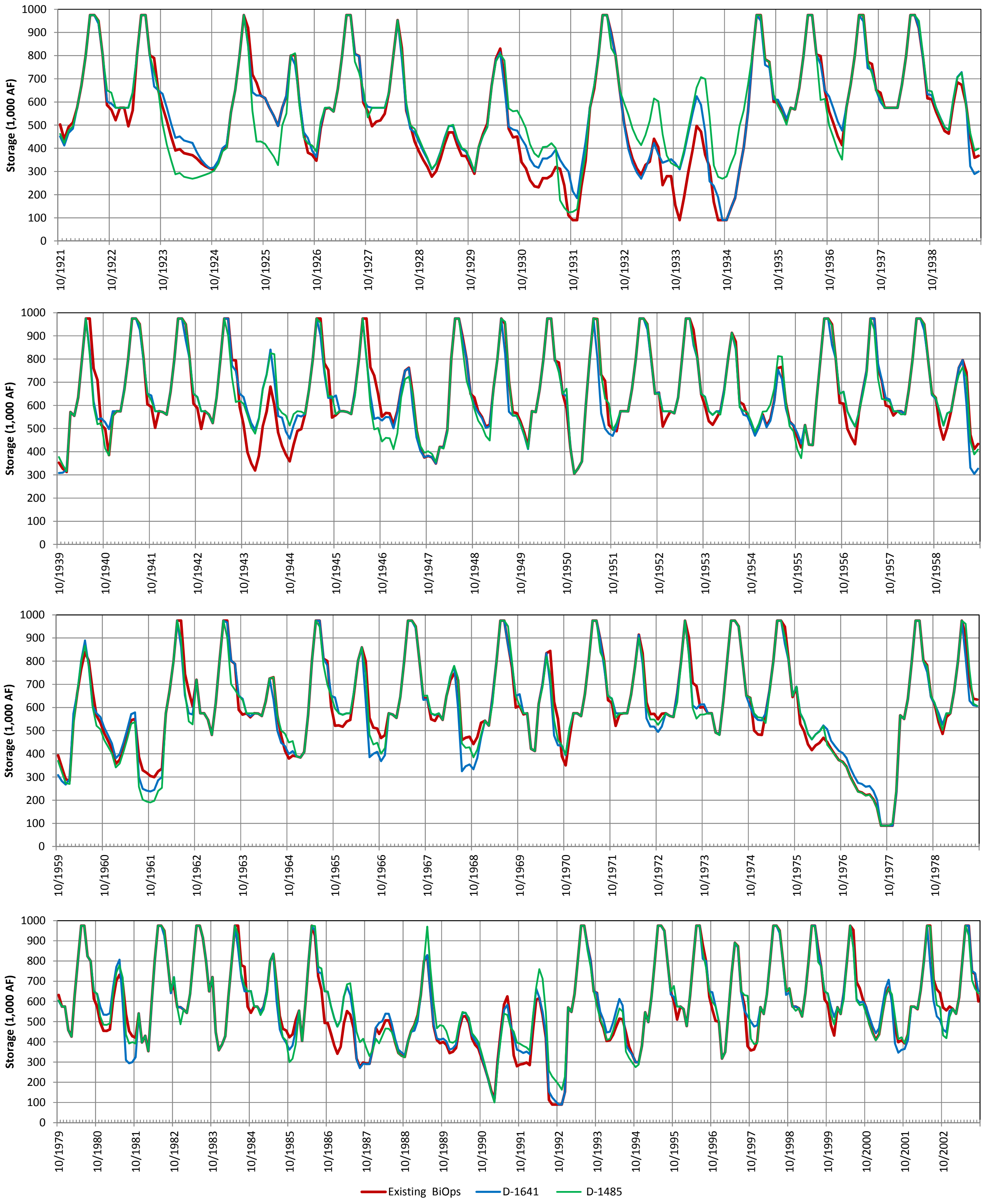
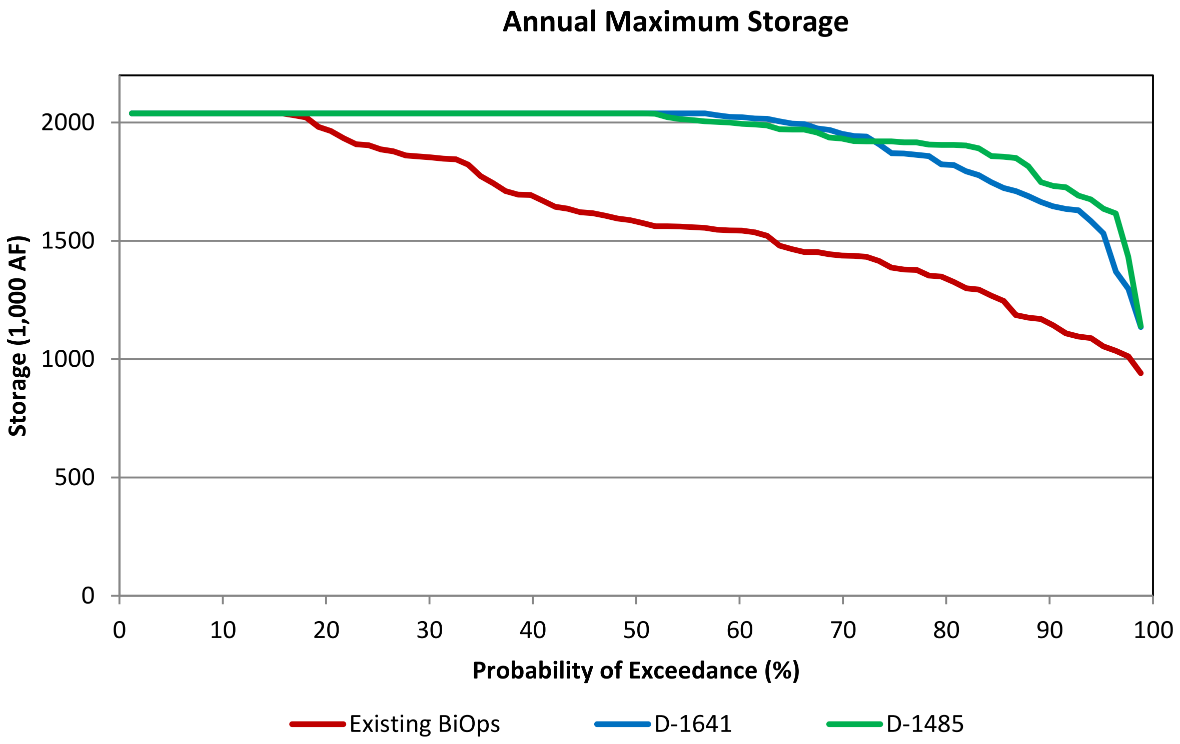
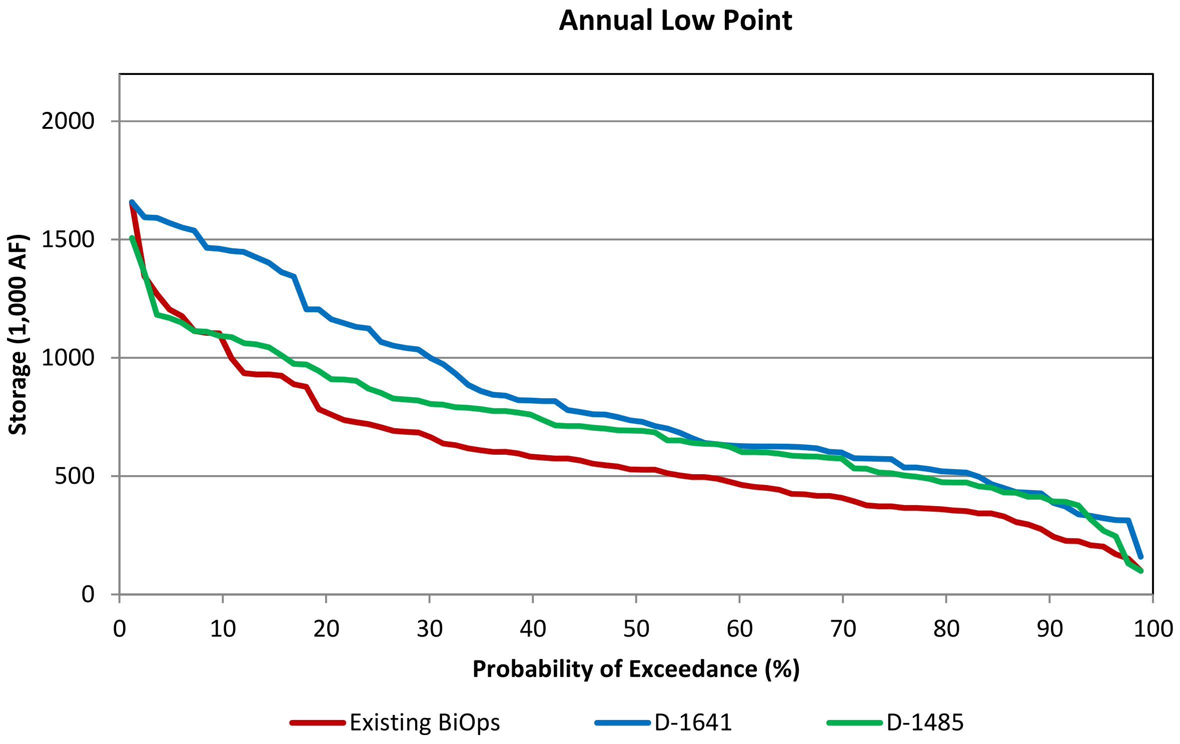


Exhibit 11 – San Luis Reservoir Storage Conditions


Annual Maximum Storage


Annual Low Point

Water Supply

On average, increases in Delta outflow are approximately equal to reductions in Delta exports. Average annual Delta exports in the D-1641 scenario are about 300,000 AF lower than the D-1485 scenario, and exports are reduced about another 1,000,000 AF in the Existing BiOps scenario relative to the D-1641 scenario. This results in a total water supply loss from D1485 to the Existing BiOPs of about 1.3 Million Acre-feet. For each year type the average water supply loss is between 1.0 Million Acre-Feet and 1.5 Million Acre-Feet.

To put this kind of water supply loss into perspective, the last major on–stream reservoir built in California (New Melones in the 1970's) had a dry year water supply of about 200,000 Acre-feet. New projects being considered are typically much less than this amount. Said another way, the water supply loss over the last 30+ years of Delta regulations have cost the State the equivalent of about 6 major reservoirs.

Exhibit 12 contains average annual changes in total Delta exports by water year type, changes at Jones and Banks pumping plants are also displayed.

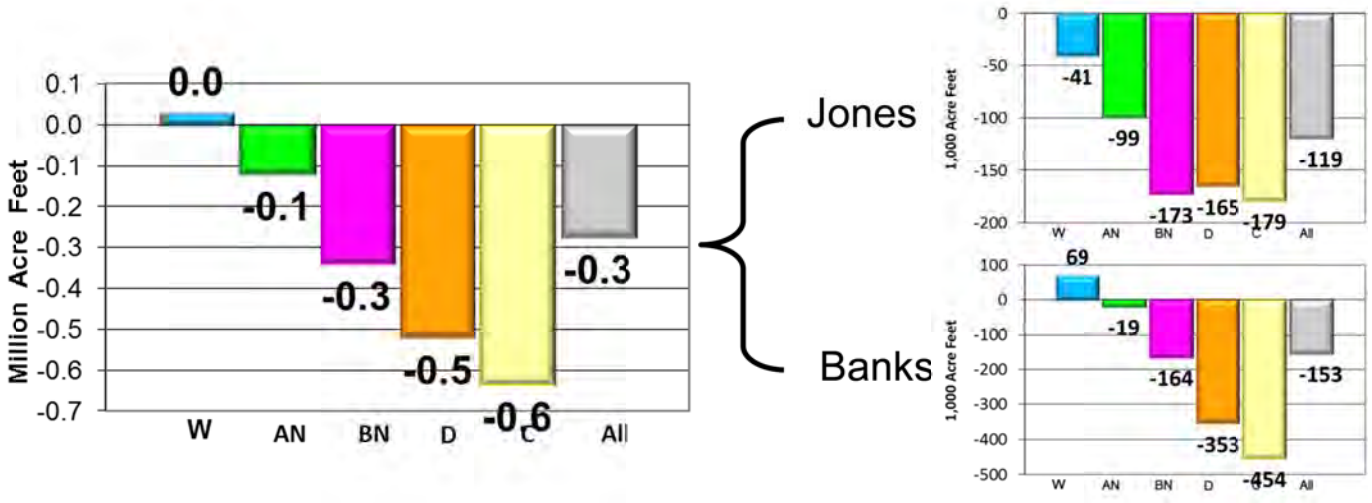
Project Deliveries

Exhibit 13 contains a tabular CVP water delivery summary for the D-1485 scenario and changes relative to the D-1641 and Existing BiOps scenarios. Exhibit 14 contains exceedance probability plots for annual deliveries and allocations. Water allocations in the D-1641 scenario are less than in the D-1485 scenario for both agricultural and M&I contractors in areas north and south of the Delta. Allocations are more significantly reduced in the Existing BiOps scenario relative to the D-1641 scenario than the D-1641 scenario relative to the D-1485 scenario. There are years with no allocation for both north and south of Delta contractors and several additional years when deliveries may be insufficient to maintain permanent crops.

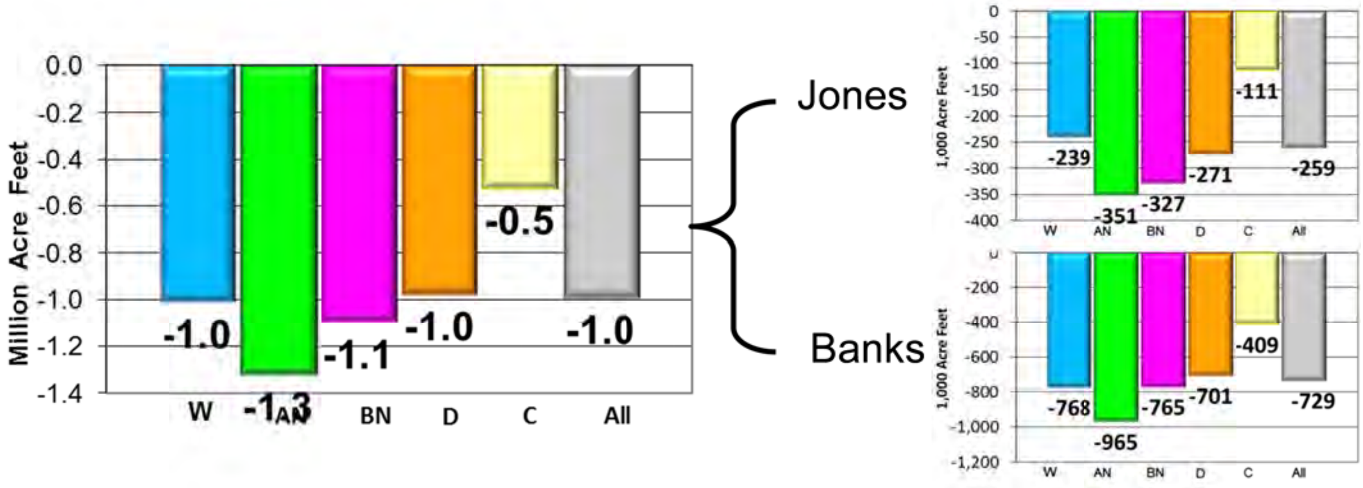
Exhibit 15 contains a tabular SWP water delivery summary for the D-1485 scenario and changes relative to the D-1641 and Existing BiOps scenarios. Exhibit 16 contains exceedance probability plots for annual deliveries and allocations. Water allocations in the D-1641 scenario are less than in the D-1485 scenario and allocations are more significantly reduced in the Existing BiOps scenario relative to the D-1641 scenario, than the D-1641 scenario relative to the D-1485 scenario. In addition to this reduction in allocation, surplus water (available under Article 21 of SWP contracts) was available in about 90% of years in the D-1485 scenario, 82% of years in the D-1641 scenario, and only 25% of years in the Existing BiOps scenario.

Exhibit 12 – Change in Delta Exports

D-1641 minus D-1485



Existing BiOps minus D-1641



Existing BiOps minus D-1485

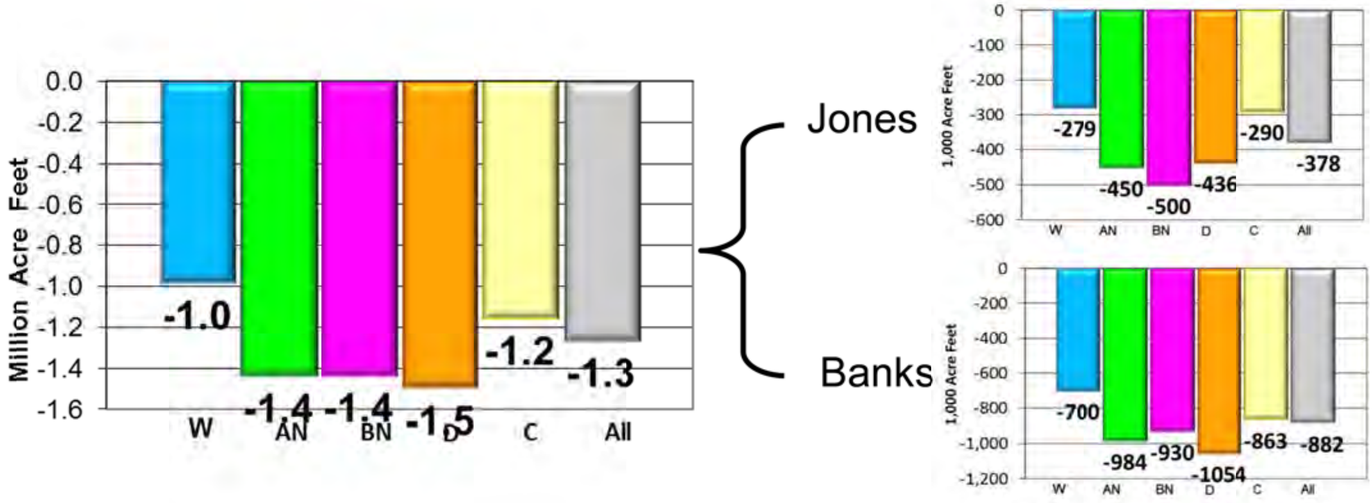


Exhibit 13 -CVP Average Annual Deliveries by Water Year Type

D-1485 Average Annual Delivery (1,000 AF)

	Agricultural Service Contractors		M&I Service Contractors	
	North of Delta	South of Delta	North of Delta	South of Delta
W	324	1783	93	147
AN	303	1590	85	135
BN	283	1435	89	137
D	198	1006	82	121
C	99	524	74	106
All	256	1357	87	134

Average Annual Delivery Change D-1641 minus D-1485 (1,000 AF)

	Agricultural Service Contractors		M&I Service Contractors	
	North of Delta	South of Delta	North of Delta	South of Delta
W	-2	-235	0	-2
AN	-3	-312	1	-5
BN	-20	-349	-1	-9
D	-1	-100	1	-2
C	-23	-134	-3	-6
All	-8	-224	0	-4

Average Annual Delivery Change Existing BiOps minus D-1641 (1,000 AF)

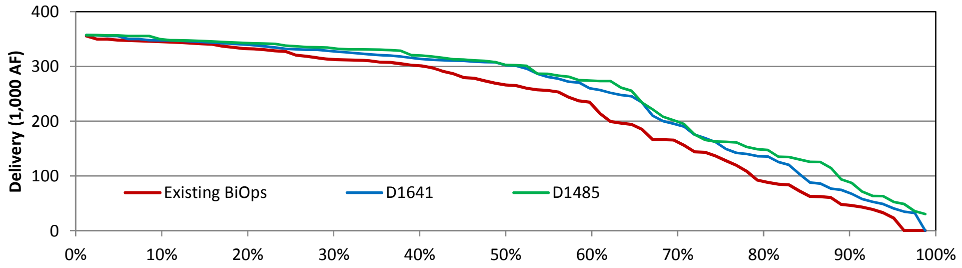
	Agricultural Service Contractors		M&I Service Contractors	
	North of Delta	South of Delta	North of Delta	South of Delta
W	-4	-161	0	-11
AN	-12	-291	-1	-16
BN	-36	-358	-2	-17
D	-38	-286	-2	-11
C	-24	-152	-4	-11
All	-21	-243	-2	-13

Average Annual Delivery Change Existing BiOps minus D-1485 (1,000 AF)

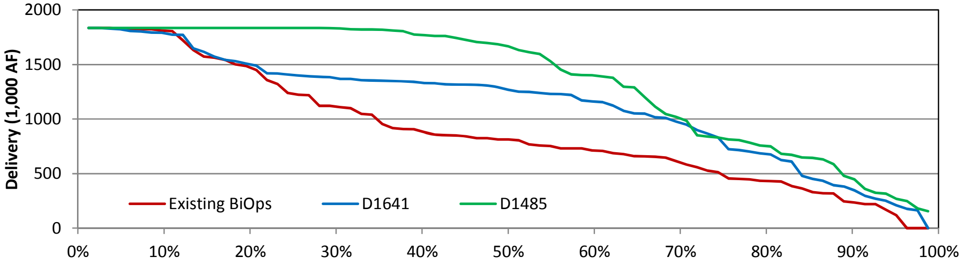
	Agricultural Service Contractors		M&I Service Contractors	
	North of Delta	South of Delta	North of Delta	South of Delta
W	-6	-395	0	-12
AN	-14	-603	0	-21
BN	-56	-707	-3	-26
D	-40	-386	-2	-13
C	-46	-286	-7	-17
All	-30	-467	-2	-17

Exhibit 14 - CVP Delivery and Allocation Summary

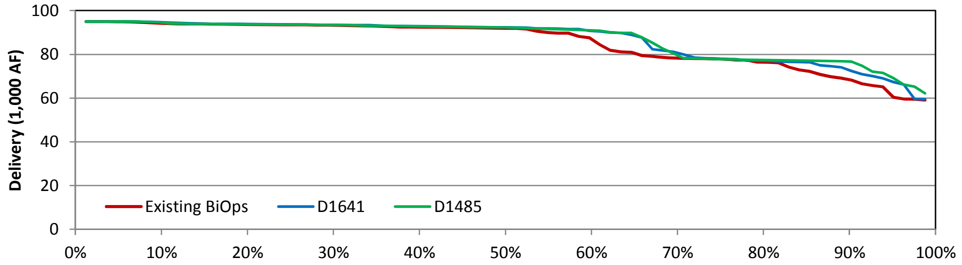
CVP North of Delta Agricultural Service Contract Delivery



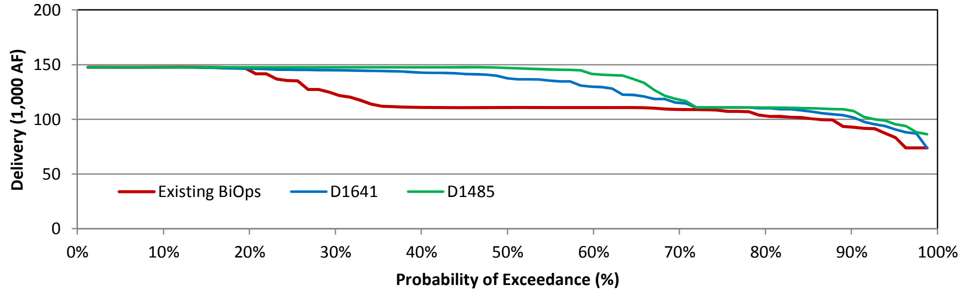
CVP South of Delta Agricultural Service Contract Delivery



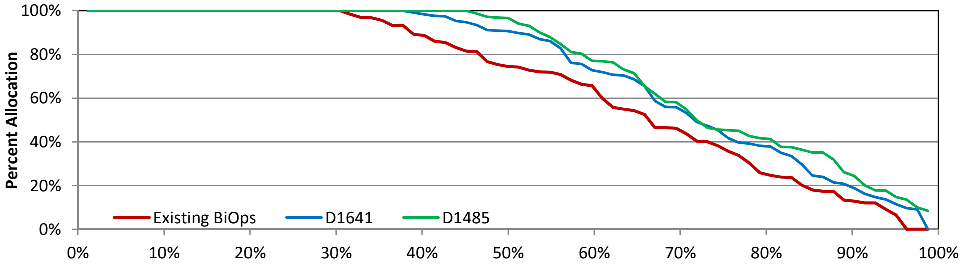
CVP North of Delta M&I Contract Delivery



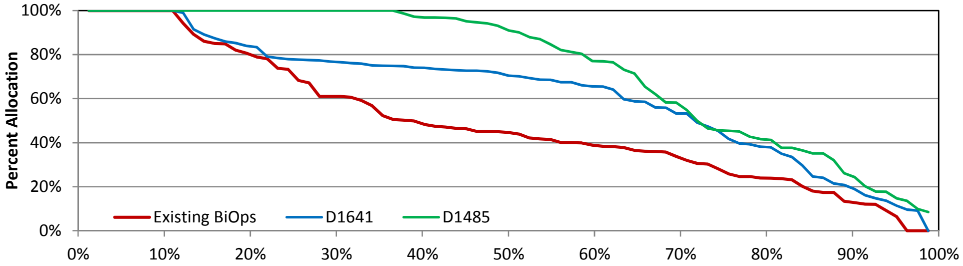
CVP South of Delta M&I Contract Delivery



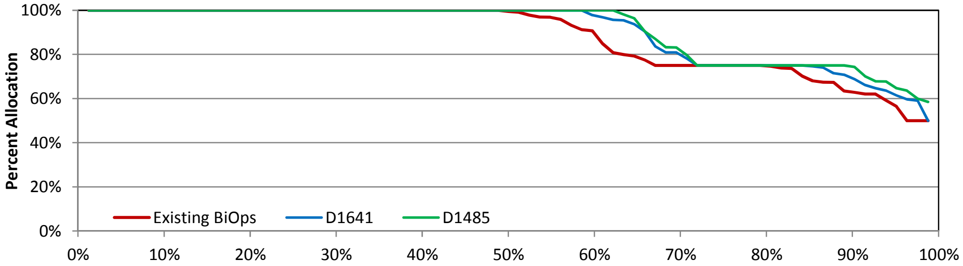
CVP North of Delta Agricultural Service Contract Allocation



CVP South of Delta Agricultural Service Contract Allocation



CVP North of Delta M&I Contract Allocation



CVP South of Delta M&I Contract Allocation

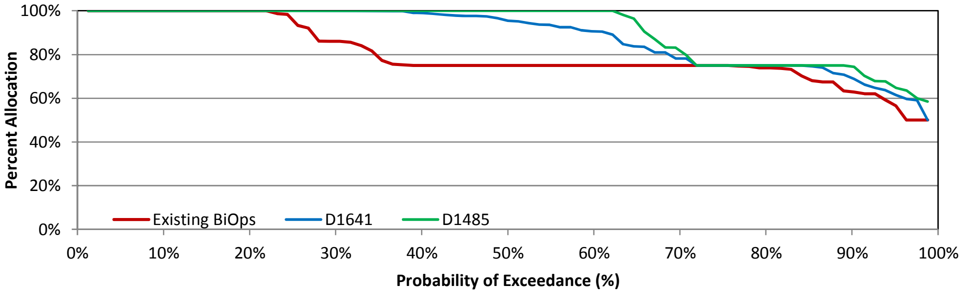


Exhibit 15 - SWP Average Annual Deliveries by Water Year Type

D-1485 Average Annual Delivery (1,000 AF)

	MWD	Other M&I	Agriculture	Article 56	Article 21	M&I	Table A	Total
W	1226	789	824	503	511	2015	2839	3853
AN	1186	715	757	457	298	1900	2657	3412
BN	1335	760	819	418	287	2095	2914	3619
D	1227	671	681	326	332	1897	2579	3237
C	792	475	432	179	178	1267	1699	2055
All	1190	710	734	400	358	1900	2633	3392

Average Annual Delivery Change D-1641 minus D-1485 (1,000 AF)

	MWD	Other M&I	Agriculture	Article 56	Article 21	M&I	Table A	Total
W	-19	4	3	-19	63	-15	-12	32
AN	12	2	3	-166	98	14	17	-51
BN	-7	-7	-7	0	-4	-14	-21	-24
D	-31	-28	-29	41	-129	-59	-88	-176
C	-144	-90	-84	150	-96	-234	-318	-264
All	-34	-19	-19	1	-9	-53	-72	-80

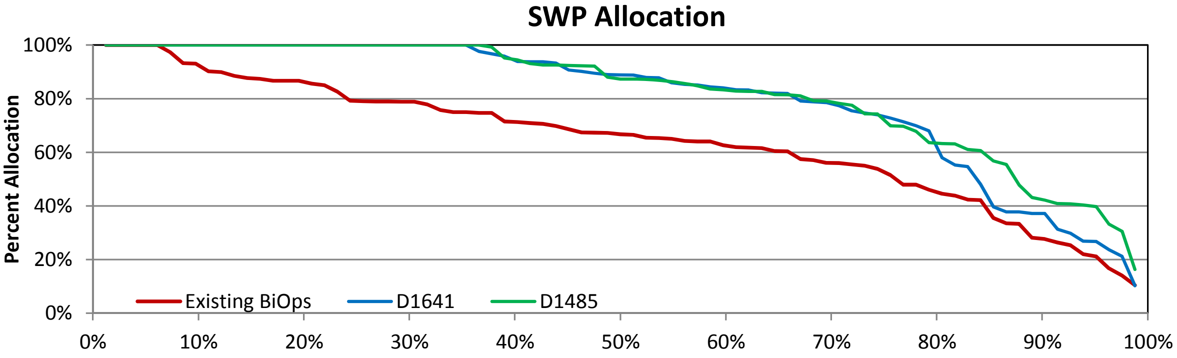
Average Annual Delivery Change Existing BiOps minus D-1641 (1,000 AF)

	MWD	Other M&I	Agriculture	Article 56	Article 21	M&I	Table A	Total
W	-24	-79	-86	-76	-442	-103	-189	-707
AN	-134	-124	-163	-50	-324	-257	-421	-794
BN	-188	-114	-189	-36	-230	-302	-492	-758
D	-247	-89	-146	-93	-183	-336	-482	-758
C	-102	-40	-51	-126	-62	-142	-193	-381
All	-130	-89	-125	-77	-280	-219	-344	-701

Average Annual Delivery Change Existing BiOps minus D-1485 (1,000 AF)

	MWD	Other M&I	Agriculture	Article 56	Article 21	M&I	Table A	Total
W	-43	-75	-83	-96	-379	-118	-201	-676
AN	-121	-122	-161	-216	-226	-243	-404	-845
BN	-196	-121	-196	-36	-234	-316	-513	-782
D	-278	-118	-175	-52	-312	-396	-570	-934
C	-245	-131	-135	23	-158	-376	-510	-645
All	-164	-108	-143	-77	-288	-272	-415	-780

Exhibit 16 - SWP Delivery Summary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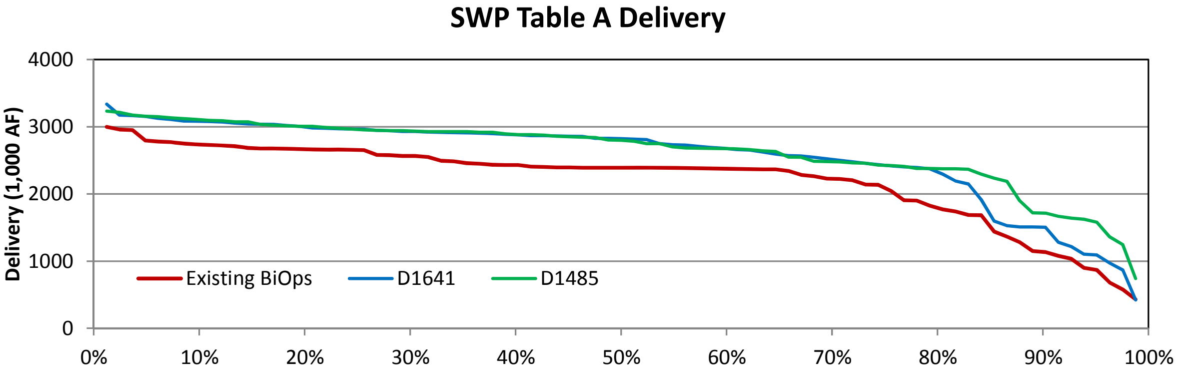
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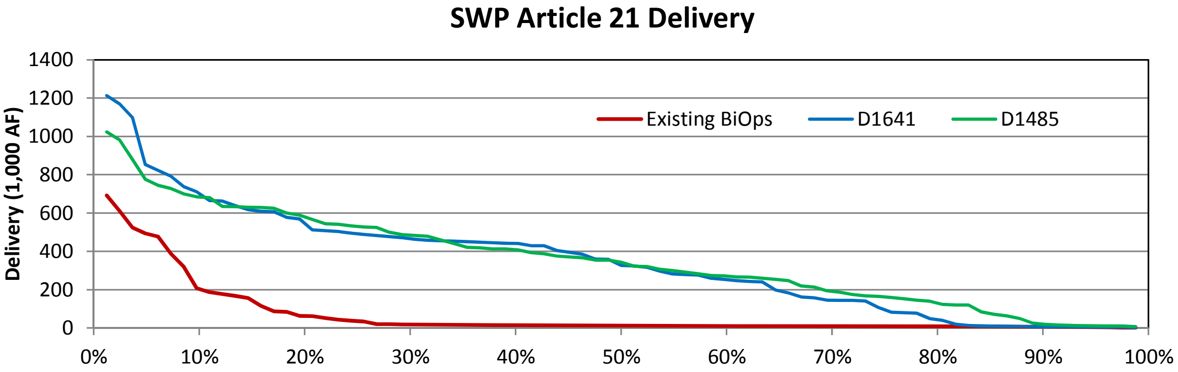
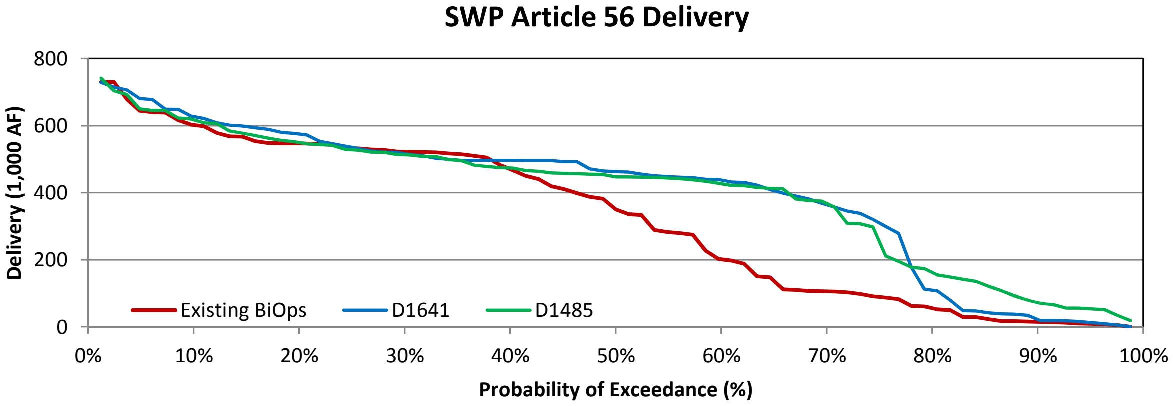

SWP Article 21 Delivery


SWP Article 56 Delivery

Appendix 3

Comments and Recommendations on the October 2016 Working Draft Scientific Basis Report for New and Revised Flow Requirements on the Sacramento River and Tributaries, Eastside Tributaries to the Delta, Delta Outflow, and Interior Delta Operations Pertaining to Anadromous Salmonids

December 16, 2016

Written Submittal of David A. Vogel, Natural Resource Scientists, Inc.
on behalf of Glenn-Colusa Irrigation District, Sacramento Valley Water Users (SVWU), and Northern California Water Association (NCWA)

INTRODUCTION

I am a fisheries scientist with Natural Resource Scientists, Inc., and have been employed in this discipline for 41 years while conducting anadromous salmonid studies in the Central Valley for the past 35 years. I previously worked for the U.S. Fish and Wildlife Service (USFWS) and National Marine Fisheries Service (NMFS) for 15 years, and I have worked as a private consultant for the past 26 years. During this time I have served as a Principal Scientific Investigator in dozens of fish research projects in the western United States on behalf of state and federal agencies, Indian tribes, county governments, municipalities, water districts, consulting firms, and numerous other organizations. I have authored approximately 100 technical reports on fishery science. Most of my work has focused on anadromous fish throughout the Sacramento River basin, the Delta, and the San Joaquin River basin.

The following are comments and recommendations on the October 2016 Working Draft Scientific Basis Report (SBR) for New and Revised Flow Requirements on the Sacramento River and Tributaries, Eastside Tributaries to the Delta, Delta Outflow, and Interior Delta Operations. These comments and recommendations specifically focus on anadromous salmonids.

COMMENTS AND RECOMMENDATIONS

1) Despite claims in the SBR, the best available science concerning anadromous salmonids was not used in preparing that report.

The SBR is severely deficient in fully reporting the science and, for the material presented, the document provides highly selective and misleading use of the existing science concerning anadromous salmonids. Information involving Sacramento River basin anadromous salmonids presented in the SBR (including the prior 2009 SWRCB Staff Report and the 2010 Delta Flow Criteria Report) is incomplete and largely out-of-date. In particular, the SBR does not provide the science contradicting the assumptions postulated in the document, alternative perspectives on the available science, and uncertainties in the science pertaining to anadromous salmonids. In this regard, much of the relevant science on anadromous salmonids specific to the Sacramento

River basin was previously provided to the State Water Resources Control Board (SWRCB) for the 2012 SWRCB Workshops, but was overlooked or ignored (see Exhibit 3 in the SWRCB submittal: http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/bay_delta_plan/comments_042512/andrew_hitchings.pdf) (hereafter referred to as "Vogel Report 1"[1]) and http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/docs/cmnt091412/david_vogel.pdf (hereafter referred to as "Vogel Report 2"). Those two documents, in their entirety, should be considered by the SWRCB for the revised SBR. For example, Vogel Report 1 provides nearly 100 technical references relevant to Sacramento River basin anadromous salmonids beyond those provided in the SBR. The extensive scientific material offered in those two reports will not be repeated in these comments on the SBR (e.g., Vogel Report 1 is 154 pages), but some of the most-relevant information is emphasized here, as well as presenting additional information and recommendations for a revised SBR.

Recommendation: A revised SBR should, at the very least, incorporate the extensive information on the anadromous salmonid science specifically relevant to the Sacramento River basin included in Vogel Reports 1 and 2 to improve the scientific bases in the document. Unless the SWRCB explicitly acknowledges and incorporates this previously submitted information, the SWRCB's focus may be directed in the wrong areas.

2) The SBR provides substantial information related to San Joaquin River basin anadromous salmonids and flow-related issues that have no bearing on the Sacramento River basin.

The juxtaposed discussions on the San Joaquin River and Sacramento River imply the flow and non-flow factors affecting anadromous salmonids are similar between the watersheds; this is obviously invalid because the basins are radically different in hydrologic and biological conditions.

Recommendation: Discussions regarding the San Joaquin River should be removed from the SBR.

3) The SBR largely ignores that there have already been unprecedented, major actions and progress to restore anadromous salmonids through both flow-related measures (implemented differently than the postulated concept of percent of unimpaired flow) and non-flow measures linked with flow.

The SBR greatly mischaracterizes existing conditions for anadromous salmonids in the Sacramento River basin. As such, the SBR risks undermining the past and present actions to increase the quantity and quality of salmon habitats throughout the basin. Contrary to the lack of description in the SBR on habitat improvements, there has been significant progress over the last

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[1] Vogel, D.A. 2011. Insights into the problems, progress, and potential solutions for Sacramento River basin native anadromous fish restoration. Report prepared for the Northern California Water Association and Sacramento Valley Water Users. Natural Resource Scientists, Inc. April 2011. 154 p.

few decades on relevant Sacramento River basin salmonid restoration actions, including the following:

- Adult fish passage at many important upstream migration barriers has been extensively improved and some major barriers have been completely removed, providing fish access to upstream areas essential for increased fish production.

- Thermal conditions in the rivers downstream of large dams have dramatically improved, yielding critically important protection of fish during highly temperature-sensitive periods in the life cycle.

- Remedial actions at the abandoned Iron Mountain Mine near the upper Sacramento River have largely eliminated a previous major source of fish mortality.

- A massive program over the past two decades to screen unscreened or inadequately screened water diversions costing approximately $574 million has resulted, or will soon result, in protection of fish at most diversions, which collectively divert a maximum of nearly 13,000 cfs.

- Watershed restoration programs to protect and enhance conditions on numerous tributaries have proliferated in recent times, and are believed to have benefited fish habitats and overall watershed health.

- Improved flow regimes in the rivers downstream of the Sacramento River basin's major dams have been implemented in recent decades, providing additional fish protection during all the freshwater life phases.

An uninformed reader of the SBR would likely conclude that if new, undefined flow-related measures (based on a hypothetical criterion of a very high percent of unimpaired flow) are administered, then all Sacramento River basin salmonid populations would positively respond. To the contrary, if implemented as proposed, without considering the risk of drastically reducing reservoir levels in some years, cold-water storage may be depleted, resulting in devastating impacts on anadromous fish egg incubation at critical times. Additionally, improperly timed high flows could provide unfavorable conditions for mainstem rearing fish. Execution of the flows described in the SBR would have a high potential of largely undoing recent decades' progress in restoring conditions for salmonids in the Sacramento Valley. Careful examination of the impacts of large flow increases is warranted by thorough modeling studies to determine the effects on water supplies, thermal impacts to fish, and alteration of instream habitats. The SBR has neglected to address those analyses. Unfortunately, little progress has been made on parsing out the various and most important factors related to flow that may influence fish survival. The causal effects of flow and salmon survival relationships in the Sacramento River have been difficult to determine because of complex inter-relationships with numerous variables associated with flow, which are not sufficiently described in the SBR. Focused studies to ascertain those relationships are needed and must be conducted to accurately justify the SBR's flow recommendations.

Recommendation: To provide a more-scientifically balanced discussion on factors affecting anadromous salmonids, the SBR should provide a detailed description of the accomplishments that have been achieved on a site-specific basis throughout the basin to benefit anadromous salmonids. Much of this information was previously provided to the SWRCB in Vogel Reports 1 and 2, and should be incorporated into a revised SBR.

4) There are numerous conflicting and confusing statements in the SBR concerning unimpaired flows, natural flows, sculpted flows, and functional flows.

The SBR appropriately points out that unimpaired flows are not the same as natural flows, yet the document frequently uses the two terms interchangeably. Additionally, the SBR often recommends "mimicking the natural hydrograph" for purported benefits to anadromous salmonids, yet provides conflicting and confusing statements recommending artificially "sculpting" flows for salmonids that would not reflect natural hydrologic conditions. Furthermore, the SBR also deems that it would be most appropriate, in some instances, to implement functional flows to benefit salmonids. Importantly, the SBR provides no analysis of the origin of such flows from upstream areas.

Recommendation: The discussions in the SBR on unimpaired flows, natural flows, sculpted flows, and functional flows need to be reconciled for consistency.

5) Many statements in the SBR concerning anadromous salmonids are unsubstantiated with no supporting scientific basis.

The SBR is replete with assertions concerning fishery resources in the Sacramento River basin without providing the scientific basis to support those statements. For example, the SBR states that Biological Opinion requirements for salmonids are insufficient to protect the fish while neglecting to provide any technical basis for that statement (SBR Page 1-4). As another example, the SBR proclaims to describe the science supporting recommended instream flow requirements for tributaries to the Sacramento River basin to protect fish; that science is not provided (SBR Page 1-9). In a further example, the SBR "*… specifically finds that flows are needed that more closely mimic the conditions to which native fish species have adapted, including the frequency, timing, magnitude and duration of flows, as well as the proportionality of flows from tributaries*." (SBR Page 1-11). Here again, the support for that explanation is missing. There is also a pattern in the SBR of repeating the same or similar unsubstantiated statements. These are just a few of the numerous examples in the SBR.

Recommendation: The revised SBR should cite to and reference the scientific documentation and basis to support the unproven statements.

6) The SBR lacks descriptions of alleged flow-related problems for anadromous salmonids in the Sacramento River and its tributaries on a specific spatial and temporal basis.

Only vague statements are given in the SBR on this topic. The SBR largely ignores the numerous existing flow requirements on the Sacramento River and its tributaries which have been specifically formulated over many years to protect anadromous salmonids. Instead, the SBR implies that flow-related requirements are largely lacking. Existing flow standards already in place in the basin to protect the fish populations must be taken into account. In this regard, NCWA wrote a report (NCWA Report) to compile and summarize those flow standards and the report was submitted to the SWRCB as Exhibit 4 to the SVWU's April 2012 Comments (see: http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/bay_delta_plan/comments_042512/andrew_hitchings.pdf). Information in that report, as it relates to anadromous salmonids, is highly instructive to include in the SBR because flow standards already in place in the Sacramento River basin to protect the fish populations must be taken into account. The following are relevant highlights of the NCWA report.

Sacramento River

There are a variety of state and federal regulatory measures in place to protect fishery resources in the Sacramento River downstream of Keswick Dam (the upstream terminus for salmon migration). These instream flow schedules were carefully crafted by the fishery resource agencies and water project operators to ensure fish protection downstream of the major dams. These include:

- A 1960 Memorandum of Agreement between the Department of Fish and Game [DFG; now the Department of Fish and Wildlife (DFW)] and the U.S. Bureau of Reclamation (USBR) for flow objectives to protect fishery resources in normal and critically dry years, including minimum water level fluctuations.

- A 1981 agreement with DFG and USBR negotiated to eliminate the deleterious effects of salmonid redd dewatering from the original minimum flow of 3,900 cfs during the fall down to 2,600 cfs in the winter. The new agreement established a base flow of 3,250 cfs during the fall and winter.

- SWRCB Water Rights Orders 90-5 and 91-1 modified USBR's water rights to operate Shasta and Keswick Dams and the Spring Creek Powerplant to provide for cold water (56°F) as far downstream from Keswick Dam as practicable during periods when higher temperatures would be harmful to salmon. A Sacramento River Temperature Task Group (including the three fishery resource agencies: NMFS, USFWS, and DFW) is responsible for formulating and coordinating appropriate water temperature regimes in the Sacramento and Trinity Rivers each year with the SWRCB having overall authority on the sufficiency of annual plans.

- At times, the USFWS may use its discretionary use of Central Valley Project (CVP) Improvement Act (CVPIA) 3406(b)(2) water to benefit Sacramento River fishery resources.

- The 2009 NMFS Biological Opinion outlines a comprehensive strategy to manage CVP operations in the upper Sacramento River basin for the needs of anadromous fishery resources (i.e., primarily winter-run Chinook salmon, but also other salmon runs). The Biological Opinion specifies Reasonable and Prudent Alternative measures for fish

> protection in the upper Sacramento River that include flows, water temperature control, and reservoir carryover storage levels, among other measures. That document lists an array of performance measures to achieve specific water temperature objectives at certain compliance locations downstream of Keswick Dam over varying frequencies in multi-year periods.

Clear Creek

The 2009 NMFS Biological Opinion specifies a range of Reasonable and Prudent Alternative flow-related measures to benefit salmon production in Clear Creek, including spring attraction flows, channel maintenance flows, spawning gravel replenishment, water temperature objectives, and flows to adaptively manage physical habitat attributes for salmon.

Wilkins Slough Standard

As mandated by Congress, USBR must comply with a 5,000 cfs navigation flow standard at Wilkins Slough on the lower Sacramento River. For the design of Sacramento River water diversion fish screens, the screen criteria were based on the Wilkins Slough flow standard. A description of the Wilkins Slough standard and interrelationships with the 2009 NMFS Biological Opinion is provided in the NCWA Report.

Yuba River

Using a collaborative process, the Yuba County Water Agency (YCWA), DFG, NMFS, USFWS, and environmental groups developed streamflow requirements for the lower Yuba River to address stressors for salmon and steelhead. As a result, in 2008, the SWRCB adopted Corrected Order WR 2008-0014 that implemented the Yuba River Accord’s new instream flow requirements and related measures to benefit anadromous salmonids in the lower Yuba River as changes to YCWA’s water right permits, thereby resolving 20 years of streamflow disputes. That process was recognized as a landmark achievement for benefits to fish habitat protection and water supply reliability.

Feather River

In connection with the Federal Energy Regulatory Commission (FERC) relicensing of the Department of Water Resources’ (DWR) Oroville Project on the Feather River, the SWRCB adopted a water quality certification (SWRCB Order WQ 2010-0016) which contains a range of instream flow and water temperature control requirements downstream of Oroville Dam for both the Low-Flow and High-Flow Channels to protect fishery resources.

Lower American River

In 2000, a diverse group of individuals and organizations working with USBR, DFG, NMFS, and USFWS developed the Flow Management Standard (FMS) which is intended to improve habitat conditions for Chinook salmon and steelhead in the lower American River downstream of Folsom and Nimbus Dams. The FMS includes: 1) minimum flow requirements, 2) water temperature objectives, 3) implementation criteria, 4) creation of an agency group to address river management and operational actions, and 5) a monitoring and evaluation component. In its 2009 Biological Opinion for the CVP, NMFS included the FMS flow, operational criteria, agency group, and monitoring requirements as Reasonable and Prudent Alternative measures, and also required an iterative temperature management planning process consistent with water temperature objectives of the FMS.

Antelope, Mill, and Deer Creeks

Although not described in the NCWA report, NMFS and DFW have recently worked cooperatively with water users in these three watersheds to improve upstream and downstream flow conditions for spring-run Chinook salmon and steelhead.

Collectively, the foregoing instream flow and water temperature standards for the rivers downstream of the major dams in the Sacramento River basin provide a wide range of protection for the various runs of anadromous salmonids in the mainstem and major tributaries. Those standards were developed to be protective for fish as they were formulated in concert with the fishery resource agencies based on site-specific conditions.

Recommendation: The revised SBR should provide more specificity concerning the timing and location of alleged flow problems, and articulate a more-complete and balanced discussion on this topic with clear recognition that flow standards already established throughout the basin were formulated to protect fish.

7) The SBR does not provide any meaningful details on non-flow measures that could be implemented to benefit salmonids.

The document is severely lacking any details on non-flow measures that could be implemented to increase the quality and quantity of anadromous salmonid habitats. Despite the SBR's much generalized statements concerning the benefits of such measures, relevant information is not provided. Although there are many examples of this deficiency, a good representation is the provision to retrofit the Freemont Weir to provide Yolo Bypass floodplain inundation during lower flows and longer durations to benefit outmigrating salmon. This measure would also prevent fewer salmon from entering Georgiana Slough, which is the primary rationale for the SBR's high-flow recommendation at Freeport. This simple non-flow action could result in biological benefits greatly exceeding those postulated for the SBR's Freeport flow proposal, without jeopardizing critical water supplies necessary for all salmon runs and life stages in upstream areas. Numerous other examples are provided in Vogel Reports 1 and 2 previously provided to the SWRCB in 2012.

Recommendation: Information on this topic was previously provided during the 2012 SWRCB Workshops (Vogel Reports 1 and 2) and should be incorporated into the revised SBR.

8) The SBR provides only a very generalized description for the timing of anadromous salmonid life stages, and has not adequately characterized the benefits to outmigrating salmonids created from turbidity resulting from accretions events, and instead, implies that flow alone creates benefits for all salmonids.

As a primary basis for the recommended flows for salmonids, the SBR relies heavily on two simple graphs [SBR Figure 3.4-12(a) and (b)]. Those graphs compare the average catch/effort of unmarked salmon in the Chipps Island trawl during April through June, 1976 – 1997 and April through June, 1976 – 2015 versus average Rio Vista flows for the same periods. It is particularly evident that the SBR has not addressed all of the significant uncertainties associated with the underlying assumption of the Chipps Island trawl data and the timing of salmon outmigration. Other than the obvious problem of relying on this uncertainty, there are several major problems with using those graphs as the sole basis for the SBR's flow recommendations:

1) The Chipps Island trawl captures salmon originating from the entire Central Valley, not just the Sacramento River basin.

2) The April through June period is not reflective of when many of the juvenile salmon emigrate from the Delta (e.g., June is not considered a month of high salmon emigration and many salmon emigrate earlier than April). For example, SBR Table 3.4-2 shows that ***only 1%*** of juvenile winter-run Chinook enter the Delta during the April through June period; the other 99% enter the Delta prior to April. As pointed out in the SBR, many of the juvenile salmon migrate out of the Delta rapidly. Therefore, using the April – June Chipps Island trawl data would be inappropriate to formulate flow recommendations for winter-run Chinook.

3) The primary driver for the linear relationship in SBR Figure 3.4-12 is due to very high, uncontrolled runoff during wet and above-normal water years. In fact, exclusion of those several outliers shows no apparent relationship between Chipps Island trawl data and Rio Vista flows in April – June. Three of the extreme outliers were in 1982, 1983, and 1995 which were ***the three wettest years of record during the period of 1956 – 2009***. Flows during those years are far beyond flows that could be purposefully achieved through management actions by the SWRCB and should not be used as the primary basis for formulation of flow recommendations in the SBR, particularly because lesser flows in the realm of management show no apparent relationship on salmon catches.

4) The catch efficiency of the Chipps Island trawl may vary among hydrologic conditions (e.g., higher turbidity and lower tidal excursion during wet years may result in higher efficiency in capturing young salmon).

5) The data points for graph (b) for 1976 – 1997 do not appear to match the data points for the same period in graph (a). Also, the specific years are noted for graph (a) but not for graph (b), preventing any meaningful analyses.

6) The SBR inappropriately extrapolates beyond the bounds of the April – June graphs to the January – March period.

7) During the period from 1976 – 2015, some conditions in the Delta had changed significantly (e.g., implementation of provisions in the NMFS Biological Opinions to protect salmon such as Delta Cross Channel closures, export limitations, etc.).

8) An annual index of trawl catch/effort versus flow, by itself, cannot be a reliable indicator of relative annual abundance because many other factors can have an over-riding influence on abundance. For example, in some years, the strength of a particular year-class of salmon can be significantly affected by the total numbers of salmon spawning in the various rivers, conditions on the spawning and rearing grounds can vary significantly between years, etc. In this regard, the SBR mistakenly confuses relative abundance in the Chipps Island trawl with salmon survival through the Delta.

9) The SBR states that "*The abundance and survival of juvenile fall and winter run Chinook salmon emigrating past Chipps Island increase when Sacramento River flow is greater than 20,000 cfs between February and June (Table 3.4-7)*". However, SBR Table 3.4-7 cannot be used as the scientific basis for that conclusion because it is simply the SBR's flow recommendations, not empirical or modeled scientific data (i.e., a recommendation is not a supporting scientific justification).

Furthermore and importantly, the SBR's proposed extremely high flows at Freeport and Rio Vista over many months does not account for the effects of turbidity on outmigration, nor does the SBR account for when salmonids may naturally be outmigrating. Incorporating the natural variability in salmon outmigration timing is critical for any flow recommendation and should be articulated in the revised SBR. This natural variability is very crucial for any flow recommendation to ensure flows occur when salmonids are actually present. For example, the outmigration of salmon occurs in pulses associated with a combination of flow and accretion events causing increased turbidity. Existing scientific information is readily available on the specific outmigration timing of the runs of anadromous salmons under various hydrologic conditions and factors such as turbidity that affects that timing. The SBR, however, only briefly mentions the topic and has not incorporated that information into the flow recommendations. The most important abiotic[2] factors stimulating episodic salmon emigration from the upper to the lower river are likely combinations of river flow and turbidity, which can be auto-correlated with precipitation and natural accretion events. Juvenile salmon downstream migrations tend to occur in groups, and pulses and have shown to correspond with increased flow events and increased turbidity as demonstrated in USFWS salmon research performed by Kjelson et al. (1982) and Vogel (1982, 1989). The life stage activities for each run of Sacramento River Chinook salmon highly correspond with hydrologic conditions during any given year (Vogel and Marine 1991). This phenomenon has been frequently observed through many years of sampling in Central Valley rivers and streams (e.g., Martin et al. 2001, Poytress et al. 2014). However, the SBR has not incorporated this science, and largely appears to assume that salmon outmigration stimulae and survival are primarily functions of increased releases from water storage reservoirs; that assumption is not supported by the best available science. In this regard, the SBR has greatly confused the issue of the biological effects of flow on salmon resulting from natural accretion events in contrast to the effects of flow resulting from water storage. The SBR's ambiguous and

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[2] An abiotic factor is smoltification.

incomplete discussion on this topic is very misleading. This serious issue with the SBR's recommendation of high flow from reservoirs would undoubtedly significantly reduce available water supplies to ensure critically important functional flows at other times of the year that provide cold water and support salmon spawning and rearing.

Recommendation: The SBR should include a more accurate and balanced discussion on the topic using the best available science.

9) The purported biological benefits of the flow recommendations are not quantified and only vague, generalized statements are given in the SBR.

The SBR does not provide a description of any clear scientific benefits associated with the flow recommendations for anadromous salmonids. Additionally and importantly, the SBR fails to address the fact that little progress has been made on parsing out the various factors related to flow that may influence fish survival. Additionally, the SBR does not address major scientific uncertainties and highly complex variables affecting salmonids (both in upstream areas and, in particular, the Delta) where the SWRCB could more appropriately focus its attention. However, the SBR appears to simply conclude "more flow is always better," without determining numerical thresholds or examination of site-specific causal mechanistic effects of flow on survival. There are many variables intertwined with flow that may be the most important to affect fish survival. For example, the very large SBR-recommended flows at Freeport for the entire period of January through May are proposed to push back the flood tides at the Georgiana Slough flow split under the auspices of reducing some outmigrating salmon from entering the interior Delta. However, the SBR provides no description that benefits would be minimal if the following scenarios exist (among other uncertainties):

1) Significant numbers of salmon are not present in the small, localized vicinity at the junction during the brief periods of tidal excursion;

2) Most salmon have already passed the junction during prior outmigration periods; and

3) A higher proportion of salmon are diverted into Sutter and Steamboat Sloughs as a consequence of those flows resulting in higher salmon mortality.

Any potential benefits of such a measure could be greatly offset from adverse impacts to salmon habitats in upstream areas (e.g., reduced water supplies for cold water and salmon spawning and rearing habitats). The SBR provides no explanation of anticipated quantitative benefits or detriments to salmon resulting from such a measure.

Recommendation: The revised document should provide detailed descriptions of the specific causal mechanisms of flow effects on salmon survival, and the anticipated quantitative benefits and adverse impacts for salmonids resulting from the flow recommendations. Additionally, the SBR should address the major scientific uncertainties and highly complex variables affecting the fresh-water life stages of anadromous salmonids.

10) The SBR provides no meaningful, tangible understanding of redirected impacts on other species and life stages resulting from the flow recommendations.

By far, the most-overwhelming adverse effects to salmonids in the Sacramento River basin resulting from attempts to implement extremely high unimpaired Delta inflow and outflow criteria are major reductions in water storage in the large reservoirs (Shasta, Oroville, Folsom). Without this critical water supply available for fishery resources, the negative effects on anadromous salmonids could be devastating. Although the SBR claims that it provides "new requirements for cold water" and "describes the science supporting a new narrative cold water habitat requirement", there are no relevant details. Additionally, improperly timed high flows could provide unfavorable conditions for mainstem rearing fish. Careful examination of the impacts of large flow increases is warranted by thorough modeling studies to determine the effects on water supplies, thermal impacts to fish, and alteration of instream habitats. Here again, the SBR risks undermining the progress to date to increase the quantity and quality of anadromous salmonid habitats in the watershed. This critical deficiency seriously undermines the scientific credibility of the SBR.

Recommendation: Detailed modeling studies should be conducted to show the impact of the high flow regimes contemplated in the SBR for fish outmigration to determine consequences to water supplies, and the thermal regime in the basin's storage reservoirs as those factors affect anadromous salmonid spawning, egg incubation, and rearing. A revised SBR should incorporate results of those analyses.

11) The SBR is severely deficient in the section concerning other stressors (Chapter 4) on anadromous salmonids, and additional management actions which could be implemented to benefit salmonids.

The SBR states: "*Chapter 4 summarizes the various categories of other aquatic ecosystem stressors in the Bay-Delta Watershed, and how stressors interact in the ecosystem.*" The SBR, however, is severely lacking in providing critically important scientific information of the effects of other stressors on the various life stages of anadromous salmonids. This information is relevant because, as pointed out in the SBR, flow needs could be reduced by addressing other ecosystem stressors. Matching potential stressors on particular fish life phases in time and space should help to tease out the most important factors that have affected and continue to affect the fish populations. If definite stressors co-occur with the anticipated or known impact on specific fish life stages, it may indicate those stressors which are most important. Such an analysis could also suggest that some variables may have minimal importance. The SBR only provides a cursory, vague overview of some of the stressors for anadromous salmonids and lacks descriptions of the location, timing, and magnitude for those stressors affecting salmonids throughout the watershed. Highly significant information on that topic was previously provided during the 2012 SWRCB Workshops, and should be incorporated into the revised SBR (see Vogel Reports 1 and 2).

Recommendation: The SBR should provide much more detail on the role of other stressors affecting anadromous salmonids throughout the Sacramento Basin and in the Delta, and include the scientific information on this topic provided in Vogel Reports 1 and 2.

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Appendix 4

Technical Comments on the Working Draft Scientific Basis Report for New and Revised Flow Requirements on the Sacramento River and Tributaries, Eastside Tributaries to the Delta, Delta Outflow, and Interior Delta Operations

Prepared for:

The Sacramento Valley Water Users Group

By

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16 December, 2016

Background

The State Water Resources Control Board (SWRCB) is in the process of reviewing and updating its 2006 Water Quality Control Plan for the Bay-Delta. A working draft Scientific Basis Report (referred herein as the Report) has been prepared to support the update of the Bay-Delta Plan's protection of fish and wildlife in the Sacramento River watershed and related areas. The update considers four categories of requirements including levels of inflow, outflow, interior flow, and cold water habitat in an effort to protect Bay-Delta fish and wildlife throughout their migratory range. The Report is structured to include syntheses of available information on the hydrology of the Sacramento River watershed (Chapter 2), flow needs for fish and wildlife (Chapter 3), and other aquatic stressors (Chapter 4). The information in these sections is then used as the scientific basis for recommended new and revised flow requirements (Chapter 5).

In reading through the Report, and with respect to drafting comments based on my review, note that I elected to take a somewhat higher level view of the overall body of science (the so-called scientific enterprise) supporting regulatory activities in the Delta rather than focus on arguably smaller-scale, less impactful, specific technical details. A second objective was to keep my comments relatively brief. Given that background, I would offer the following global observation:

The scientific enterprise used to generate information about flow effects on fish populations in the Delta requires considerable modification. Currently, the scientific enterprise in the Delta that forms the basis for the SWRCB's Report ignores large amounts of readily available information that could support more robust analyses of the environmental factors affecting Delta fish population abundances. Instead, simplistic statistical correlative analyses of survey abundance indices and environmental factors are viewed as the leading scientific method even though extant analyses fail to consider the underlying uncertainty in those indices themselves. As a result, the Report presents a scientific discussion of flow effects on Delta fish species that does not *satisfy the minimum analytical standards applied in other similar fish population management frameworks in the United States.*

Building a successful scientific enterprise for fish population management

Science-based management of fish populations requires research activities in three broadly defined areas: (i) natural history and life cycle biology, (ii) ecology, including investigations of habitat preferences and how fish populations or components of populations interact with surrounding environments, and (iii) population dynamics, where focus is directed at understanding how the abundances of fish populations change over time through explicit consideration of birth, death, movement, and other biological processes. Approaches taken to advance science in these three areas are wide ranging but typically involve studies that are observational, empirical/phenomenological, and mechanistic modeling in nature, respectively. Embedded in mechanistic modeling studies are simulation analyses, which have become very common in the fisheries literature over the past several decades due to advancements of computing power, and are often designed to explore dynamic responses of key population metrics such as abundance to hypothesized 'states of nature' representative of past or future contemplated regulatory actions. There is little debate within the scientific community associated with the management of natural aquatic resources that successful management frameworks require continually evolving synergistic and interdisciplinary activity in all three of the above arenas.

Scientific enterprise in the Delta

Here I briefly summarize my impression of research progress made in the Delta with respect to building a scientific enterprise structured by the aforementioned three research areas and necessary for successful management of fish populations. My rating system includes three tiers: Good, Fair, and Poor.

(i) Observational studies. Over the past several decades, significant advancements have been made regarding studies of natural history and life cycle biology for fishes in the Delta, and many published studies are synthesized and cited in the Report. There is too much literature to cite here, but one notable work in this area is the text by Moyle (2002) which provides a vast array of information about inland fishes of California, including species accounts for native and alien fishes in the Delta that span many topics ranging from taxonomy to biology/ecology to conservation. Although more life history studies are likely needed in the Delta (a sentiment that is true for fishes worldwide), a great deal is currently known about the basic biology and ecology of Delta fish species. Overall rating: Good.

(ii) Empirical/phenomenological studies. Regarding empirically-based ecological analyses of fishes in the Delta, many published works have appeared in the primary literature over the years. Studies by Jassby et al. (1995), Kimmerer (2002), Sommer et al. (2007), and Feyrer et al. (2007, 2011) represent just a few that are discussed and cited in the Report. However, these studies share a common analytical theme in that they statistically correlate annual indices of relative abundance and/or presence-absence of several fish species in the Delta to environmental covariates such as X_2, turbidity, and flows within the Delta. Two conclusions are drawn from these studies: a) such empirical investigations would not be possible without a wealth of systematically collected, long-term, and highly spatiotemporally resolved fish survey data, and b) results of published correlative analyses are informative but they do not analyze existing data to their fullest extent or in accordance with standard analytical frameworks used by fisheries scientists worldwide (more details below). Regarding availability and maintenance of fish survey databases, my overall rating is: Good. However, with respect to the historical analytical treatment of survey data, my rating is: Fair.

(iii) Population dynamics modeling. Studies designed to develop population dynamics models and/or utilize simulation analyses to explore potential impacts of management alternatives are arguably the most vital component of a scientific enterprise underpinning science-based management of fish populations. Such studies achieve three essential goals: a) they mechanistically integrate fundamental biological processes of fish populations such as birth, death, growth, and sexual maturity into a single dynamic framework, b) they facilitate direct inferences about the status of fish populations (e.g., depleted, healthy) which, in turn, shed light on the effectiveness of past management strategies, and c) they can be used to explore expected effects of future hypothesized management strategies on key population attributes such as abundance, thereby providing a natural feedback that can be used to judge the efficacy of regulatory decision-making prior to implementation. Although the structure of some population dynamics models can be statistical in nature, the core state variables are mechanistically linked through time.

For fish populations in the Delta, such studies are largely absent from both the primary and grey literature, and as a result, they are absent from the core science on how flow affect fish species discussed in the Report. This represents a massive hole in the scientific enterprise underpinning the development of regulatory actions in the Delta. Applied scientific inquiry in the Delta has seemingly evolved to place an unbalanced and overemphasis on simple empirical/phenomenological/correlative studies, despite there being a wealth of life-cycle biology information and survey data that are so often used elsewhere in the U.S. to aid population dynamics modeling activities structured to inform management. There is a very clear disconnection between the evolution of science in the Delta and the needs of policy makers. My overall rating: Poor (very).

Modifications to the existing scientific enterprise in the Delta

Here I outline three key modifications should be made to the scientific enterprise supporting policy decision-making in the Delta, including the SWRCB's decision-making concerning amendments to the Water Quality Control Plan for the Delta. In my professional opinion, implementation of these modifications would greatly enhance what is known about fish populations in the Delta which, in turn, would significantly advance the management framework for the SWRCB, among other agencies. In the absence of such modifications, the existing framework for the Delta fails to meet the minimum standards of requisite scientific analyses supporting other management programs of fish populations in the United States, such as the scientific-management framework used by NOAA Fisheries and the Regional Management Councils for the setting acceptable biological catch levels for commercial marine fisheries.

Modification 1: *Within the arena of empirical/phenomenological/correlative investigations, efforts should focus on analyses of raw survey data.*

Much of the literature cited in Chapter 3 of the Report, including the cornerstone studies of Jassby et al. (1995) and Kimmerer (2002) used as the basis for Section 3.3.1, Updated Quantitative Analyses, involved statistically relating annual indices of relative abundance (or survival) of various fish species to flow through regression. Such an approach may be attractive due to its simplicity, but it must be recognized that any index of abundance is a synthesis of a large number of raw field observations. Although the primary purpose of a fish survey is to obtain a collection of measures of fish relative abundance across different time periods and spatial locations, associated measurements of environmental parameters are also routinely recorded for the explicit purpose of providing synoptic representations of how fishes are interacting with the surrounding environment. Therefore, analytical efforts that focus on only annual abundance indices explicitly ignore and lose the wealth of highly informative auxiliary data intentionally collected with each stand-alone survey observation. In the case of the Fall Midwater Trawl Survey (FMWT), the overall loss of information is substantial since each annual index of relative abundance is based on ~400 individual survey samples. Latour (2016) therefore argued against ignoring the raw survey data and provided detailed analyses of raw FMWT survey data for four species at different temporal scales and in relation to a fairly broad suite of biotic and abiotic covariates. Results from that study failed to confirm the effect of a single dominate flow covariate on fish catch-per-unit-effort (CPUE), and further showed that effect of annualized total suspended solids (TSS) on CPUE was far greater for all analyzed species than any annualized flow covariate (16 flows measures were examined). The results of this study highlight an important conclusion: correlations among response variables and predictor variables are not always preserved across different scales of data aggregation (raw survey observations vs. annual indices of relative abundance). The Report, however, does not cite or discuss Latour (2016).

Secondarily, but of equal importance, is the realization that many of the biotic and abiotic covariates in the Delta act synergistically on fish populations such that effects may be hierarchical. A simple example is the following: greater precipitation leads to increase freshwater input to an estuary which elevates nutrient loads that then boost phytoplankton and zooplankton densities. The result is more food availability for juvenile and planktivorous fishes. Simply relating annual indices of abundance to mean flow over a given time period glosses over key mechanistic processes and does not permit elucidating the hierarchical effects of those mechanisms. Within an empirical framework, such hierarchical linkages can only be investigated through analyses of raw survey data.

Modification 2: Within the arena of empirical/phenomenological/correlative investigations, efforts should focus on more comprehensively evaluating uncertainties in raw survey data and resultant analyses.

When regression-type analyses are performed that relate, for example, annual indices of relative abundance to environmental variables such as X_2 or flow, there are two types of variation in the data that should be considered. First is the variation of the index values themselves which underpins estimation of standard errors of regression parameters. This variation is discussed in the Report and used to support conclusions regarding statistical significance of temporal trends (declines) in relative abundance of Delta fish populations. The second source of variation lies in the survey data that are used to estimate the annual indices. The California Department of Fish and Wildlife routinely publishes FMWT trawl indices for several Delta fish species. That agency, however, does not also provide estimates of precision (standard errors, coefficients of variation, confidence intervals) for those indices. Failure to provide precision estimates for estimated quantities (in this case relative abundance estimates) violates one of the most fundamental rules in quantitative, inferential science. Uncertainty estimates are essential for interpreting and judging the quality of estimates of interest. For example, if over consecutive years t and $t+1$, the FMWT indices for a fish species are estimated to X and $0.85X$, respectively, then a natural conclusion is that the relative abundance of that species declined over the period of one year. However, if the confidence intervals associated with the two indices overlap, then there is no statistical difference between those indices and, from a purely inferential point of view, it cannot be concluded that the population has declined. For all regression analyses of relative abundance indices updated in the Report, as well as in the many aforementioned foundational correlative studies of fish relative abundance indices and environmental covariates such as such as X_2 or flow (Jassby et al. 1995, Kimmerer 2002, and those alike), treatment of the uncertainty inherent to the survey data themselves is inappropriately absent. Consequently, and setting aside the previously noted limitations of basing analyses on survey indices rather than raw data, it is impossible to truly judge the robustness of conclusions regarding impacts of flow on fish populations when the analysis does not fully consider the uncertainty inherent in the underlying data.

Modification 3: The scientific enterprise in the Delta should be modified to increase/redirect focus toward fish population dynamics modeling and related simulation analyses.

Comments regarding the severe limitations of not having population dynamics and simulation analyses prominently within the scientific enterprise of the Delta have been noted previously. However, to support this assertion and to add meaningful context to the science summarized in the Report, a brief comparison is made between the scientific enterprises of the Delta with regard to informing the SWRCB on Bay-Delta flow requirements, and the U.S. oceanic ecosystem with regard to informing NOAA Fisheries and the Regional Management Councils about acceptable levels of biological catch for commercially harvested marine fisheries.

As stated in the Report, the SWRCB's mission is to preserve, enhance, and restore the quality of California's water resources and drinking water for the protection of the environment, public health, and all beneficial uses. A component of that mission, as evidenced by the 2006 Bay-Delta Water Quality Control Plan and the current draft update Report involves measures to protect fish and wildlife beneficial uses. The mission of NOAA Fisheries in managing commercial harvests is responsible stewardship of the nation's ocean resources to ensure productive, safe, and sustainable sources of seafood. This mission could be stated alternatively as the long-term protection of marine fisheries resources for beneficial uses. Hence, the two agencies share the common goal (protection of aquatic natural resources for beneficial uses), so it would seem logical that the respective underlying scientific enterprises would be similar. However, they are not, and the most obvious difference lies in the role and utility of population dynamics models and simulation analyses of management alternatives.

For all managed marine fisheries where there are basic harvest data (catch statistics), life-cycle information, and survey data, like those available for fish populations in the Delta, a stock assessment analysis is conducted to inform agency decision-making. Stock assessments are quantitative modeling studies that, at their core, utilize population dynamics models designed to reconcile underlying processes such as birth, natural deaths, growth, and sexual maturation with deaths attributable to harvest by fisheries. Such modeling analyses are standard operating protocol for NOAA Fisheries in managing commercial harvests, yet they are not for the scientific enterprise of regulatory agencies in the Delta. In contrast, the type of sole use of empirical/phenomenological/correlative analyses that appears to be occurring in the Delta and that is reflected in the SWRCB's Report would undoubtedly fail to pass the peer-review used for harvest management and thus could not be used to guide policy implementation (see http://www.nefsc.noaa.gov/saw/ and http://sedarweb.org/ for more information on peer-review of stock assessments for fisheries in the Atlantic). Clearly, the two scientific enterprises under discussion have somewhat divergent evolutionary histories, but given such commonality among core management objectives, it would seem appropriate that they become much more similar.

Summary statement

Unless the Delta scientific enterprise reflected in the Report is revised to better utilize existing raw survey information for Delta fish populations, structure analyses of survey data - like those discussed in the Report – to more explicitly account for data uncertainty, and begin to more centrally focus on population dynamics modeling, it will continue to not meet the scientific standards characteristic of other U.S. fish population management frameworks such as the one used by NOAA Fisheries and, more importantly, it will not adequately serve the needs of the SWRCB and related agencies as they work to fulfill their missions.

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Sample Design-based Methodology for Estimating Delta Smelt Abundance

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ABSTRACT

A sample design-based procedure for estimating pre-adult and adult delta smelt abundance is described. Using data from midwater trawl surveys taken during the months of September, October, November, and December for the years 1990 through 2006 and estimates of size selectivity of the gear from a covered cod-end experiment, stratified random sample ratio estimates of delta smelt abundance were made per month. The estimation procedure is arguably an improvement over the dimensionless delta smelt indices that have been used historically in that (1) the volume sampled is used in a manner that leads to directly interpretable numbers and (2) standard errors are easily calculated. The estimates are quite imprecise, i.e., coefficients of variation in the range of 100% occurred. The point estimates are highly correlated with the monthly indices, and conclusions on abundance declines are quite similar. However, both the estimates and indices may suffer from selection biases if the trawl samples are not representative of the true densities. Future work is needed in at least three areas: (1) gathering additional information to determine the validity of assumptions made, in particular determining the possible degree of selection bias; (2) developing procedures that utilize survey data gathered from earlier life history stages, such as larval surveys; (3) embedding a life-history model into the population estimation procedure.

KEYWORDS

Gear selectivity, Horvitz-Thompson, *Hypomesus transpacificus*, ratio estimators, stratified random sampling

SUGGESTED CITATION

Newman KB. 2008. Sample design-based methodology for estimating delta smelt abundance. San Francisco Estuary and Watershed Science 6(3): article 3. Available from: http://repositories.cdlib.org/jmie/sfews/vol6/iss3/art3

INTRODUCTION

Delta smelt (*Hypomesus transpacificus*) is a fish endemic to upper (or northern) San Francisco Estuary

(Bennett 2005). It is a small (adult FL < 80 mm typically), short-lived (one to two years) fish. It was listed in 1993 as a threatened species under the Federal and California State Endangered Species Acts (USFWS 1993) and is of considerable public interest for both environmental and economic reasons.

A key survey that was used as supporting evidence for the threatened species listing is the fall midwater trawl (FMWT) survey, which is conducted during the months of September, October, November, and December in the Estuary. The survey, which samples for pre-adult (age 0) and adult (age 1) delta smelt as well as other fish species, began in 1967. Tows are taken once a month at around 100 locations or stations. The catches from these tows are used to construct an annual FMWT index for delta smelt abundance (http://www.delta.dfg.ca.gov/data/mwt/charts.asp). Declines in the annual FMWT index beginning in the 1980s (Sweetnam and Stevens 1993; USFWS 1993) led to the threatened species listing of delta smelt. Surveys at larval and juvenile life history stages have also indicated precipitous declines in abundance over the last twenty-plus years (Greiner and others 2007; Sommer and others 2007).

The annual FMWT index is the sum of four monthly indices. To calculate a monthly index, the sampling region is partitioned into fourteen areas or strata. Figure 1 shows the current configuration of sampling locations (stations) and areas. Within each area, the average number of fish caught per trawl is calculated. Letting $\bar{f}_{m,a}$ denote the average in month m and area a:

$$\bar{f}_{m,a} = \frac{1}{n_a} \sum_{s=1}^{n_a} f_{m,a,s}$$

where n_a is the number of stations in area a (generally constant between months) and $f_{m,a,s}$ is the number of fish caught during month m in area a at station s. The monthly index is a weighted sum of the $\bar{f}_{m,a}$, h=1,...,14, where the weights are estimates of water volume in each area (presumably the volume occupied by delta smelt) in ten thousands of acre feet. Letting w_a denote the weight for area a, the monthly index, denoted I_m, is

$$I_m = \sum_{a=1}^{14} w_a \bar{f}_{m,a}, \quad m = Sep, Oct, Nov, Dec. \tag{1}$$

The annual index is then

$$I = \sum_{m=Sep}^{Dec} I_m. \tag{2}$$

The indices, both monthly and annual, may be somewhat difficult to interpret and are to some degree technically deficient, e.g., lacking measures of uncertainty, and these criticisms are discussed in the next section. A primary purpose of this article is to present a first step in the development of estimates of delta smelt abundance that are simpler to interpret, and are more statistically rigorous in the sense of clearly stated assumptions, use of standard survey sampling methodology, and inclusion of standard errors.

Before proceeding with criticism of the indices and presentation of the alternative estimation procedure, however, it should be emphasized that the ostensibly more rigorous statistical estimates of delta smelt presented herein do not differ in substantial ways from the FMWT indices, however technically flawed they might be. Relatedly, biases present in the new estimates are largely ones that the indices would share, particularly selection bias. From a management perspective, what is important is that both the indices and the new abundance estimates indicate a steady, consistent decline in the abundance of delta smelt (Sommer and others 2007).

I also emphasize that additional steps are needed, and are in process, to further develop estimation procedures, ones which incorporate life history processes and utilize data from surveys of other life history stages. Areas of future research and data analysis which could yield more statistically defensible and practically useful estimates of delta smelt abundance are presented at the end of the article.

CRITICISM OF THE INDICES

The first criticism is two-fold: (a) the units of the (monthly) indices are the sum of the product of water volumes and fish counts, rather than fish counts alone; (b) the area weights, w_a in equation (1), which are measures of water volume, are constant within

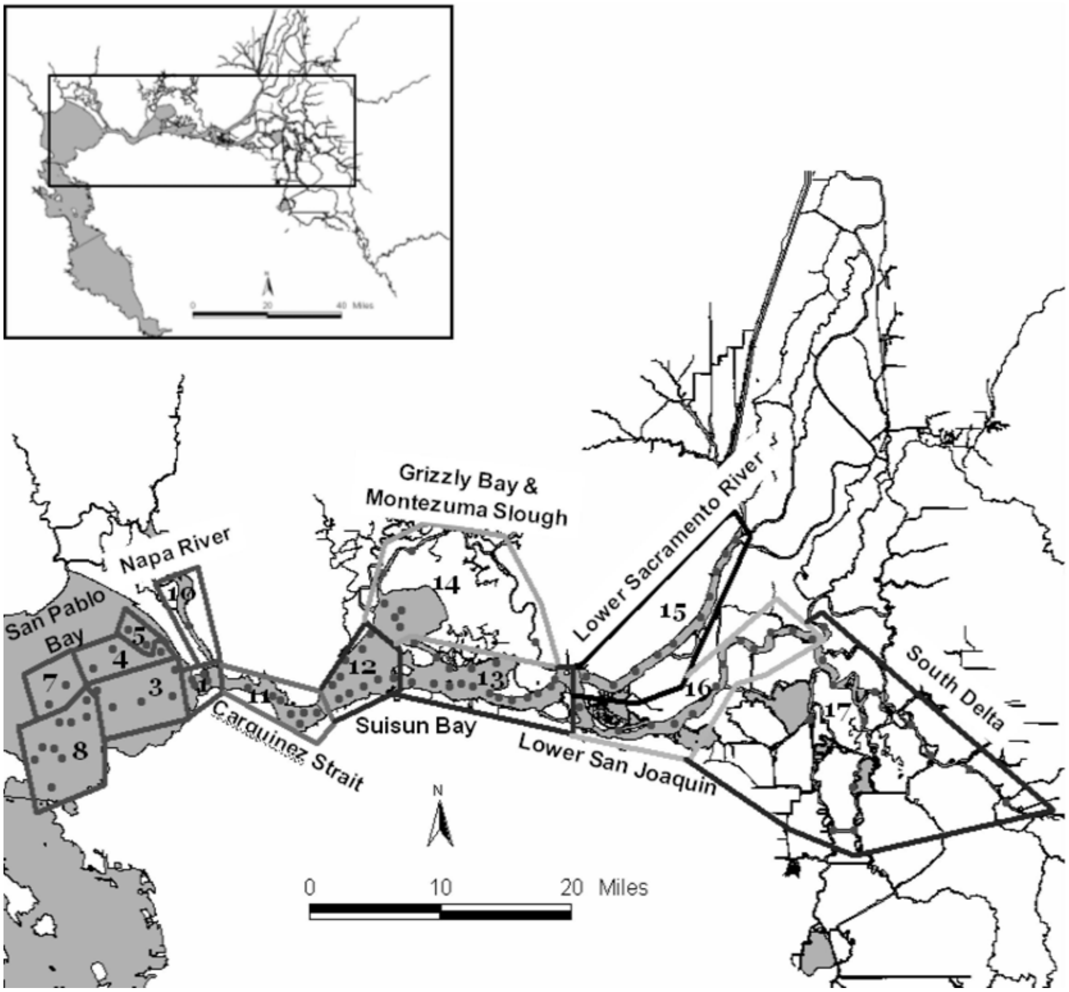

Figure 1. Sampling station locations for fall midwater trawl and areal stratification, separated by straight lines and numbered. Stations in strata 2, 6, and 9 have not been sampled since 1973 and have been removed from the index calculation.

each area, even though the volume sampled by the trawl has varied considerably between tows. Figure 2 shows the extent of variation in tow volumes between stations by month and year. Area weights should change if the volume filtered changes. For example, suppose the true abundance was the same in a given area during September for two years in a row but the volume filtered in each tow during the second year was double the volume filtered in the first year. With constant weights the September index for the second year will be approximately twice that of the first year even though the abundances did not change. In fairness to the indices, however, changes in the abundance of delta smelt have been sizeable enough to dwarf inaccuracies due to variation in volume sampled.

A second criticism of the index is that size-selectivity of the midwater trawl gear is not accounted for. The probability of a delta smelt being caught, given that it is present in the volume swept by the trawl, varies among fish of different size. Thus the number of fish caught at a given station in a given month will depend not only on the abundance of fish present but also the size distribution. The fact that the fork lengths of delta smelt have declined since 1967 (Sweetnam 1999; Bennett 2005) confounds interpretation of the index. As an extreme and artificial case, suppose the fish stayed at the same station during two consecutive months, there was no mortality nor immigration, the fish were all the same length, say 40 mm, in the first month, and then they all grew to the same length, 50 mm, in the second month. Further assume that a constant volume of water was sampled in each tow. Because of gear selectivity, the expected number of fish caught in the second month would be greater than the number for the first month. Thus the month-

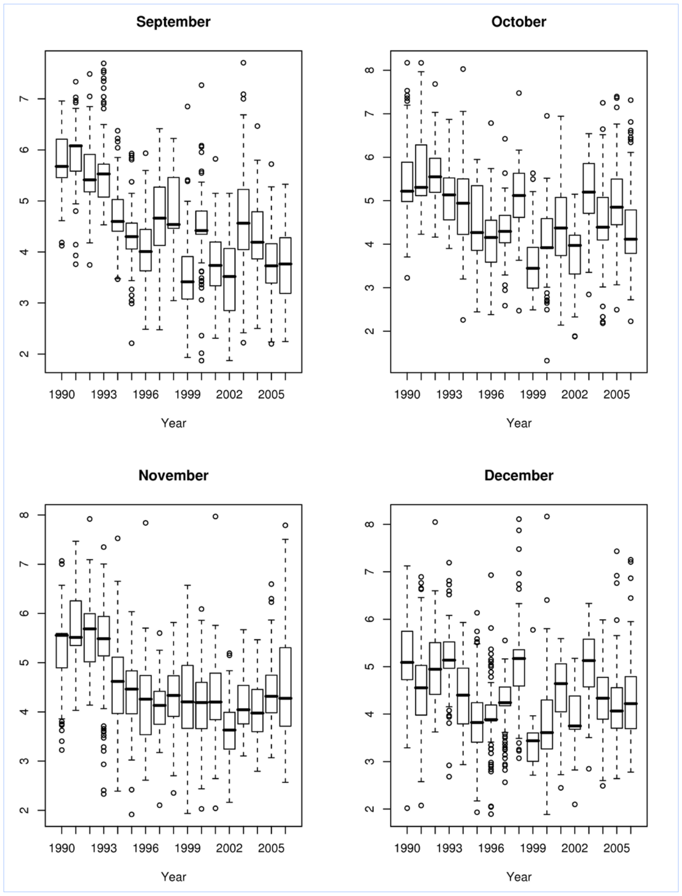

Figure 2. Tow volumes (acre-feet) by month and year

ly index will increase for the second month, but the number of fish has not changed.

The third criticism questions the utility of an annual index [equation (2)]. Interpretation of the annual index is potentially clouded by between year variation in monthly survival. To make the effect of variation in survival more apparent, suppose that the annual index for year *y* was based on catches from a single station, i.e.,

$$I_y = f_{S,y} + f_{O,y} + f_{N,y} + f_{D,y},$$

where the *f*'s are the catches at the station by month (with *S*, *O*, *N*, *D* denoting the months September through December). Further suppose that the probability of catching a fish, given that it is present in the volume swept by the trawl, is constant, denoted *p*, both within and between years (thus eliminating the gear selectivity issue). Let $F_{m,y}$ be the total abundance in the area during month *m* in year *y* and assume the fish are distributed at random throughout the area around the station. The expected catch in month *m* can be written as $E\left[f_{m,y}\right] = p\left(v/V\right)F_{m,y}$, where *v* is the volume swept, and *V* is the volume of water in the area; i.e., *v* and *V* are constant between months. Assume that there is no emigration, immigration, or births during the fall months, but that there is natural mortality. The probability of surviving from month *m* to month *m*+1 is denoted $\phi_{m,y}$. The expected value of the index, in a given year, is then

$$E\left[I_y\right] = N_{S,y} p \frac{v}{V}\left(1 + \phi_{S,y} + \phi_{S,y}\phi_{O,y} + \phi_{S,y}\phi_{O,y}\phi_{N,y}\right)$$

If the survival probabilities remain constant between years, then $E[I_y] = F_{S,y}k$, where *k* is a constant, and the variation between annual indices would, on average, be a reflection of changes in the abundance in September. However, between year differences in survival probabilities do exist and interpretation of differences in annual indices is problematic. For example, suppose that F_S for two consecutive years is 500,000 but for the first year $\phi_S, \phi_O, \phi_N = (0.7, 0.8, 0.9)$ and for the second year $\phi_S, \phi_O, \phi_N = (0.5, 0.6, 0.7)$. The expected abundances by month for the first year are 500,000; 350,000; 280,000; and 252,000; while for the second year they are 500,000; 250,000; 150,000; and 105,000. Letting pv/V=0.001, the expected index value for the first year is 1382, while for the second year it is 1005. If primary concern was over the abundance prior to spawning, i.e., the December abundance, then indices are not reflecting the fact that the abundance for December in the first year is more than twice the abundance the second year.

The procedure described next yields estimates of fish, as opposed to a relative index, it addresses the issues of variation in volume swept and gear selectivity, and produces standard errors for the estimates. The complication of between year variation in survival and the annual index is avoided as only monthly estimates are made. Future work will address variation in monthly survival probabilities.

DESIGN-BASED ESTIMATION PROCEDURE

The estimation procedure is a slight variation of a stratified random sample ratio estimator (Cochran 1977; Thompson 2002), where the auxiliary variable is the volume of water sampled during a tow. The variation is due to the use of a gear selectivity-based expansion of the caught fish, which complicates the variance calculations in particular.

While the FMWT survey dates back to 1967, complete length information for the catches, which is needed for the gear selectivity expansion, was only available from 1990. Estimates of delta smelt abundances were calculated on a per month basis for the months September through December for the years 1990 through 2006.

Appendix A provides technical details on the gear selectivity model used for the expansion of observed catches to the total number in the sample volume. The gear selectivity model was fit using data collected during a covered cod-end experiment (Sweetnam and Stevens 1993), where a cover was attached to the cod-end of a midwater trawl which trapped fish that slipped through the cod-end.

Point Estimation

Informal description. The trawl data are stratified by year, by month, and by area, where the areas are the same 14 non-overlapping regions of the estuary (Figure 1) used in the current delta smelt index calculation. Given 17 years, 4 months, and 14 areas there are 952 (17*4*14) strata. Within each stratum, at each sample station, the number of fish caught in the tow is expanded to yield an estimate of the total number of fish in the tow volume, caught and uncaught. The expansion is made using a model for gear selectivity based on length of fish (Appendix A). Using data from all the stations within a stratum, a stratum-specific ratio of the expanded abundance to volume filtered is calculated. This ratio is then multiplied by the total volume (in acre-feet) of the stratum to yield an estimate of the total abundance within the stratum.

Formal description. Let $f_{y,m,a,s}$ denote the number of delta smelt in the volume of water swept by the trawl net at station s in area a during month m and year y. Likewise let $v_{y,m,a,s}$ denote the volume of water swept by the net (at that place and time). Let $F_{y,m,a}$ and $V_{y,m,a}$ be the total number of fish and total water volume in year y, month m, and area a. Total water volume per area will be assumed constant over time, thus V_a suffices. The number of stations (equivalently tows) in a given year, month, area stratum is denoted $n_{y,m,a}$. The number of fish actually caught in a particular tow (at station s) is $z_{y,m,a,s}$, and $L_{y,m,a,s,i}$, i=1,..., $z_{y,m,a,s}$, is the length of the ith fish caught in that tow.

The estimate of total abundance (in year y and month m) is:

$$\hat{F}_{y,m} = \sum_{a=1}^{14} \hat{F}_{y,m,a} = \sum_{a=1}^{14} V_a \hat{R}_{y,m,a} = \sum_{a=1}^{14} V_a \frac{\sum_{s=1}^{n_{y,m,a}} \hat{f}_{y,m,a,s}}{\sum_{s=1}^{n_{y,m,a}} v_{y,m,s,a}} \quad (3)$$

with

$$\hat{f}_{y,m,a,s} = \sum_{i=1}^{z_{y,m,a,s}} \frac{1}{\widehat{\Pr}\left(L_{y,m,a,s,i}\right)}, \quad (4)$$

where $\widehat{\Pr}\, L_{y,m,a,s}$ is the estimated probability that a fish of length L is caught. The estimate comes from the gear selectivity model (equation (9) in Appendix A). Equation (4) is an example of a Horvitz-Thompson (Horvitz and Thompson 1952) estimator of a population total, in this case the population is all fish in the volume of water the net is towed through.

Variance Calculation

The variance of the estimated total for a given month is a modification of the formula for a stratified random sample ratio estimate of the total that uses separate ratios per stratum (Cochran 1977; Thompson 2002). The modification is due to the additional variation caused by the expansions of fish present in the tow volume, leading to a two-stage variance formula:

$$\widehat{Var}(\hat{F}_a) = \frac{V_a^2}{\bar{v}_{y,m,a}^2}\left[\frac{1}{n_{y,m,a}^2} \sum_{s=1}^{n_{y.m.s}} \sum_{i=1}^{z_{y,m,a,s}} \left(\frac{1 - \hat{\Pr}(L_{y,m,a,s,i})}{\hat{\Pr}(L_{y,m,a,s,i})^2}\right) + \frac{S_{\hat{R}_{y,m,a}}^2}{n_{y,m,a}}\right] \quad (5)$$

where $S_{\hat{R}_{y,m,a}}^2 = \dfrac{\sum_{s=1}^{n_{y,m,a}} \left(\hat{f}_{y,m,a,s} - \hat{R}_{y,m,a} v_{y,m,a,s}\right)^2}{\left(n_{y,m,a} - 1\right)}$.

Mathematical details of the derivation are provided in Appendix B. A demonstration of the calculation of a point estimate and variance for a single stratum is shown in Appendix C.

Implicit to the variance formula is independence between sampling units. If sampling locations are chosen by a simple random sample (and are non-overlapping in space), then independence is assured. If data are combined from two or more months and are based on samples taken at the same location, then some degree of dependence is introduced, perhaps some temporal correlation, and the variance formula would need to be modified.

There is another layer of uncertainty, sampling error in the gear selectivity parameters, which has been ignored in equation (5) and the estimated variances may be underestimates to some degree. The bootstrapping procedure described next accounts for this uncertainty.

Bootstrapping Confidence Intervals

The normal distribution-based approach to calculating confidence intervals, e.g., $\hat{\theta} \pm 2 * se\left(\hat{\theta}\right)$, while simple to carry out, can be quite inaccurate when the sampling distribution of the point estimate is not close to normal. Additionally, as will be the case for some of the monthly delta smelt point estimates, when the coefficient of variation exceeds 50%, such normal distribution-based 95% confidence intervals would include negative values.

An alternative is bootstrapping (Davison and Hinkley 1997). There are several ways to carry out bootstrapping, but the general idea is to view the sample as if it were the population and then to resample from the sample and carry out the same estimation procedures applied to the original sample. Although the emphasis here is on confidence intervals, the bootstrapping procedure can be used to calculate standard errors as well. For the particular problem at hand, sampling error in the gear efficiency estimates, which was ignored in the previous theoretical calculations, can be included.

With the stratified random sampling framework, independent bootstrap sampling is done within each year-month-area stratum. Within each stratum, two levels of sampling occur: the resampling of stations and the resampling of fish in the volume trawled. To exactly mimic the actual sampling process, the sampling of stations should be done without replacement. However, the volume of water sampled within a stratum is so small relative to the entire volume of a stratum, treating the sampling as with replacement is sufficiently accurate. A third level of sampling is added which reflects the uncertainty in the gear efficiency calculations. The number of stations within a stratum are sometimes relatively small, and the bootstrap performance can be relatively poor with such small samples. For example, area 4 has only three stations, and there is a relatively high chance that a resample will consist of three repeats of the same station, and the variance would be zero for that sample.

The steps in the bootstrapping algorithm are the following. For a single iteration of the bootstrap resampling:

1. The covered cod-end experiment data is resampled parametrically by randomly sampling the 812 caught fish (Table 1), where each fish was caught with probability $\widehat{\Pr}(L)$ and the estimated probability value is the maximum likelihood estimate from the logistic model. The logistic gear efficiency model is then re-fit to the resampled fish to yield a fitted gear selectivity model,

$$\Pr(L)^* = \frac{\exp(\hat{\beta}_0^* + \hat{\beta}_1^* L)}{1 + \exp(\hat{\beta}_0^* + \hat{\beta}_1^* L)} \tag{6}$$

2. For area a, the n_a stations in the stratum are sampled with replacement.

3. For station s in area a, a sample of observed fish, $\boldsymbol{Z}^*_{a,s}$, is generated using the following binomial distribution,

$$z^*_{a,s} \sim \text{Binomial}\left(\left[f\right]^*_{a,s}, p^*_{a,s}\right),$$

where $\left[f\right]^*_{a,s}$ is the *rounded* bootstrap-generated number of actual fish at the station, calculated

Table 1. Approximate catches by length (mm) of delta smelt in the August 1991 covered cod-end experiment. $\hat{r}_I(L)$ is the observed fraction of fish of length L caught by the inside net.

Group	Length	Outside	Inside	$\hat{r}_I(L)$
1	21.25	1	0	0.00
2	23.75	1	0	0.00
3	26.25	0	0	NA
4	28.75	2	0	0.00
5	31.25	2	0	0.00
6	33.75	1	1	0.50
7	36.25	7	2	0.22
8	38.75	8	6	0.43
9	41.25	20	6	0.23
10	43.75	33	27	0.45
11	46.25	91	29	0.24
12	48.75	77	50	0.39
13	51.25	153	31	0.17
14	53.75	77	27	0.26
15	56.25	62	9	0.13
16	58.75	19	5	0.21
17	61.25	10	2	0.17
18	63.75	2	2	0.50
19	66.25	2	1	0.33
20	68.75	1	2	0.67
21	71.25	0	2	1.00
22	73.75	0	4	1.00
23	76.25	0	8	1.00
24	78.75	0	9	1.00
25	81.25	0	11	1.00
26	83.75	0	6	1.00
27	86.25	0	1	1.00
28	88.75	0	2	1.00
Total		569	243	

using equations (4) and (6), $p^*_{a,s} = z_{a,s} / \hat{f}^*_{a,s}$.

4. For station s in area a, given $Z^*_{a,s}$, an estimate of the number of actual fish, $\hat{f}^*_{a,s}$, is calculated by $z^*_{a,s} / p^*_{a,s}$

5. Given the $\hat{f}^*_{a,s}$, the stratified sample ratio formula (equation (3)) is used to calculate a bootstrapped total abundance estimate.

The above steps essentially mimic the sampling and estimation procedure carried out with the real data. The generation of observed fish using the binomial distribution is based on the result that the overall probability of capturing fish of varying sizes can be found by integrating the joint probability of capture and fish size over size, i.e., $p = \int \Pr(L) g(L) dL$, where g(L) is the probability distribution for size. The probability distribution for size classes can be estimated by $\hat{f}(L) / \hat{f}(\cdot)$, where $\hat{f}(\cdot)$ is the estimated total number of fish and $\hat{f}(L)$ is the estimated total number of size L fish. For a given trawl with z total fish captured with lengths $L_1,\ldots,L_Z$, the overall capture probability can then be approximated as follows:

$$p = \int \Pr(L) g(L) dL \approx \frac{\sum_{i=1}^{z} \Pr(L_i) \frac{1}{\Pr(L_i)}}{\sum_{i=1}^{z} \frac{1}{\Pr L_i}} = \frac{z}{\hat{f}(\cdot)}.$$

In other words p is estimated by the actual total number of caught fish divided by the estimated number present in the trawled volume.

RESULTS

The observed number of delta smelt caught each month for the years 1990 through 2006 are shown in Table 2. Delta smelt caught by the midwater trawl during the fall months are predominantly age 0 fish, although some age 1 fish are caught. However, exactly which fish are age 0 and are age 1 is not routinely determined and estimates were based on the total number of fish caught by the midwater trawl.

Data on volumes swept were missing for some of the stations where there were no delta smelt recover-

Table 2. Numbers of delta smelt caught by month for 1990-2006, summed over all 14 sampling areas

Year	September	October	November	December
1990	88	42	157	15
1991	104	213	237	30
1992	61	2	48	22
1993	334	414	85	131
1994	56	7	6	17
1995	96	322	346	73
1996	16	21	11	82
1997	9	93	62	123
1998	185	87	14	68
1999	192	374	131	130
2000	415	107	54	125
2001	68	409	17	25
2002	14	42	27	44
2003	13	118	15	36
2004	9	17	19	6
2005	2	8	7	7
2006	30	4	4	1

ies. This occurred 16% of the time, for 155 of the 952 year-month-area samples. A value of 6,351 m^3, which was based upon the size of the net mouth opening, net length, and typical length of time of towing (Dave Contreras, California Department of Fish and Game, personal communication) was substituted for the missing values.

Table 3. Monthly estimates, in thousands of fish, and theoretical standard errors (in subscripts) of ages 0 and age 1 delta smelt abundances for 1990-2006, summed over all 14 sampling areas

Year	September	October	November	December
1990	553_{277}	286_{89}	887_{333}	72_{32}
1991	613_{217}	1114_{355}	1182_{324}	186_{65}
1992	464_{148}	21_{21}	310_{108}	136_{67}
1993	2703_{990}	3029_{1138}	605_{178}	866_{208}
1994	442_{334}	75_{44}	48_{28}	91_{46}
1995	983_{252}	2760_{712}	2761_{761}	554_{178}
1996	124_{50}	134_{46}	66_{37}	618_{282}
1997	64_{32}	924_{422}	577_{208}	691_{167}
1998	1882_{527}	616_{149}	77_{49}	366_{100}
1999	1760_{500}	2876_{930}	762_{163}	1405_{621}
2000	4433_{1333}	830_{221}	394_{132}	1087_{421}
2001	735_{285}	3659_{1114}	102_{46}	144_{69}
2002	125_{51}	336_{142}	230_{91}	277_{100}
2003	96_{42}	964_{488}	137_{78}	242_{97}
2004	77_{44}	98_{46}	146_{59}	37_{22}
2005	13_{11}	53_{31}	56_{30}	45_{23}
2006	309_{123}	26_{17}	35_{25}	4_{5}

The monthly point estimates and standard errors for delta smelt abundances are shown in Table 3. The standard errors are based on equation (5), thus exclude error in the gear efficiency estimates. The bootstrap standard errors, however, were quite close to these theoretical estimates (Pearson correlation coefficient = 0.999, median difference of theoretical − bootstrap = 1.8) suggesting that the variance due to error in the gear efficiency model had relatively little impact on the total standard error. The standard error from area 10 cannot be estimated and has been set equal to zero because there is only one sampling station in that area; in practice, delta smelt are almost never recovered in area 10 and the standard error would be zero anyway. The coefficients of variation (not shown) range from 22% to 130%, with a median value of 41%. The bootstrap confidence intervals (95% level), based on 1000 bootstrap samples, for the monthly estimates are shown in Table 4 and indicate the relatively high degree of uncertainty in the point estimates. That uncertainty is also apparent in Figure 3, which contains side-by-side boxplots of the bootstrap sample point estimates by month and year. Note that the zero valued lower bounds are not technically correct since at least one fish was caught in any given year-month, but with the bootstrap resampling there was a relatively high probability of getting zero recoveries in some cases, e.g., December 2006 when only one fish was caught (Table 2).

Table 4. Bootstrap confidence intervals (95% level) summed over all 14 sampling areas for age 0 and age 1 delta smelt abundances (in thousands of fish) for 1990-2006

Year	September		October		November		December	
1990	141	1109	129	459	361	1549	21	137
1991	260	1048	488	1817	599	1894	79	319
1992	234	767	0	72	125	525	28	265
1993	1016	4841	1198	5647	288	959	510	1319
1994	26	1237	10	176	6	115	16	183
1995	530	1507	1561	4542	1481	4303	247	968
1996	46	228	54	224	11	143	179	1196
1997	12	133	292	1877	218	988	399	1043
1998	1054	2927	348	921	13	182	204	571
1999	920	2800	1307	4684	466	1107	447	2740
2000	2216	7121	425	1279	170	670	461	1972
2001	255	1378	1719	5805	29	203	41	310
2002	42	225	117	656	82	441	103	517
2003	21	182	311	1988	24	309	76	441
2004	10	182	25	196	43	271	0	83
2005	0	36	6	126	9	122	9	93
2006	112	579	0	67	0	90	0	16

The monthly point estimates (in thousands of fish) for the delta smelt abundances, summed over strata, are plotted against year in Figure 4. The FMWT monthly indices, (multiplied by 10 to make comparison easier), are also plotted in Figure 4. The point estimates and the monthly indices are highly correlated (r = 0.97, 0.98, 0.95, and 0.98 for September through December, respectively). The deviations between the point estimates and the indices are largely a reflection of the effect of accounting for gear selectivity and accounting for variations in volume filtered. General results, however, about the status of the delta smelt population levels are the same for both measures: precipitous declines are apparent.

BIAS, PRECISION, AND FUTURE DIRECTIONS

The quality of estimates of abundance can be measured by the amount of bias and variance. Bias is a systematic departure from the underlying true values, i.e., either consistent under- or over-estimation, and is largely due to assumptions of the estimation procedure not being met. Some of the important assumptions of the estimation process are discussed below along with concerns about violations of these assumptions. Variance, on the other hand, is a measure of non-systematic, random deviations from the underlying true values, i.e., the degree of precision, and factors affecting variance are also discussed. Given the inherent variability in fish densities throughout the Estuary over time, however, and the fact that delta smelt are a dynamic population,

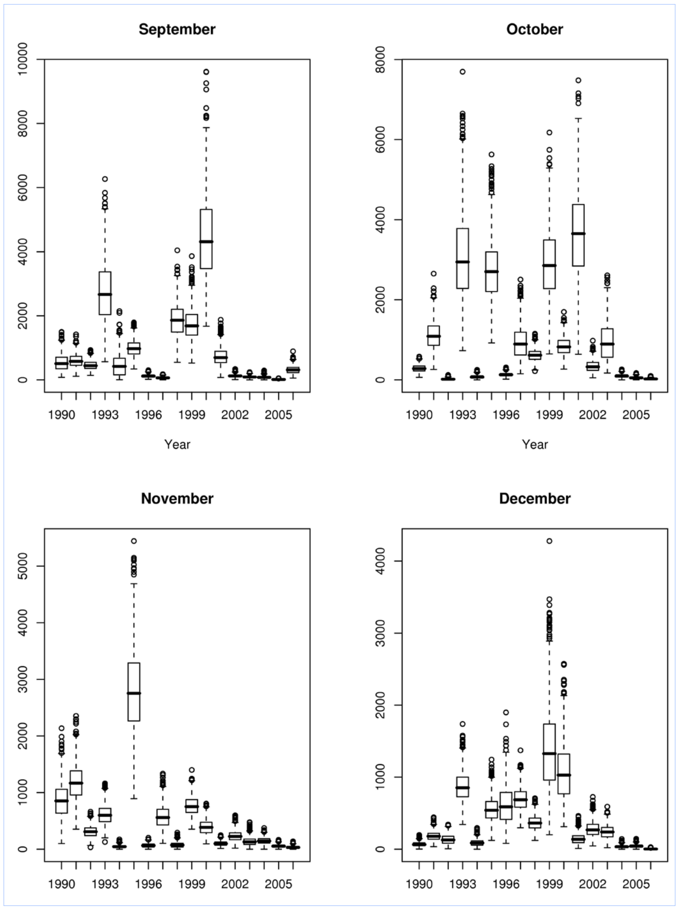

Figure 3. Bootstrap sample estimates of abundance by month and year

the best way to improve the precision of abundance estimates may be to develop alternative estimation procedures that explicitly recognize underlying population dynamics and spatial-temporal factors, and initial thoughts about such an alternative are given.

Bias

Within a stratum, the estimate of total abundance is a function of three components (see equation (3)),

$$\text{Stratum Volume x } \frac{\text{Estimated Sample Abundance}}{\text{Sample Volume}}$$

where "Estimated Sample Abundance" is the sum over the sample stations of expanded estimates of the number of smelt in the volume swept by the midwater trawl and "Sample Volume" is the sum of those swept volumes. Bias in any one of these terms can lead to bias in the stratum abundance estimate.

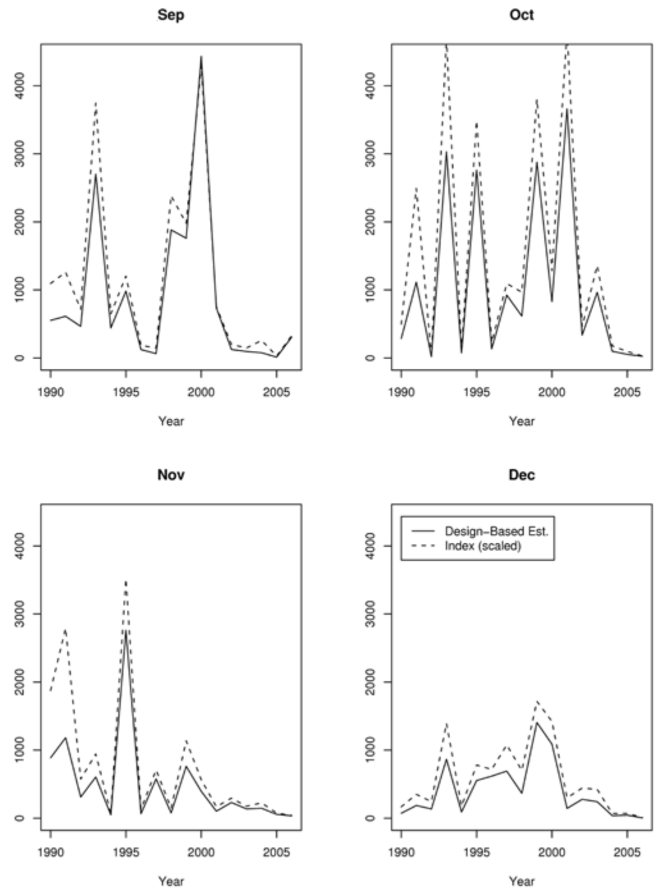

Figure 4. Stratified ratio estimates (solid lines, thousands of fish) of monthly delta smelt abundance (1990–2006) and monthly fall midwater trawl indices (dashed lines, multiplied by 10)

Stratum volume, V_a, is not constant over time, e.g., tidal variation affects water volume, but the assumption is that V_a is on average unbiased. A more critical concern, perhaps, is whether the total volume, $\sum_{a=1}^{14} V_a = 1,706,000$ acre-feet, is an unbiased estimate of the volume of water occupied by delta smelt during the fall months.

Regarding the volume of water sampled by the trawl ("Sample Volume"), measurements of individual tow volumes were calculated from flowmeters pulled alongside the vessel during net retrieval and from estimated average net mouth area during the tow.

However, actual tow volumes could on occasion be less than the estimated values in shallow areas where planing doors, which held the net mouth open, periodically contacted the bottom, and tension from water pressure on net meshes caused the net mouth to partially collapse (Randy Baxter, California Dept. of Fish and Game, personal communication). In those cases, the tow volume measurements would be overestimates and abundance estimates would be biased low. As an aside, the monthly estimates are relatively robust to variation in reported tow volumes. Substitution of the median tow volume, from all tows, for individual tow volumes led to monthly estimates very similar (Pearson correlation coefficient = 0.978) to those shown in Table 3.

Bias in the estimated sample abundance is potentially the most serious bias and there are two possible sources of bias. Bias could arise in the expansion of actual catch to estimated fish present in the volume swept. If fish below some length L_{min}, say, had zero probability of capture, then the abundance estimate would clearly be an underestimate. However, the fact that average fork length during September is 40 to 50 mm (Bennett 2005) and that the midwater trawl caught fish as small as 28 mm supports the assumption that the vast majority of fish present during the fall months did have a positive probability of being caught. The expansion could still be biased if the capture probability estimate was biased. The calculation of $\widehat{\Pr}(L)$, based on the covered cod-end data of Sweetnam and Stevens (1993), assumed that: (a) the cover outside the cod-end was 100% effective; (b) there was no gear avoidance in the volume swept by the trawl; (c) the probability of capture by the cod-end was a logistic function of length; (d) probability of capture was independent of towing distance, towing speed, and fish abundance within the volume swept. Avoidance of gear due to avoidance of the survey vessel itself, trawl doors, or the trawl is always a concern (Gunderson 1993), and would lead to negative biases in abundance estimates. While the fraction of the catch of length L fish retained in the cod-end, relative to fish caught in the cover, tended to increase with increasing length, it was not a very smooth increase (Appendix A), which does call into question the appropriateness of the logistic model.

Even assuming that the expansion of catch in the tow volume to actual numbers present was unbiased, say estimated sample abundance ≈ abundance in the volume towed, bias could arise if the water the trawl sampled was not representative of the water volume in the stratum, i.e., selection bias. This would not be a problem if the fish were uniformly distributed throughout the volume of water in a region, any sampling of the water by the trawl would be representative. However, if there were systematic spatial inhomogeneities in the fish density, such as fish tended to cluster near the surface and away from shoreline, and if the trawl systematically under- or over-sampled higher density volumes, then bias would result.

Concerns over selection bias are triggered by large differences in estimates of abundance presented here and recent estimates by Kimmerer (2008), who used the spring Kodiak trawl (SKT) survey data. The Kodiak trawl survey began in 2002, samples during the months of January through May, and overlaps to a large degree the area sampled by the FMWT, except for the San Pablo Bay areas (areas 1, 3, 5, 7, and 8; Figure 1) which has had relatively few recoveries. As an example of the wide discrepancy in values, the December 2004 abundance estimate based on the FMWT is 37,000 fish (Table 3) while the January 2005 abundance estimate based on the SKT is over 800,000 fish. Kimmerer (2008) also used a ratio estimator, sample abundance to water volume sampled, but did not stratify. Much of the difference can be attributed to considerably greater number of delta smelt caught by the Kodiak trawl: the December 2004 FMWT survey caught six delta smelt (Table 2) at a total of 112 sampling locations and sampled approximately 632,000 m^3 of water, while the January 2005 SKT survey caught 220 delta smelt at a total of 38 sampling locations and sampled approximately 900,000 m^3 of water (Dave Contreras, California Dept. of Fish and Game, personal communication). The Kodiak trawl tends to sample the upper portions of the water column while the midwater trawl takes an oblique tow from the lower to upper portions of the water column. It is unclear, however, whether either trawl is taking a representative sample of the water volume, i.e., selection bias could be present in both surveys. Careful investigation of the abundance of delta smelt by position in the water column combined with estimation of the water volume sampled by depth, by gear type, is clearly necessary.

Increasing Precision

Even if bias in the abundance estimates was minimal, imprecision is large, e.g., coefficients of variation exceed 50% for over 30% of the year-month estimates. For the stratified random sample ratio estimator, the imprecision is largely a sample size issue. Variability in fish numbers between tows, potentially a function of fish aggregation and relative rareness of the fish, is considerable enough that even in highly favorable conditions delta smelt will not be caught in every tow.

Precision can be increased by increasing the number of stations and sample size determination is possible using the variance formula (equation 10 in Appendix B). Given the observed large coefficients of variation for 100 stations, even a doubling of the number of stations may not yield satisfactory levels of precision for management actions. This, however, will likely be prohibitively expensive and practically impossible. An alternative is to use a combination of design- and model-based inference.

Alternative Estimation Procedures

The stratified random sample ratio estimator is largely a design-based estimator. A design-based estimator just uses the fact that probability samples are taken, where the probability of including a particular sampling unit is known, to calculate point estimates and standard errors. For example, the sample average, $\bar{y}$, from a simple random sample of size n from a population of size N is unbiased by design, each sampling unit has probability n/N of being selected and the average value of $\bar{y}$ over the $\binom{N}{n}$ samples is the population average.

In contrast, with model-based inference underlying structure is assumed about the population of interest. In a trivial sense, the use of water volume as the auxiliary variable in the ratio estimator is an example of model-based inference: as the water volume increases, the number of fish in the sample is assumed to increase in a linear manner. Less trivially, other covariates could be included in the estimation procedure so long as covariate measurements are available for both the sampled and unsampled volumes. For example, salinity or turbidity could be used as covariates so long as these measurements were available for the unsampled portions of an area. The sample data would be used to fit a regression model such as

$$f_{y,m,s} = \beta_0 + \beta_1 v_{y,m,s} + \beta_2 salinity_{y,m,s} + \varepsilon_{y,m,s}$$

where v is volume sampled. Then for unsampled volumes, the number of fish would be estimated by plugging in the corresponding covariate values.

A limitation of the estimation approach presented in this paper is that the abundance estimates were calculated independently on a per year, per month, and per area basis, with no connection in time or space between estimates. This meant that estimates of total abundance for one month could exceed the estimated total for the previous month even though no births have occurred and even if the system were closed in the sense that immigration into the fourteen areas was unlikely. For example, the estimated abundance in December 1999 is nearly double that for November 1999. This deviation is partly a function of sampling variation but it is also a reflection of the lack of spatial-temporal connectivity in the estimation procedure.

An alternative that could be much more statistically efficient is to develop a spatial-temporal model for abundances such that estimates for a given month and area are a function of data from the given month and area as well as data from adjacent months and areas. Additional data from other surveys besides the FMWT, such as the 20 mm surveys (samples larvae) and the summer townet surveys (samples juveniles), could inform the estimates, too. Such an estimation procedure would be underpinned by a life history model (Newman and Lindley 2006), and a small step in that direction is described in a companion paper. Such a model-based approach, which recognizes both the underlying continuity in the spatial and temporal distribution of delta smelt as well as the population dynamics of the species, could potentially serve as a tool for understanding reasons for the decline in delta smelt abundances. Life history parameters, such as survival probabilities or fecundity rates, for example, could be modeled as functions of biological and environmental covariates thought to influence population abundance.

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APPENDIX A: GEAR SELECTIVITY ESTIMATION

To estimate the number of fish present in the volume swept by the midwater trawl, the selectivity of the gear is needed. Exactly what is meant by gear selectivity needs defining.

To begin, suppose at time t and location x a given fish of size or shape would be present in the absence of fishing gear passing through or by this location. The probability that such a fish would be caught by the gear is defined to be the long run relative frequency of times the gear would capture such a fish if the fishing process could be carried out repeatedly under (nearly) identical conditions. For delta smelt it will be assumed that length, L, is the only factor affecting this probability and it will be denoted $p(L)$. Note that $1-p(L)$ is the probability of either *evading* the gear or *escaping* the gear. A fish evades if it is stimulated by the gear to leave or avoid location x prior to time t. A fish escapes gear if it remains present at location x at time t as the gear passes through, or occupies, that location but the fish is able to escape from the gear; e.g., it slips through the mesh of a net. A gear is said to be *selective* if the $p(L)<1$ for at least some L, and *nonselective* if $p(L)=1$ for all L. Absolute gear selectivity will be defined to be the same as $p(L)$, a probability of capture that varies with fish size. In contrast, relative gear selectivity is defined, with reference to two or more gear types, as the ratio of capture probabilities for fish of size L; i.e., $p_i(L)/p_j(L)$ is the ratio of capture probabilities for gear type i to gear type j.

Millar (1992) developed a general procedure for estimating the gear selectivity of various fishing gear, including trawl gear, given data from gear efficiency studies. One type of the trawl gear efficiency study he considers is a covered cod-end study where a relatively fine mesh net is attached outside the cod-end, which presumably catches all fish that pass through the cod-end. The procedure is next explained and then applied to data from a covered cod-end experiment discussed by Sweetnam and Stevens (1993).

Millar's General Approach

Millar formulated a probability distribution for the catch of length L fish by one gear type *given* the total catch of length L fish by two or more gear types fishing the same region. The essence of his idea as it pertains to trawl studies can be stated as follows, where for simplicity only two gear types are considered. First define p_1 to be the probability that a fish comes into contact (is exposed to, say) with gear type 1 given that it contacted by either gear type; then $p_2 = 1-p_1$ is the probability for gear type 2. Assume that the number of length L fish coming in contact with any gear, n_L, is a Poisson random variable with rate λ_L, $n_L \sim \text{Poisson}(\lambda_L)$. The number of fish of length L coming into contact with gear type 1 is then $\text{Poisson}(p_1\lambda_L)$, and for gear type 2 it is Poisson $((1-p_1)\lambda_L)$. Let $r_i(L)$ be the probability that a fish of length L is caught by gear type i conditional on it contacting that gear type. Then the number of fish of length L caught by gear type i, say $y_i(L)$, is $\text{Poisson}(r_i(L)\,p_i\lambda_L)$. It can then be shown that the probability distribution for $y_1(L)$ conditional on the total number caught, $y.(L) = y_1(L) + y_2(L)$, is binomial:

$$y_1(L)\,|\,y.(L) \sim Binomial\left(y.(L), \frac{r_1(L)p_1}{r_1(L)p_1 + r_2(L)(1-p_1)}\right).$$

The key advantage, thus, of conditioning on the total catch is that the parameters specifying the density, and implicitly the size distribution, of fish of length L, namely the λ_L's, have been eliminated from the distribution of catches.

The practical question for applications then reduces to the particular formulation of $r_1(L)$ and $r_2(L)$ and whether or not all the parameters are estimable given the observed catches, $y_1(L)$ and $y_2(L)$, say.

An illustrative example given by Millar is the case of alternate hauls with two different size mesh trawl nets, where the net with the finer mesh size is assumed to be non-selective. Denote the selective net gear 1 and the non-selective net gear 2; $r_2(L)$ then equals 1 for any L. A logistic model is assumed for

$r_1(L)$, i.e.,

$$r_1(L) = \frac{\exp(\beta_0 + \beta_1 L)}{1 + \exp(\beta_0 + \beta_1 L)}, \tag{7}$$

and

$$y_1(L) \,\middle|\, y.(L) \sim Binomial\left(y.(L), \frac{r_1(L)p_1}{r_1(L)p_1 + r_2(L)(1-p_1)} = \frac{p_1\exp(\beta_0 + \beta_1 L)}{\exp(\beta_0 + \beta_1 L) + (1-p_1)}\right)$$

Millar then applies this model to an alternate haul study of haddock, yielding estimates of p_1, β_0, and β_1.

Millar (1992, page 967) makes brief mention of covered cod-end studies where he implicitly assumes that the outer mesh is non-selective. While he does not describe his reasoning, he states that the probability distribution for the number of fish caught by the inner cod-end net, $y_I(L)$, conditional on the total number of fish caught, is binomial with probability $r_I(L)$. His reasoning is not necessarily based on his general model due to the uniqueness of the covered cod-end trawl, because contact by the inner net in a sense implies contact by the outer cover net. A conclusion similar to his, however, can be arrived at by the following argument. Let $n(L)$ be the number of fish of length L present in the region to be fished, and let $y_O(L)$ be the number of fish caught in the outer cover. Then the joint distribution of $y_I(L)$ and $y_O(L)$ is trinomial

$$\left(y_I(L), y_O(L)\right) \sim \text{Trinomial}\left(n(L), pr_I(L), p\left(1 - r_I(L)\right)r_O(L)\right),$$

where p is the probability of coming into contact with the combined gear. Assuming the outer mesh is non-selective, $r_O(L) = 1$. The conditional probability for $y_I(L)$ given $y.(L)$is then

$$y_I(L) \mid y.(L) \sim Binomial\left(y.(L), \frac{pr_I(L)}{pr_I(L) + p(1 - r_I(L))r_O(L)} = r_I(L)\right) \tag{8}$$

where a reasonable formulation for $r_I(L)$ is the logistic model in equation (7).

Application to a Delta Smelt Gear Efficiency Study

During August 28-29, 1991, a covered cod-end study was carried out by the California Department of Fish and Game (Sweetnam and Stevens 1993) using a standard midwater trawl net, where the cod-end had a 1/2 inch mesh size and the cover was 1/8 inch mesh size. A total of 243 delta smelt were caught in the inner (cod-end) net and 569 delta smelt were caught in the outer cover. The original data giving the exact lengths of fish are no longer available but the approximate catches by lengths can be calculated using the frequency histogram shown in the 1993 report (page 32).

Table 1 contains the constructed data. The column labeled $\hat{r}_I(L)$ is the number caught by the inner net divided by the total number caught, i.e., an empirical estimate of $r_I(L)$. The data are at odds with the model in equation (8) in that one would expect $\hat{r}_I(L)$ to increase monotonically as length increases, but it varies in a non-systematic way between lengths 36.25 and 66.25 mm. Once a fish reaches 71.25 mm in length, however, it was estimated to be caught with certainty.

With the above concern in mind, the cod-end model in equation (8), with the logistic formulation, was fit and yielded the following capture probability:

$$r_I(L) \equiv \widehat{\Pr}(L) = \frac{\exp\left(\hat{\beta}_0 + \hat{\beta}_1 L\right)}{1 + \exp\left(\hat{\beta}_0 + \hat{\beta}_1 L\right)} = \frac{\exp(-3.89 + 0.0585 * L)}{1 + \exp(-3.89 + 0.0585 * L)}. \tag{9}$$

For example, if a fish is of length 55 mm, its probability of capture is 34%. Figure 5 plots the fitted values for $r_I(L)$ against length (the line) and includes the observed fractions of the catch in the inner mesh, relative to total catch, for each length class (the points). The fitted line is smoothing the observed relative fractions.

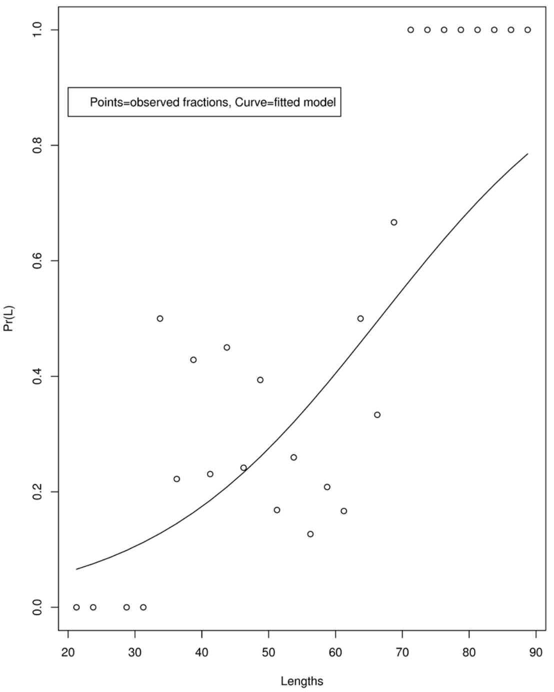

Figure 5. Fitted values for Pr(L) for the Millar model for the August 1991 covered cod-end experiment. The conditional and unconditional Pr (L) (r_l) values are identical for the Millar model. Plotted points are the observed fractions of catch (by length class) from the inside net.

APPENDIX B: MATHEMATICAL DETAILS OF VARIANCE ESTIMATION

Assuming independence between strata, the variance of the total is the sum of variances for the individual strata:

$$Var\left(\widehat{F}_{y,m}\right)=\sum_{a=1}^{14}Var\left(\widehat{F}_{y,m,a}\right). \tag{10}$$

The variance of the estimated total within a stratum is (see Cochran 1977, eq'n 6.13; or Thompson 2002, pp 68-69):

$$Var(\widehat{F}_{y,m,a})=(V_a)^2 Var(\widehat{R}_{y,m,a})=(V_a)^2 Var\Big(\frac{\Sigma_{s=1}^{n_{y,m,a}}\widehat{f}_{y,m,a,s}}{\Sigma_{s=1}^{n_{y,m,a}}v_{y,m,s,a}}\Big) \tag{11}$$

Given the tiny volume of water sampled relative to the total water volume within an area, the finite population correction factor can safely be assumed negligible.

Accounting for the uncertainty in the estimate, $\widehat{f}_{y,m,a,s}$, involves using the two-stage variance formula, which for two random variables, X and Y, is $Var(Y) = E_X[Var\,(Y|X)]+Var_X[E(Y|X)]$. In this particular setting, Y is $\frac{\sum_{s=1}^{n_{y,m,a}}\widehat{f}_{y,m,a,s}}{\sum_{s=1}^{n_{y,m,a}}v_{y,m,a,s}}$, and the $f_{y,m,a,s}$ and $v_{y,m,a,s}$ terms make up X. To reduce notation X will be retained in the following:

$$Var(\widehat{f}_{y,m,a,s})=E_X\Big[Var(\frac{\Sigma_{s=1}^{n_{y,m,a}}\widehat{f}_{y,m,a,s}}{\Sigma_{s=1}^{n_{y,m,a}}v_{y,m,s,a}}\,|\,X)\Big]+Var_X\Big[E(\frac{\Sigma_{s=1}^{n_{y,m,a}}\widehat{f}_{y,m,a,s}}{\Sigma_{s=1}^{n_{y,m,a}}v_{y,m,s,a}}\,|\,X)\Big] \tag{12}$$

First Component

Regarding the first component of equation (12):

$$E_X\Big[Var(\frac{\Sigma_{s=1}^{n_{y,m,a}}\widehat{f}_{y,m,a,s}}{\Sigma_{s=1}^{n_{y,m,a}}v_{y,m,s,a}}\,|\,X)\Big] = E_X\Big[\frac{\Sigma_{s=1}^{n_{y,m,a}}Var(\widehat{f}_{y,m,a,s}\,|\,X\,)}{(\Sigma_{s=1}^{n_{y,m,a}}v_{y,m,s,a})^2}\Big]$$

$$=E_X\Big[\frac{1}{(\Sigma_{s=1}^{n_{y,m,a}}v_{y,m,a,s})^2}\sum_{s=1}^{n_{y,m,a}}Var\,(\sum_{i=1}^{z_{y,m,a,s}}\frac{1}{\widehat{\Pr}(L_{y,m,a,s,i})})\Big]$$

$$\approx\frac{1}{(\Sigma_{s=1}^{n_{y,m,a}}v_{y,m,s,a})^2}\sum_{s=1}^{n_{y,m,s}}\sum_{i=1}^{z_{y,m,a,s}}\frac{1-\widehat{\Pr}(L_{y,m,a,s,i})}{\widehat{\Pr}(L_{y,m,a,s,i})^2}. \tag{13}$$

The last step in the above derivation is based on an estimate of the variance of a Horvitz-Thompson (Horvitz and Thompson 1952) estimate of a population total. Given a population with N individuals, where the probability that individual i is selected is $\pi_i,\ i=1,\ldots,N,$ and n individuals are selected, the Horvitz-Thompson estimate of N is $\widehat{N}=\sum_{i=1}^{n}\frac{1}{\pi_i}$. Defining an indicator variable I(j) to equal 1 when fish j is caught and 0 when it is not, the variance of $\widehat{N}$ is as follows:

$$Var(\widehat{N})=\sum_{j=1}^{N}Var\Big(I(j)\frac{1}{\pi_j}\Big)=\sum_{j=1}^{N}\frac{1}{\pi_j^2}Var(I(j))$$

$$\sum_{j=1}^{N} \frac{\pi_j (1-\pi_j)}{\pi_j^2} = \sum_{j=1}^{N} \frac{1-\pi_j}{\pi_j},$$

assuming that the capture of one animal is independent of the capture of any other animal. In practice, however, N is unknown as are the π_j 's for the unobserved animals. An unbiased estimate of the variance in practice (see equation (6) on page 54 of Thompson 2002) is

$$\widehat{Var}\left(\widehat{N}\right) = \sum_{j=1}^{n} \frac{1-\pi_j}{\pi_j^2}.$$

The capture probability, Pr(L), is estimated, but that uncertainty has been ignored here, thus the variance will be somewhat underestimated. To properly account for this uncertainty requires a “triple” variance formula.

Second Component

Looking at the second component of equation (12):

$$Var_X\left[E\left(\frac{\sum_{s=1}^{n_{y,m,a}} \widehat{f}_{y,m,a,s}}{\sum_{s=1}^{n_{y,m,a}} v_{y,m,s,a}} \mid X\right)\right] = Var_X\left[\frac{\sum_{s=1}^{n_{y,m,a}} \widehat{f}_{y,m,a,s}}{\sum_{s=1}^{n_{y,m,a}} v_{y,m,s,a}}\right]$$

$$\approx \frac{1}{\overline{v}_{y,m,a}^2} \frac{\sum_{s=1}^{n_{y,m,a}} (\widehat{f}_{y,m,a,s} - \widehat{R}_{y,m,a} v_{y,m,a,s})^2}{(n_{y,m,a}-1) n_{y,m,a}} \qquad (14)$$

where $\overline{v}_{y,m,a}$ is the average volume of samples taken within the area.

Total Variance

Given equations (13) and (14), the variance estimator within a stratum is:

$$\widehat{Var}(\widehat{F}_a) = \frac{V_a^2}{\overline{v}_{y,m,a}^2}\left[\frac{1}{n_{y,m,a}^2} \sum_{s=1}^{n_{y.m.s}} \sum_{i=1}^{z_{y,m,a,s}} \left(\frac{1-\widehat{\Pr}(L_{y,m,a,s,i})}{\widehat{\Pr}(L_{y,m,a,s,i})^2}\right) + \frac{S_{\hat{R}_{y,m,a}}^2}{n_{y,m,a}}\right] \qquad (15)$$

$$\text{where } S_{\hat{R}_{y,m,a}}^2 = \frac{\sum_{s=1}^{n_{y,m,a}} \left(\widehat{f}_{y,m,a,s} - \widehat{R}_{y,m,a} v_{y,m,a,s}\right)^2}{\left(n_{y,m,a}-1\right)}.$$

APPENDIX C: DEMONSTRATION OF ESTIMATION PROCEDURE

The estimation procedure is demonstrated numerically for area 1, which includes 4 stations, 336, 337, 338, and 339, during September 1995. There were two fish caught, both with length 49 mm, one at station 336 and one at station 338. The data relevant to the calculation are shown below.

Station	Fish Length (mm)	Estimated # of fish	Volume Swept (m^3)	Volume Swept (acre-feet)
336	49	3.783	5866	4.7556
337	N/A	0	6351	5.1488
338	49	3.783	4761	3.8597
339	N/A	0	2728	2.2117
Total		7.566	19706	15.9759

There are three steps to calculate an estimate:

1. *Expand the number of observed length L fish to total number of length L fish.* The expanded number of fish represented by a 49 mm fish is 3.783. This is estimated by inverting the probability of catching a 49 mm fish, $1/\widehat{\Pr}$ (length 49 mm fish is caught), where Pr(L) is based on the fitted gear selectivity model (see equation (9) in Appendix A). The probability that a length 49 mm fish is caught is exp(–3.89+0.0585*49)/[1+exp(–3.89+0.0585*49)] = 0.2643462. Thus, the estimated number of 49 mm fish in the volume trawled is 1/0.2643462= 3.783.
2. *Calculate the ratio of total fish to total volume sampled.* The estimated total number fish in the four tows is

   $$\widehat{f}_{1995,\,Sept,\,1,\,\cdot} = 3.783 + 0 + 3.783 + 0 = 7.566.$$

   The estimated ratio of fish to volume swept (in acre-feet):

$$\widehat{R}_{1995,\,Sept,\,1} = \frac{\widehat{f}_{1995,\,Sept,\,1,\,\cdot}}{v_{1995,\,Sept,\,1,\,\cdot}} = \frac{7.566}{15.9759} = 0.4735782,$$

where $v_{1995,\,Sept,\,1,\,\cdot}$ is the total sample volume swept.

3. *Estimate total fish in stratum, F_h, by multiplying the ratio by total volume.* The total volume for area 1 is 81,000 acre feet. The estimated number of fish in 1995 in September in area 1 is

$$\widehat{F}_{1995,\,Sept,\,1} = 81000 * 0.4735782 = 38,360.$$

The expansion from the observed number to the estimated number is considerable, and this is due to the sampled volume being about 0.02% of the total volume. If the fish density was relatively constant throughout each area, this would not necessarily be worrying; however, as will be evidenced by the standard errors, density is quite variable.

The variance for the estimated total is calculated using equation (5). Some of the values needed in the formula include the average volume swept at the four stations (3.994 acre-feet), the probability of catching a 49 mm fish (0.264), and the estimated ratio, $\widehat{R}$ (0.4736). The estimate of the variance for the total is

$$\widehat{Var}(\widehat{F}_{1995,Sept,1}) = \frac{81,000^2}{3.993974^2}\left[\frac{1}{4^2}\left(\frac{1-0.264^2}{0.264^2} + 0 + \frac{1-0.264^2}{0.264^2} + 0\right)\right]$$

$$+\frac{81,000^2}{3.993974^2}\left[\frac{(3.783-\hat{R}*4.7556)^2 + (0-\hat{R}*5.1488)^2 + (3.783-\hat{R}*3.8597)^2 + (0-\hat{R}*2.2117)^2}{4(4-1)}\right]$$

$$= 541,248,696 + 452,710,045 = 993,958,741$$

The first component in the previous sum reflects the uncertainty in the gear effectiveness expansions while the second component reflects the between sample variation of the ratio estimates. The coefficient of $\sqrt{\text{variance}}\,/\,\text{point estimate}$, is 82%.

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Explaining Patterns of Pelagic Fish Abundance in the Sacramento-San Joaquin Delta

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Abstract Investigating the effects of environmental, biological, and anthropogenic covariates on fish populations can aid interpretation of abundance and distribution patterns, contribute to understanding ecosystem functioning, and assist with management. Studies have documented declines in survey catch per unit effort (CPUE) of several fishes in the Sacramento-San Joaquin Delta, a highly altered estuary on the US west coast. This paper extends previous research by applying statistical models to 45 years (1967–2012) of trawl survey data to quantify the effects of covariates measured at different temporal scales on the CPUE of four species (delta smelt, *Hypomesus transpacificus*; longfin smelt, *Spirinchus thaleichthys*; age-0 striped bass, *Morone saxatilis*; and threadfin shad, *Dorosoma petenense*). Model comparisons showed that along with year, the covariates month, region, and Secchi depth measured synoptically with sampling were all statistically important, particularly in explaining patterns in zero observations. Secchi depth and predicted CPUE were inversely related for all species indicating that water clarity mediates CPUE. Model comparisons when the year covariate was replaced with annualized biotic and abiotic covariates indicated total suspended solids (TSS) best explained CPUE trends for all species, which extends the importance of water clarity on CPUE to an annual timescale. Comparatively, there was no empirical support for any other annualized covariates, which included metrics of prey abundance, other water quality parameters, and water flow. Top-down and bottom-up forcing remain important issues for understanding delta ecosystem functioning; however, the results of this study raise new questions about the effects of changing survey catchability in explaining patterns in pelagic fish CPUE.

Keywords Delta and longfin smelt · Sacramento-San Joaquin Delta · Zero-inflated generalized linear models · Water flow · Zooplankton · Water quality

Introduction

The dynamics of fish populations involve a complex suite of biological processes operating at different temporal and spatial scales. Abiotic and biotic variables modulate the intrinsic biological properties of individual fish species and structure the diversity and abundances of species within ecosystems. Such variables can be ecological, environmental, climatic, and anthropogenic, and they synthetically influence ecosystem dynamics. Ecological variables are often described in the context of bottom-up (Chavez et al. 2003; Frederiksen et al. 2006) or top-down (Cury and Shannon 2004; Hunt and McKinnell 2006) control of food webs, while environmental variables such as temperature, dissolved oxygen, and others have been shown to influence early life history (Norcross and Austin 1988) and the distribution of fishes within ecosystems (Breitburg 2002; Craig 2012; Buchheister et al. 2013). Climate variability can have a multipronged impact, exerting influence on specific life stages, such as the formation of new year classes (Houde 2009), or at the level of individual species (Hare et al. 2010) or whole ecosystems (Winder and Schindler 2004; Drinkwater et al. 2009). Numerous anthropogenic stressors such as pollution, nutrient enrichment and eutrophication, introduction of nonnative species, and perhaps most notably, overexploitation have been documented to influence

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ecosystem structure and fish abundance (Islam and Tanaka 2004; Molnar et al. 2008; Diaz and Rosenberg 2008;Worm et al. 2009).

Globally, centuries of anthropogenic change have transformed estuarine and coastal waters into systems with reduced biodiversity and ecological resilience (Jackson et al. 2001; Lotze et al. 2006). Given the importance of these areas to marine life, efforts to remediate the cascading effects of anthropogenic stressors will undoubtedly require deep consideration of principles inherent to ecosystem-based management (EBM; Link 2010). However, before strategic and tactical management policies can be effectively implemented, EBM rooted or otherwise, the relative roles of natural and anthropogenic factors that affect ecosystem structure and associated species abundances must be well understood.

San Francisco Bay is a tectonically created estuary located on the US Pacific coast that has experienced considerable anthropogenic change (Nichols et al. 1986). The bay and its watershed occupies 1.63×10^7 ha and drains 40 % of California's land area (Jassby and Cloern 2000). Freshwater is supplied to the estuary primarily from the Sacramento and San Joaquin rivers, which converge to form a complex mosaic of tidal freshwater areas known collectively as the Sacramento-San Joaquin Delta (referred herein as the delta). Most naturally occurring wetlands in the estuary have been lost due to morphological changes to the system for agriculture, flood control, navigation, and water reclamation activities (Atwater et al. 1979). Other notable changes include modifications to the volume of freshwater entering the delta and thus the natural delivery of land-based sediment (Arthur et al. 1996), massive sediment loading resulting from large-scale hydraulic mining activities (Schoellhamer 2011), introduction and invasion of nonindigenous species (Cohen and Carlton 1998), input of contaminants (Connor et al. 2007), and reported decreases in chlorophyll-*a* (Alpine and Cloern 1992), zooplankton (Orsi and Mecum 1996), and fish catch per unit effort (CPUE; Sommer et al. 2007).

A variety of tools can be used to understand how specific changes to ecosystem components influence fish population dynamics. These include directed field studies, statistical analyses, and multidimensional mechanistic modeling activities, with all often being required to develop a robust understanding of ecosystem dynamics. In the delta, there has been a considerable focus on empirical analyses designed to examine how temporal trends in CPUE statistically relate to various abiotic and biotic variables. Researchers have described freshwater flow within the delta as a key structuring variable of fish CPUE (Turner and Chadwick 1972; Stevens and Miller 1983; Sommer et al. 2007) along with the salinity variable X_2, which is defined as the horizontal distance up the axis of the estuary where the tidally averaged near-bottom salinity is 2 psu (Jassby et al. 1995; Kimmerer 2002; Kimmerer et al. 2009; MacNally et al. 2010). However, the evidence supporting these inferences was based on relationships between annual CPUE indices and metrics of water flow and/or X_2, which can be limiting since collapsing many raw field observations of CPUE into annual indices leads to a sizable loss of potentially valuable information. Feyrer et al. (2007, 2011) applied statistical models to raw survey data collected from the delta to quantify fish occurrences in relation to water quality variables; however, they did not examine CPUE or consider variables at broader temporal scales.

This study builds on previous empirical analyses by examining how measures of CPUE in the delta statistically relate to a broad suite of abiotic and biotic variables across multiple temporal scales and exclusively from the perspective of raw field observations. The analyses presented here follow a two-step procedure that reflects the specific objectives of this study, (1) investigate the role of covariates measured synoptically at the time of fish sampling to elucidate their effects on CPUE and (2) modify the analytical framework used for the first objective to examine the relative role of various abiotic and biotic covariates hypothesized to influence CPUE at an annual timescale. For the second objective, the covariates considered were annualized metrics of zooplankton density, chl-*a* concentration, water quality, and water flow. These analyses contribute to the understanding of ecosystem dynamics within the delta and thus aid the formulation of EBM strategies by providing foundational information of fish population responses to natural and anthropogenically modified system attributes.

Methods

Focal Fish Species

Reported declines of fish CPUE in the delta have revolved primarily around four species: delta smelt, *Hypomesus transpacificus*, longfin smelt, *Spirinchus thaleichthys*, age-0 striped bass, *Morone saxatilis*, and threadfin shad, *Dorosoma petenense*. Accordingly, these species are the focus this study. The delta smelt is a relatively small (60–70 mm standard length (SL)), endemic, annual, spring spawning, planktivorous fish that is distributed primarily in the delta and surrounding areas (Moyle et al. 1992). Delta smelt were listed as threatened under the US Endangered Species Act (ESA) in 1993 and endangered under the California Endangered Species Act (CESA) in 2010. The endemic longfin smelt is also a relatively small (90–100 mm SL), anadromous, semelparous, spring spawning fish with an approximate 2-year life cycle that is broadly distributed throughout the estuary (Rosenfield and Baxter 2007). Longfin smelt were listed as threatened under the CESA in 2010. Striped bass is a larger (>1 m SL), relatively long-lived, anadromous, late-spring spawning species deliberately introduced to the San

Francisco Estuary from the US east coast in 1879 (Stevens et al. 1985). Although subadult and adult fish reside primarily in estuarine and coastal waters, age-0 fish can be found in lower salinity areas where they feed on zooplankton and macroinvertebrates. Threadfin shad was discovered in the delta during the early 1960s (Feyrer et al. 2009) and is a relative small (<100 mm SL), summer spawning planktivorous fish that primarily inhabits freshwater areas of the estuary.

Field Sampling

The California Department of Fish and Wildlife (CDFW) has been conducting the Fall Midwater Trawl (FMWT) survey in the delta nearly continuously since 1967 (Stevens and Miller 1983; see http://www.dfg.ca.gov/delta/projects.asp?ProjectID=FMWT for additional details). The survey was initiated to measure the relative abundance of age-0 striped bass; however, survey data have been used to infer patterns in relative abundance of a variety of species inhabiting the delta (Kimmerer 2002; Sommer et al. 2007). Monthly cruises are conducted from September through December, and the number of tows each month has increased from approximately 75–80 during the early years of the program to >100 in more recent years. The survey follows a stratified fixed station design such that sampling occurs at approximately the same location within predefined regional strata (17 areas excluding areas 2, 6, and 9 per the CDFW's protocol). Sampling intensity is related to water volume in each regional stratum such that samples are taken every 10,000 acre ft for areas 1–11 and every 20,000 acre ft for areas 12–17; Fig. 1). At each sampling location, a 12-min oblique tow is made from near bottom to the surface using a 3.7 m×3.7 m square midwater trawl with variable mesh in the body and a 1.3-cm stretch mesh cod end. Vessel speed over ground during tows can be variable since sampling procedures are designed to maintain a constant cable angle throughout the tow. Each catch is sorted and enumerated by species and station-specific measurements of surface water temperature, electrical conductivity (specific conductance), and Secchi depth are recorded. CPUE is defined as number of fish collected per trawl tow.

Sampling Covariates

Generalized linear models (GLMs; McCullagh and Nelder 1989) were used to evaluate the effects of sampling covariates on CPUE of the four focal fish species. GLMs are defined by the underlying statistical distribution for the response variable and how a set of linearly related explanatory variables correspond to the expected value of the response variable. The relationship between explanatory variables and the expected value of the response variable is defined by a link function, which must be differentiable and monotonic.

Since CPUE was defined as fish count per trawl, the Poisson and negative binomial distributions were considered. Plots of the proportion of FMWT tows where at least one target animal was captured across the time series for each species showed low values for many years, which gave rise to the possibility that these data were zero-inflated (Fig. 2). In general, zero-inflated count data imply that the response variable contains a higher proportion of zero observations than expected based on a Poisson or negative binomial count process. Ignoring zero inflation can lead to overdispersion and biased parameter and standard error estimates (Zuur et al. 2009).

Zero-inflated distributions are a mixture of two distributions, one that can only generate zero counts and another that includes zeros and positive counts. In effect, the data are divided into two groups, where the first group contains only zeros (termed false zeros) and the second group contains the count data which may include zeros (true zeros) along with positive values (Zuur et al. 2009, 2012). To identify the appropriate model structure (zero-inflated versus standard GLM) and distribution of the count data (negative binomial versus Poisson), a variety of preliminary models were fitted to the FMWT data. Diagnostic plots, evaluation of overdispersion, and model comparisons using likelihood ratio tests and Akaike's information criterion (AIC; Akaike 1973; Burnham and Anderson 2002) all strongly supported application of a zero-inflated negative binomial distribution, which can be expressed as (Brodziak and Walsh 2013):

$$\Pr(y_i) = \begin{cases} \pi_i + (1-\pi_i)\cdot\left(\dfrac{k}{\mu_i + k}\right)^k & y_i = 0 \\ (1-\pi_i)\cdot\dfrac{\Gamma(y_i + k)}{\Gamma(k)\cdot\Gamma(y_i + 1)}\cdot\left(\dfrac{k}{\mu_i + k}\right)^k\cdot\left(\dfrac{\mu_i}{\mu_i + k}\right)^{y_i} & \text{otherwise} \end{cases} \tag{1}$$

where y_i is the i^{th} CPUE observation, π_i is the probability of a false zero, and μ_i and k are the mean and overdispersion parameters of the negative binomial distribution, respectively. The top equation represents the probability of obtaining a zero CPUE value, which is a binomial process that can occur either as a false zero or a true zero adjusted by the probability of not obtaining a false zero. The bottom equation is the familiar negative binomial mass function adjusted by the probability of not obtaining a false zero. GLMs were specified to mode π_i and μ_i as linear combinations of covariates with logit and log link functions, respectively.

The covariates measured synoptically with sampling that were considered included year, month, area (all categorical), and the continuous covariate Secchi depth, which was rescaled by subtracting the mean and dividing by its standard deviation. Inclusion of levels of categorical covariates with very few positive CPUE values caused model convergence and estimation problems, so levels with <5 % of the total

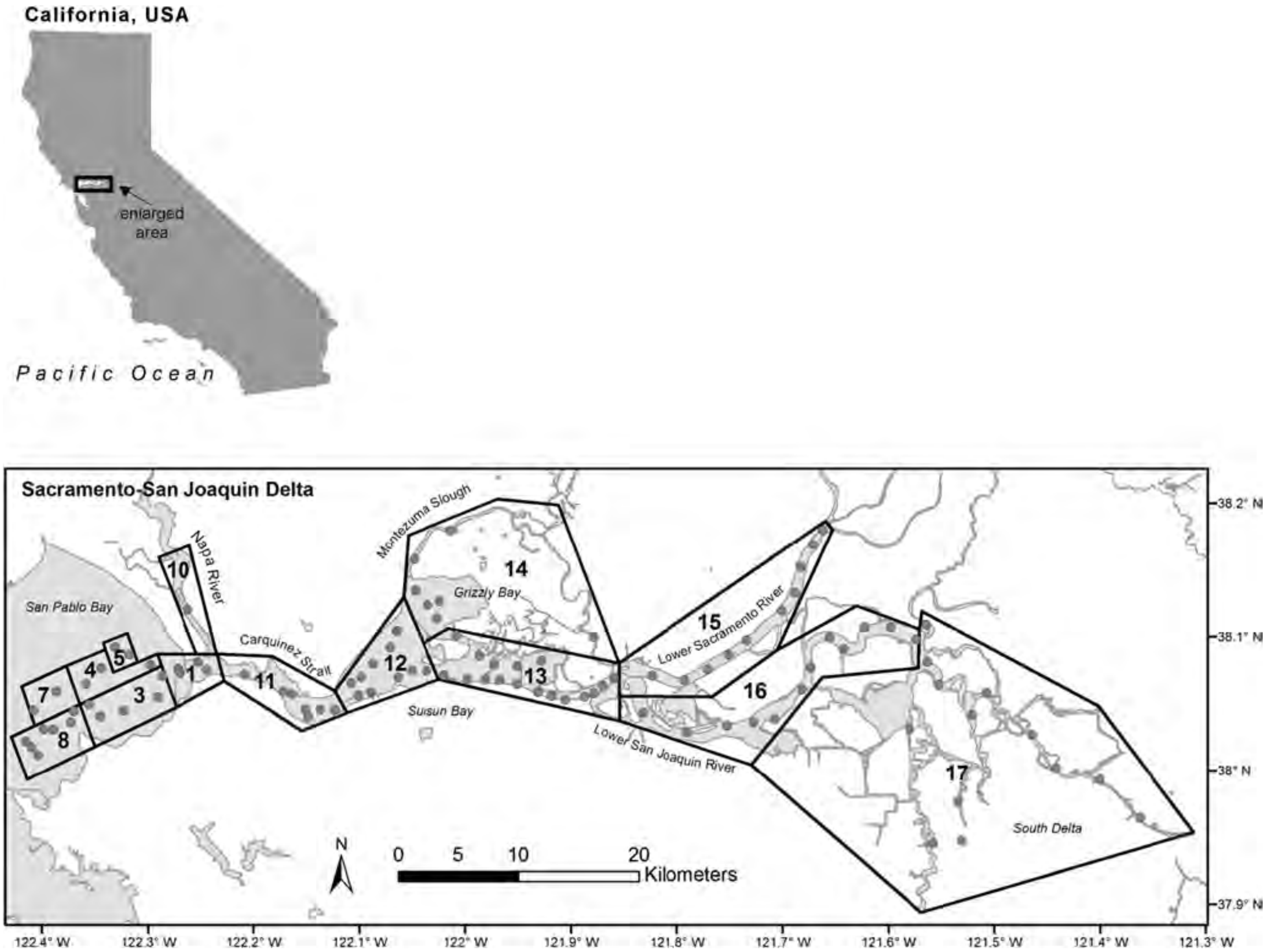


Fig. 1 Aerial stratification (*polygons*) and sampling locations (*circles*) for the Fall Midwater Trawl survey within the Sacramento-San Joaquin Delta, 1967–2012. Areas 2, 6, and 9 are not shown because they have not been consistently sampled and thus are not used by the California Department of Fish and Wildlife for estimation of catch per unit effort indices. No sampling occurred in 1974, September 1976, December 1976, and 1979. Figure adapted from Newman (2008)

survey catch of each species were deemed uninformative and excluded from the analysis. The covariates surface water temperature and surface salinity were also considered; however, variance inflation factors indicated that month/temperature and area/salinity were collinear. Month and area were chosen over temperature and salinity because an appreciable number of catch records did not have associated measures of temperature and/or salinity, and it was desirable to base analyses on the most available information. Also, the variables month and area arguably have the potential to be more useful in a management context. Interaction terms were excluded because the high proportion of zeros in the data lead to many year/area and month/area combinations for which there were no positive CPUE observations. Model parameterizations for each species ranged from inclusion of only a year covariate for the count and probability of false zero models to the saturated model with all four covariates specified for both components, including the possible combinations of unbalanced covariate specifications. AIC was used for model selection, and predictions were generated from the most supported model using estimated marginal means (Searle et al. 1980). Coefficients of variation for yearly predicted CPUE values were estimated from standard deviations of 1000 nonparametric bootstrapped samples (Efron and Tibshirani 1993). Models were fitted to data from 1967 to 2012 with the exception of 1974, September 1976, December 1976, and 1979 when no sampling occurred.

Annual Covariates

The covariate year is included in models when the goal is to develop a time series of estimated CPUE indices. However, the year covariate is simply a proxy for the ecosystem conditions over an annual timescale and thus has no direct relation to the vital rates of fish populations. Therefore, to more directly investigate factors potentially underlying interannual patterns in CPUE for each fish species, the aforementioned zero-inflated GLM structure was modified in two ways: (1) the year covariate was replaced by several hypothesized biotic and abiotic

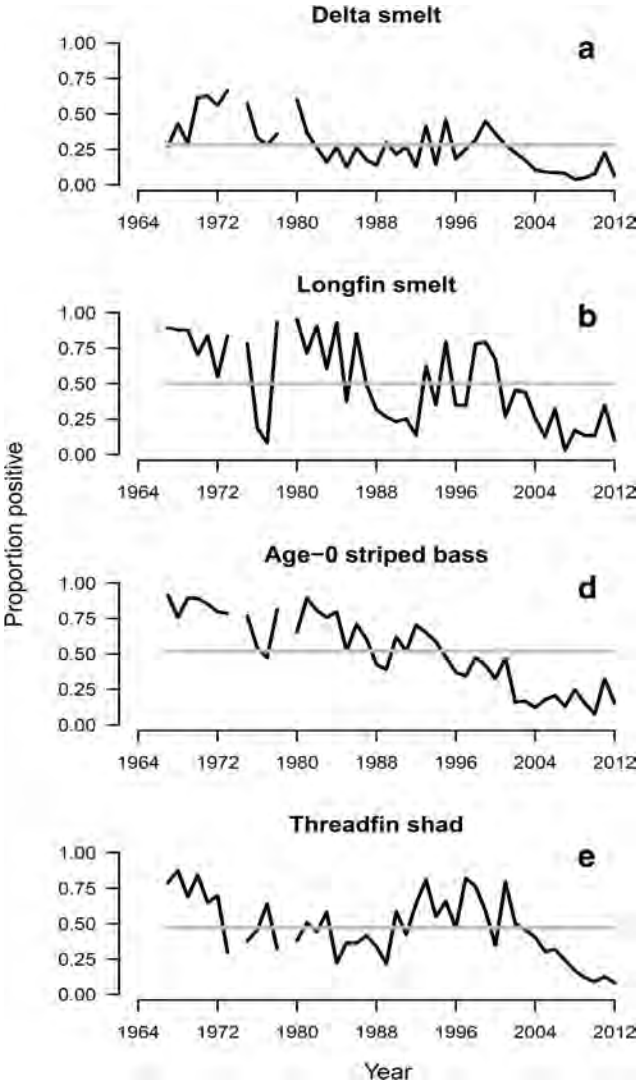


Fig. 2 Yearly proportions of positive tows (at least one target animal captured) based on the Fall Midwater Trawl survey, 1967–2012, for **a** delta smelt, **b** longfin smelt, **c** age-0 striped bass, and **d** threadfin shad. No sampling occurred in 1974, September 1976, December 1976, and 1979. *Horizontal line* is the time series mean

annualized continuous covariates, which operationally implied that the yearly value of each annualized covariate was assigned to each observed CPUE corresponding to the same year and (2) a single parameterization that included the annualized covariate along with month and area was fitted to isolate the effect of each annualized covariate on CPUE. Broad categories of the annualized covariates were zooplankton density (several taxa), chl-*a* concentration as a proxy for phytoplankton biomass, water quality metrics, and water flow (a total of 26). The years analyzed were 1976–2010, which was due to availability of chl-*a* data (began in 1976) and water flow measures (obtained through 2010). AIC was used to compare among competing annualized covariates for each fish species.

In terms of biotic covariates, the California Department of Water Resources (DWR) in collaboration with the CDFW have been compiling data on zooplankton density in the delta since 1968 (see http://www.water.ca.gov/bdma/meta/zooplankton.cfm for additional details, including specific sampling locations). The zooplankton monitoring program was initiated to investigate the population trends of pelagic organisms consumed by young fishes, particularly age-0 striped bass. Although the initial focus was to evaluate seasonal patterns in mysid abundance, the program expanded shortly after its inception to assess population levels of other key zooplankton taxa. Sampling occurs monthly at approximately 20 fixed stations. The zooplankton sampling gear consists of a Clarke-Bumpus net mounted directly above a mysid net, and the unit is deployed in an oblique fashion from near bottom to the surface. Each net is equipped with a flow meter, and all samples are preserved for sorting in the laboratory. For each station, zooplankton taxa are expressed as the total number per cubic meter of water sampled. Starting in 1976, chl-*a* concentration was recorded synoptically with zooplankton sampling.

The zooplankton taxa examined were adult calanoid copepods, adult cyclopoids, a combination of the two, and mysids. Annual estimated mean densities of zooplankton and chl-*a* were based on lognormal GLMs fitted to data from the core sampling locations and first replicate sample. The categorical covariates considered were year, survey (which is approximately equivalent to month), and area along with the continuous variable Secchi depth, which was again rescaled. Levels of categorical variables with <5 % of the total zooplankton density of each group again caused estimation problems and excluded from the analysis. Collinearity was assessed using variance inflation factors, and bias-corrected predicted (Lo et al. 1992) time series were generated from the most supported model using estimated marginal means.

In terms of abiotic covariates, the DWR has been monitoring water quality parameters at discrete sampling locations in the delta since 1970 (see http://www.water.ca.gov/bdma/meta/discrete.cfm for additional details, including sampling locations). The program was established to provide information for compliance with flow-related water quality standards for the delta set forth in the series of regulatory water right decisions and to provide abiotic data that could aid the interpretation of results from concurrent biological monitoring programs. Samples are taken at approximately 1 m depth and roughly within a 1-h window of the expected occurrence of high tide from 19 fixed stations. Sampling frequency is bimonthly during the rainy season (October/November to February/March) and monthly during the dry season (March/April to September/October).

Annual water quality metrics considered were mean summer (Jul–Sep) and winter (Jan–Mar) water temperature, total suspended solids (TSS) or filterable solids, volatile suspended solids (VSS) as a measure of the organic component of TSS, and turbidity. The annual mean water temperatures were estimated from a multiple linear regression model while annual mean TSS, VSS, and turbidity estimates were obtained from bias-corrected lognormal GLMs. The covariates considered were categorically defined year, month, and area. Variance inflation factors were again used to assess collinearity, and predicted mean values for each year were based on estimated marginal means from the most supported model.

The water flow covariates considered were classified into two groups, “historical”, which refers to measured flows taken from monitoring equipment located at various points in the delta, and “unimpaired”, which is an estimated reference quantity intended to represent broader watershed-level hydrology in the absence of man-made facilities that affect flow. For each group, monthly inflow and outflow time series were assembled. Historical inflow included combined measurements from the Sacramento River, Yolo Bypass, and Eastern Delta (San Joaquin River and adjacent areas; Fig. 1), while historical outflow is a net quantity of inflow and an estimate of delta precipitation less total delta exports and diversions. All historical flow time series were based on DAYFLOW, which is a computer program designed to estimate daily average delta outflow (see http://www.water.ca.gov/dayflow/ for more details). Unimpaired inflow is an estimate of water entering the delta from the expansive watershed while unimpaired outflow is a net value adjusted for natural losses (e.g., evaporation and vegetation uptake). Flow data were provided courtesy of W. Bourez (MBK Engineers, Sacramento, CA).

For each flow covariate, a single value was calculated by averaging monthly flow values in four different ways: (i) from Jan–Jun within the year of sampling, (ii) from Mar–May within the year of sampling, (iii) from Jan–Jun of the preceding sampling year, and (iv) from Mar–May of the preceding sampling year. This approach gave rise to 16 annual flow covariates. Lagged flow covariates were considered to investigate possible delayed effects of flow on CPUE. For the most supported annualized covariate, 95 % prediction intervals of CPUE and probabilities of false zeros were based on 1000 nonparametric bootstrapped model fits (Efron and Tibshirani 1993). All statistical analyses were performed with the software package R (version 2.15.1, R Development Core Team 2012), and zero-inflated GLMs were fitted by accessing the “pscl” library.

Results

Field Sampling

Complete tow, month, area, and Secchi depth information was available for 15,273 stations sampled during monthly fall cruises from 1967 to 2012 (excluding 1974, Sep 1976, Dec 1976, and 1979 when no sampling occurred). Application of the 5 % cutoff rule for levels of categorical covariates indicated that all levels of month contained adequate nonzero CPUEs for inclusion in analyses. However, spatial data summaries showed that CPUEs were quite low in some areas, and the 5 % rule led to the inclusion of only areas 12–16 for delta smelt, 11–14 for longfin smelt, 12–16 for YOY striped bass, and 15–17 for threadfin shad (Fig. 1). Total numbers of tows analyzed for each species were 8802 for delta smelt (max. CPUE of 156 animals in December 1982), 6582 for longfin smelt (max. CPUE of 3358 animals in September 1969), 8733 for age-0 striped bass (max. CPUE of 1100 animals in September 1967), and 5019 for threadfin shad (max. CPUE of 4012 animals in December 2001). Although high CPUE values did occasionally occur, the data for each species were strongly skewed toward zero and very low CPUE values. The average percent of nonzero catches across all years analyzed was 28.1 % for delta smelt, 50.2 % for longfin smelt, 52.1 % for age-0 striped bass, and 47.1 % for threadfin shad (Fig. 2).

Sampling Covariates

Based on AIC statistics, the full zero-inflated negative binomial GLM (model M_4) received the most empirical support for each species (Table 1). For delta smelt, model M_5 received modest empirical support ($\Delta AIC=5.9$), and for the other three species, no other parameterizations were comparatively supported. The superior performance of model M_4 suggested that all covariates were statistically important for each species and that CPUE and the probabilities of false zeros varied considerably by year, month, area within the delta, and across the domain of observed Secchi depths.

The model predicted yearly CPUE indices showed differing patterns for each species (Fig. 3). For delta smelt, higher predicted CPUE generally occurred in the early 1970s, 1980, and also for various years during the 1990s. The highest value occurred in 1991, and low CPUE was predicted for much of the 1980s and 2000s. Longfin smelt predicted CPUE was variable and high during the late 1960s, early 1970s, and for a few years during the early 1980s. Since 2000, predicted CPUE was consistently low with 2007 marking the lowest index value on record. Age-0 striped bass predicted CPUE consistently declined through time. The first year in the survey (1967) marked the highest age-0 striped bass predicted CPUE value on record while 2002 marked the lowest value. Threadfin shad predicted CPUE declined in the late 1960s, rebounded to higher but variable levels from the mid-1980s to early 2000s, and declined to the lowest value on record in 2012. Average species-specific CPUE across the time series was as follows: 1.24 fish/tow for delta smelt, 13.4 fish/tow for longfin smelt, 5.34 fish/tow for age-0 striped bass, and 22.9 fish/tow for threadfin shad. The precision of the estimated indices for all species was fairly low as bootstraped estimated

Table 1 Model selection statistics associated with the zero-inflated generalized linear models used to analyze catch-per-unit-effort data from the Fall Midwater Trawl survey for delta smelt, longfin smelt, age-0 striped bass, and threadfin shad, 1967–2012. Covariate abbreviations: *Y* year, *M* month, *A* area, *S* Secchi depth; and *nc* indicates model failed to converge successfully. No sampling occurred in 1974, September 1976, December 1976, and 1979

Model	Count covariates	False zero covariates	No. par.	Delta smelt		Longfin smelt		Age-0 striped bass		Threadfin shad	
				AIC	ΔAIC	AIC	ΔAIC	AIC	ΔAIC	AIC	ΔAIC
M_1	Y	Y	89	*nc*	*nc*	30,253.0	944.1	36,708.6	1299.4	24,364.7	1334.3
M_2	Y+M	Y+M	95	20,844.2	1348.6	29,751.4	442.5	36,630.4	1221.2	24,319.7	1289.4
M_3	Y+M+A	Y+M+A	103	19,872.9	377.3	29,602.4	293.6	36,038.7	629.5	23,336.2	305.8
M_4	Y+M+A+S	Y+M+A+S	105	19,495.6	0.0	29,308.9	0.0	35,409.2	0.0	23,030.3	0.0
M_5	Y+M+A+S	Y+M+A	104	19,501.5	5.9	29,323.0	14.1	35,423.5	14.3	23,246.9	216.7
M_6	Y+M+A+S	Y+M	100	19,795.0	299.4	29,356.0	47.1	35,537.2	128.0	*nc*	*nc*
M_7	Y+M+A+S	Y	97	19,801.9	306.3	29,690.6	381.7	*nc*	*nc*	23,332.8	302.3
M_8	Y+M+A	Y+M+A+S	104	19,635.3	139.7	29,497.7	188.8	35,677.2	268.0	23,045.0	14.6
M_9	Y+M	Y+M+A+S	100	19,795.2	299.6	29,588.6	279.7	35,988.1	578.9	23,956.3	926.0
M_{10}	Y	Y+M+A+S	97	19,834.8	339.2	29,601.4	292.5	36,137.9	728.7	23,993.2	962.8

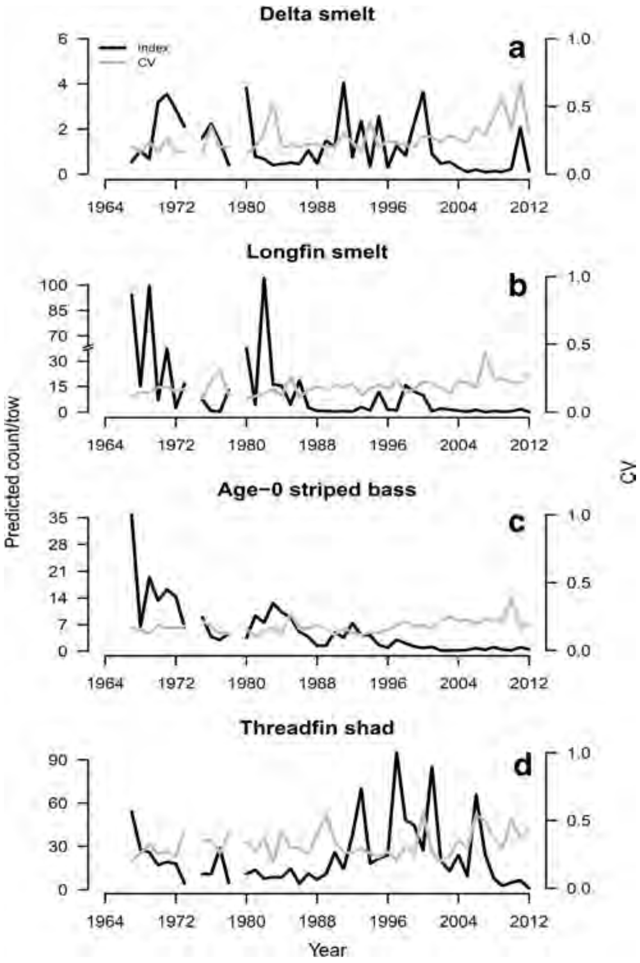


Fig. 3 Predicted yearly catch per unit effort (mean count per tow) and associated coefficients of variation (CV) based on zero-inflated generalized linear models applied to Fall Midwater Trawl survey data, 1967–2012, for **a** delta smelt, **b** longfin smelt, **c** age-0 striped bass, and **d** threadfin shad. No sampling occurred in 1974, September 1976, December 1976, and 1979. Note break in left *y*-axis for longfin smelt

yearly CVs predominately ranged between 0.15 and 0.45 with occasional values greater than 0.5.

Peak predicted monthly CPUE occurred in October for delta smelt, December for longfin smelt, September for age-0 striped bass, and November for threadfin shad (Fig. 4). Delta smelt predicted CPUE indices for November and December did not differ considerably from its peak month nor did the threadfin shad predicted December CPUE when compared to its peak. Spatially, highest predicted CPUE occurred in area 15 for delta smelt, area 12 for longfin smelt, area 15 for age-0 striped bass, and area 17 for threadfin shad. Age-0 striped bass predicted CPUE for areas 12 and 14 were comparably similar in magnitude to its peak.

The response in predicted CPUE across the range of observed standardized Secchi depths was strong and consistent across each species, as higher predicted CPUE values corresponded to low observed Secchi depths. This result emerged because the estimated Secchi depth coefficients associated with the count component of model M_4 were consistently negative across species. Related were the consistently positive estimated coefficients for the false zero model component of each species. Therefore, predicted CPUE declined with increased water clarity (higher Secchi depth) and the probabilities of false zeros increased with water clarity. In terms of actual water clarity conditions in the delta, the minimum observed Secchi depths for delta smelt, longfin smelt, age-0 striped bass, and threadfin shad were 0, 0, 0, and 0.12 m, respectively, while the maximum were 2, 1.6, 2, and 2.09 m. Relative to the maximum predicted CPUE for each species, the observed Secchi depth at which estimated CPUE decreased by 25, 50, and 75 %, respectively, was approximately 0.07, 0.17, and 0.35 m for delta smelt, 0.10, 0.25, and 0.50 m for longfin smelt, 0.11, 0.23, and 0.53 m for age-0 striped bass, and 0.4,

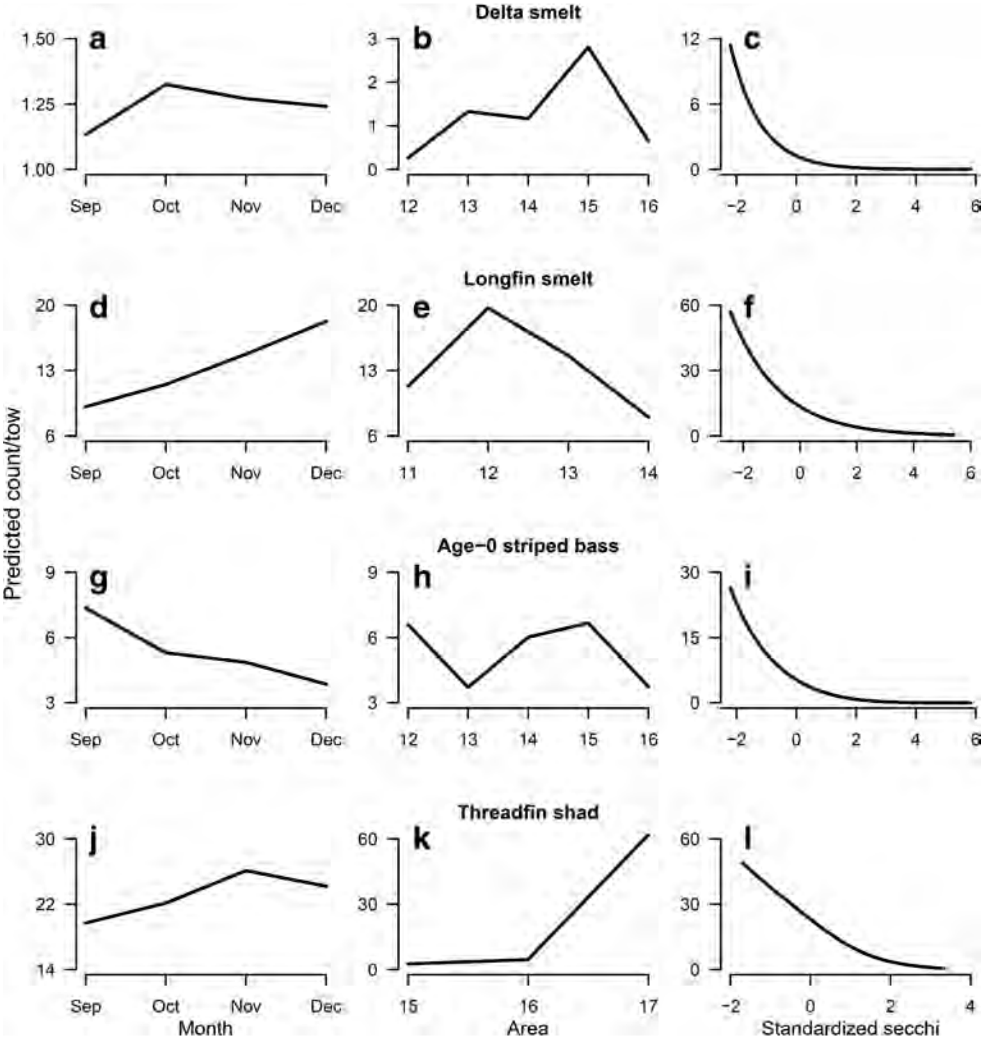


Fig. 4 Predicted catch per unit effort (mean count per tow) by sampling month, area, and across the range of observed standardized Secchi depths, respectively, based on zero-inflated generalized linear models applied to Fall Midwater Trawl survey data, 1967–2012, for (**a**–**c**) delta smelt, (**d**–**f**) longfin smelt, (**g**–**i**) age-0 striped bass, and (j–l) threadfin shad. No sampling occurred in 1974, September 1976, December 1976, and 1979

0.74, and 1.12 m for threadfin shad. Collectively, these results suggest that an increase from virtually no water clarity to roughly 0.5 to 1 m of water clarity corresponded to a 75 % or greater reduction in predicted CPUE for all species.

Annual Covariates

Predicted trends of the annualized biotic and abiotic variables showed differing patterns through time. Adult copepod density (calanoid, cyclopoid combined) has been variable but generally decreasing in the delta, with this trend being largely driven by taxa within the calanoid group (Fig. 5a–e). In contrast, the predicted trend in cyclopoid copepod density has been increasing since the mid-1990s; however, the comparably low density of cyclopoid copepods marginalized the impact of this group on the combined copepod trend. Estimated mysid density has been fairly stable since 1990 but much reduced from peak and moderate levels in the mid-1980s and late 1970s, respectively. The predicted trend of chl-*a* was relatively high and variable in the early part of the time series but considerably lower and more stable since 1987, which is when the lower trophic level food web of the delta changed in response to impacts by the introduced clam *Cobubula amurensis* (Kimmerer 2002).

Trends in predicted mean summer and winter water temperatures were generally stable over time, with estimated mean winter temperatures being slightly more variable than mean summer temperatures (Fig. 5f–j). Predicted trends of TSS, VSS, and turbidity in the delta were similar in that they showed considerable declines since the mid-1970s. Patterns in the various water flow variables showed distinct periods of "wet" and "dry" delta hydrology over time. Peak flow events occurred in 1983, the mid-1990s, and more recently in 2006, while low flows were observed in mid-1970s, early 1990s and late 2000s (Fig. 6). As expected, comparisons of type-specific (historical, unimpaired) patterns of inflows and outflows were generally the same qualitatively, with the latter simply reflecting reductions in water volume due to utilization. For the historical inflows and outflows, the two chosen averaging periods yielded virtually the same yearly volumes; however,

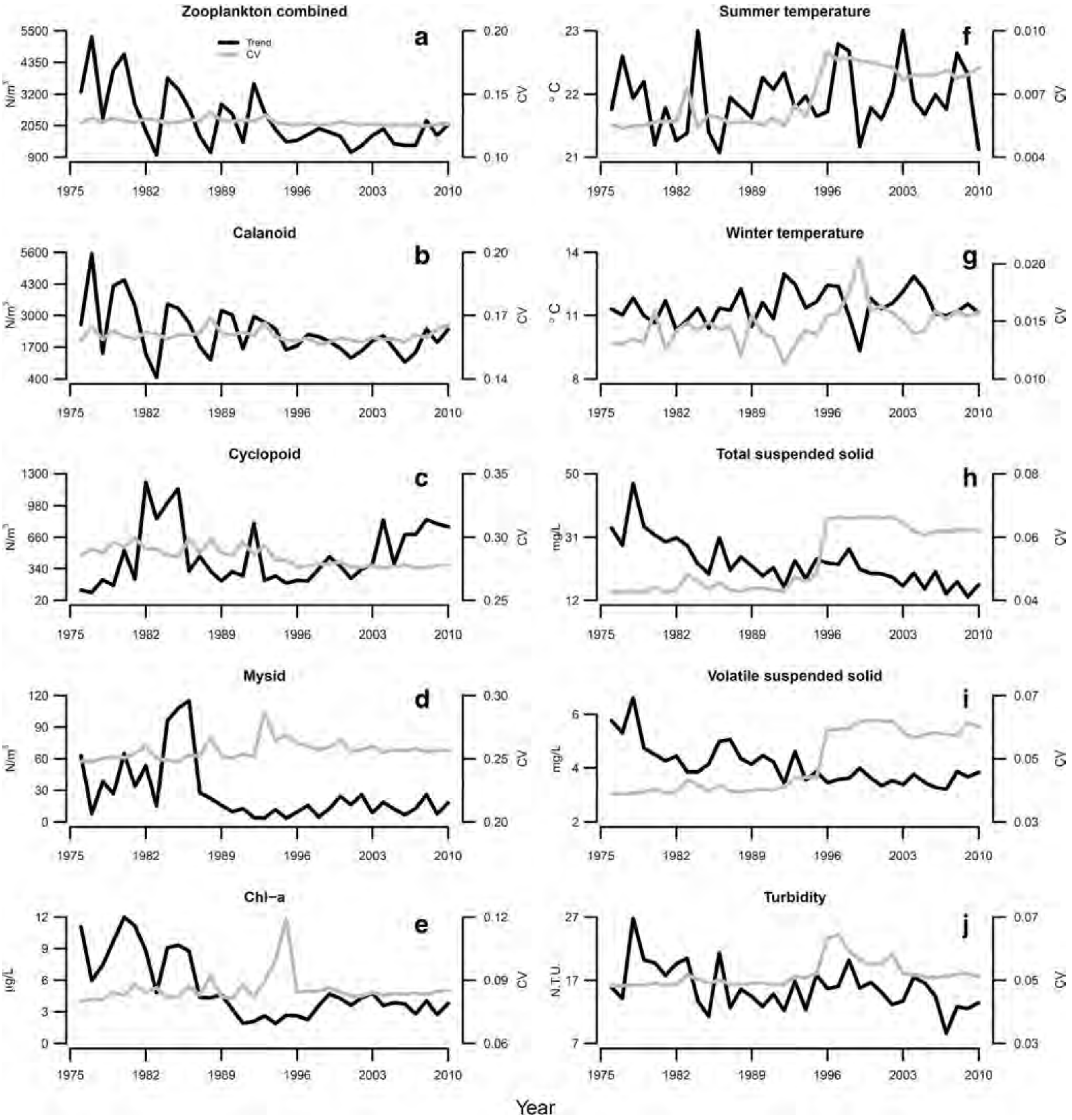
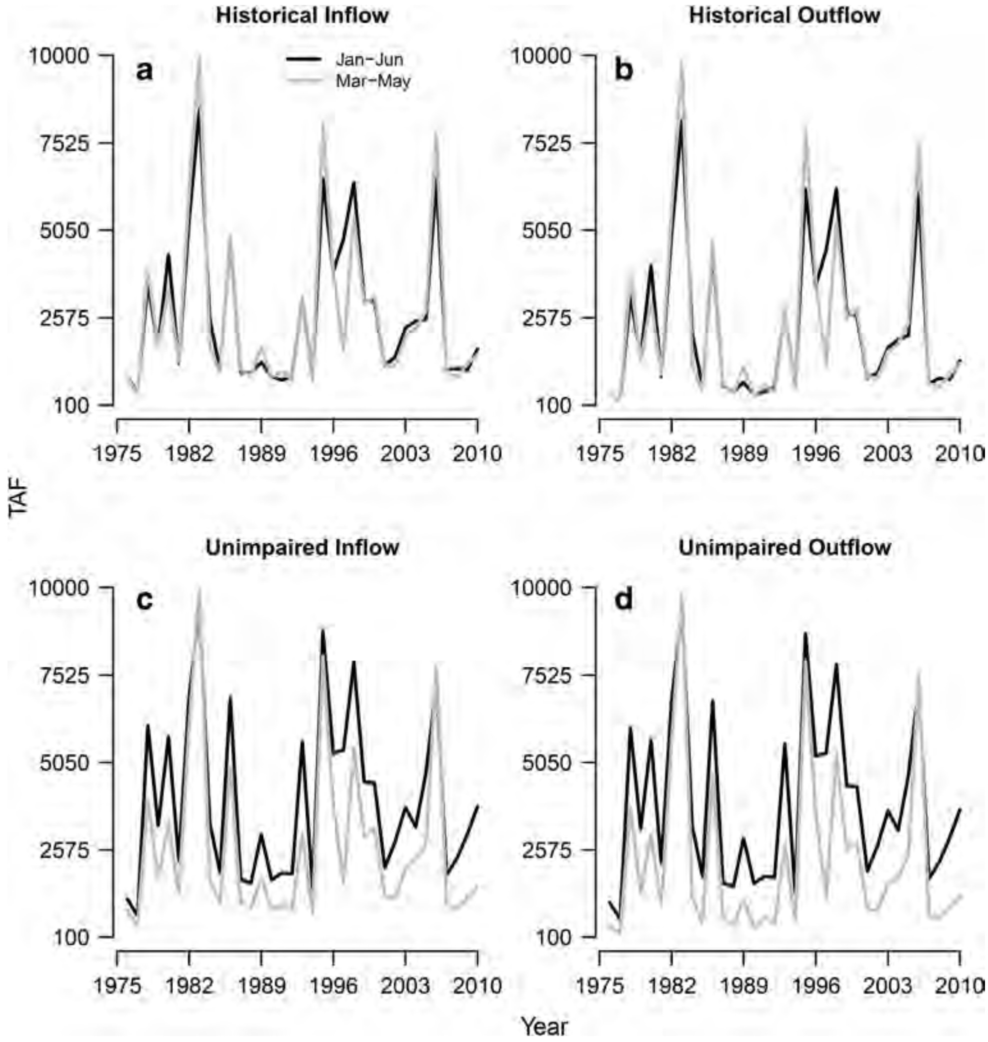


Fig. 5 Annualized mean trends and associated coefficients of variation (CV) based on various linear and generalized linear models fitted to zooplankton and discrete water quality data, 1976–2010, for **a** zooplankton combined (adult calanoid copepod and adult cyclopoid), **b** adult calanoid, **c** adult cyclopoid, **d** mysid, **e** chl-*a*, **f** summer water temperature (Jul–Sep), **g** winter water temperature (Jan–Mar), **h** total suspended solid, **i** volatile suspended solid, and **j** turbidity

there were notable differences in yearly volumes of unimpaired inflow and outflow depending on the monthly averaging period. The precision of all estimated biotic and abiotic covariates was very good as evidenced by consistently low CVs.

Based on AIC statistics, the annualized variable TSS received the most empirical support for all species (Table 2). Comparatively, there was no empirical support for any other annualized prey, water quality, or flow covariates. Predicted CPUE and probabilities of false zeros across the range of TSS were similar for three of the four species, with the exception being the predicted CPUE for threadfin shad (Fig. 7). Over the range of TSS, predicted delta smelt, longfin smelt, and age-0 striped bass CPUE increased, while the CPUE trend for

Fig. 6 Annualized trends in flow averaged monthly from January–June and March–May for **a** historical inflow, **b** historical outflow, **c** unimpaired inflow, and **d** unimpaired outflow. Flow variables lagged by 1-year are not shown



threadfin shad showed an inverse relationship. For all species, the predicted trends in probabilities of false zeros were fairly pronounced and decreasing with TSS. In terms of precision, the bootstrapped prediction intervals for both model components were generally narrow for all species.

Discussion

Sampling Covariates

Use of statistical models to quantify the importance of spatiotemporal and environmental covariates on survey CPUE can aid in understanding the dynamics of fish populations. For all species, the covariates year, month, region, and Secchi depth were important in explaining patterns in the observed CPUE data, particularly the zeros. However, relability of the results presented herein directly depends on satisfying the underlying modeling assumptions. For each species, plots of residuals for the count and false zero model components across the observed domains of the covariates showed no distinct patterns, and overdispersion was adequately handled by the zero-inflated model structure. Therefore, from a model diagnostics perspective, the means of the negative binomial and binomial distributions appear to be well estimated. In terms of precision, bootstrapped CVs of the predicted yearly CPUEs were fairly lowfor all species and likely due to the relatively high sampling intensity of the FMWT survey and the high proportion of consistently low observed CPUE values. However, the CV estimates do depend on the assumption that gear catchability (defined as q in the equation $CPUE_y = qN_y$) has remained constant over time and space, so it is possible that they are optimistic. Since the inception of the FMWT survey, the number of monthly sampling locations has grown considerably (~25 %), yet accompanying studies of potential gains/losses in bias and precision of predicted CPUE are absent from the literature. In general, model-based approaches can be useful in the design of fishery-independent surveys (Peel et al. 2013), and the methods in this study could support optimization studies to evaluate design elements, appropriate

Table 2 Model selection statistics associated with the zero-inflated generalized linear models used to evaluate the biotic and abiotic annualized covariates for delta smelt, longfin smelt, age-0 striped bass, and threadfin shad, 1976–2010

Model	Annual covariate	Delta smelt		Longfin smelt		Age-0 striped bass		Threadfin shad	
		AIC	ΔAIC	AIC	ΔAIC	AIC	ΔAIC	AIC	ΔAIC
A_{1}	Adult calanoid copepods	15,122.3	304.1	24,968.2	1642.2	27,545.5	691.4	19,325.6	263.8
A_{2}	Adult cyclopoid copepods	15,080.4	262.2	24,419.8	1093.8	27,420.7	566.6	19,247.5	185.7
A_{3}	Adult calanoid, adult cyclopoid combined	15,105.3	287.1	24,896.4	1570.3	27,433.2	579.1	19,310.9	249.1
A_{4}	Mysids	15,164.8	346.6	24,145.5	819.4	27,125.5	271.4	19,322.2	260.4
A_{5}	Chl-*a*	15,070.8	252.5	23,758.9	432.9	26,932.9	78.7	19,326.7	264.9
A_{6}	Summer temperature	15,113.2	295.0	24,633.0	1306.9	27,536.3	682.2	19,311.5	249.7
A_{7}	Winter temperature	15,095.2	277.0	24,282.6	956.5	27,472.6	618.5	19,325.3	263.5
A_{8}	Total suspended solids	14,818.2	0.0	23,326.1	0.0	26,854.1	0.0	19,061.8	0.0
A_{9}	Volatile suspended solids	15,074.5	256.3	24,612.9	1286.8	27,106.2	252.1	19,213.2	151.3
A_{10}	Turbidity	14,853.1	34.8	23,449.7	123.6	27,493.2	639.0	19,196.7	134.9
A_{11}	Historical outflow Jan–Jun	14,974.3	156.0	23,509.0	183.0	27,390.9	536.8	19,288.4	226.6
A_{12}	Historical outflow Mar–May	15,067.4	249.1	23,766.1	440.0	27,396.4	542.3	19,318.2	256.4
A_{13}	Historical outflow Jan–Jun, 1-year lag	15,164.2	346.0	24,872.2	1546.1	27,521.8	667.7	19,316.3	254.5
A_{14}	Historical outflow Mar–May, 1-year lag	15,158.5	340.3	24,925.1	1599.0	27,536.0	681.8	19,330.4	268.6
A_{15}	Historical inflow Jan–Jun	14,975.6	157.3	23,497.8	171.8	27,394.6	540.5	19,290.8	229.0
A_{16}	Historical inflow Mar–May	15,065.6	247.4	23,707.9	381.9	27,387.8	533.6	19,317.2	255.3
A_{17}	Historical inflow Jan–Jun, 1-year lag	15,162.8	344.6	24,879.9	1553.8	27,524.4	670.2	19,315.9	254.1
A_{18}	Historical inflow Mar–May, 1-year lag	15,158.4	340.1	24,929.6	1603.5	27,531.7	677.6	19,329.0	267.2
A_{19}	Unimpaired outflow Jan–Jun	14,989.8	171.6	23,615.2	289.1	27,436.2	582.1	19,315.2	253.3
A_{20}	Unimpaired outflow Mar–May	15,025.4	207.2	23,968.6	642.5	27,451.5	597.4	19,331.6	269.8
A_{21}	Unimpaired outflow Jan–Jun, 1-year lag	15,167.2	349.0	24,899.4	1573.3	27,549.8	695.7	19,317.4	255.5
A_{22}	Unimpaired outflow Mar–May, 1-year lag	15,152.6	334.4	24,944.6	1618.5	27,557.8	703.7	19,329.1	267.3
A_{23}	Unimpaired inflow Jan–Jun	14,989.9	171.7	23,613.4	287.3	27,436.7	582.6	19,315.4	253.5
A_{24}	Unimpaired inflow Mar–May	15,025.5	207.2	23,969.1	643.0	27,452.3	598.1	19,331.6	269.8
A_{25}	Unimpaired inflow Jan–Jun, 1-year lag	15,167.1	348.9	24,899.4	1573.3	27,550.0	695.9	19,317.4	255.6
A_{26}	Unimpaired inflow Mar–May, 1-year lag	15,152.7	334.5	24,944.3	1618.2	27,558.3	704.2	19,329.0	267.2

sample sizes, and allocation of resources for future FMWT surveys. The estimated monthly, regional, and Secchi depth effects generated relatively unique predicted CPUE patterns for each species, which can, in turn, be used as important foundational information for future hypothesis-driven field studies and mechanistic modeling activities.

The annual frequency of zero CPUE observations over the course of the entire FMWT survey was appreciably high for all species (Fig. 2). As a means of coarsely evaluating the temporal pattern of zero inflation in the FMWT data, model M_4 and its nonzero-inflated counterpart (intercept only parameterization for the false zero component) were sequentially fitted to subsets of the FMWT data set truncated by decade for each species. That is, the two models were applied to only 1960s data, then to 1960s–1970s data, then to 1960s–1980s data, and so on through the full time series. With the exception of the 1960s data for longfin smelt, AIC statistics strongly supported the zero-inflated parameterization for all species and time periods. Therefore, it appears that the FMWT survey data have almost always contained more zero CPUE observations than would otherwise be expected given a negative binomial count process, which raises the question, why?

Failing to successfully encounter target populations can arise because they are rare, samples are taken in suboptimal habitats (true zeros), or because samples are taken in optimal habitats but reduced survey catchability across time, space, and/or ecosystem conditions prevent successful collections (false zeros). For delta smelt, rarity may be a plausible explanation, especially given that the highest predicted yearly CPUE was only 4.04 fish per tow and the 45-year average was just 1.24 fish per tow. However, species rarity does not seem likely for the other three fishes given that predicted yearly longfin smelt CPUE values early in the time series were very high (>70 fish per tow), estimated adult striped bass abundance exceeded 1 million fish in the early 1970s (Stevens et al. 1985) thus requiring considerable age-0 production, and threadfin shad have been viewed as highly abundant since appearing in the delta (Feyrer et al. 2009).

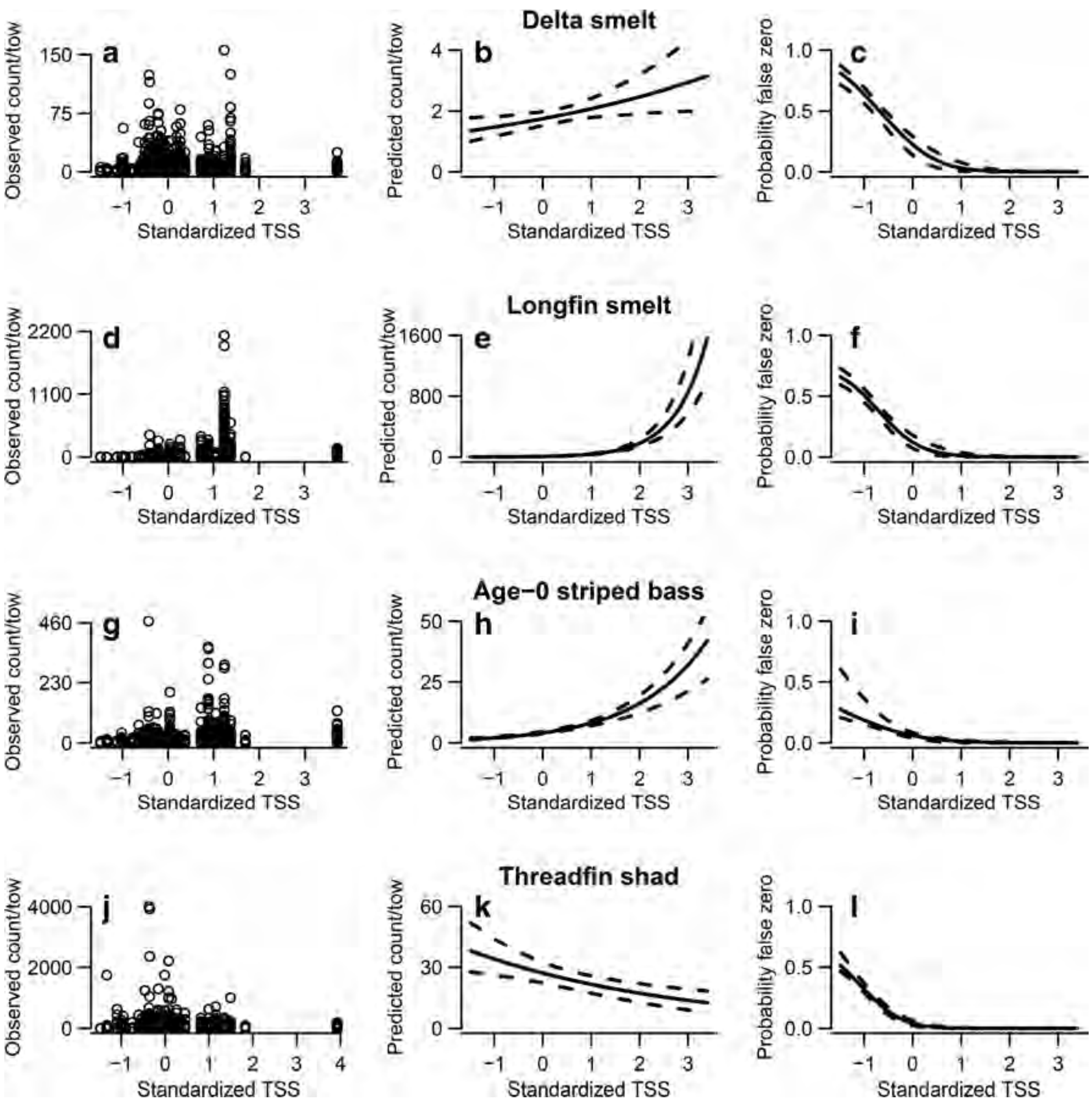


Fig. 7 Observed catch per unit effort (CPUE, mean count per tow, *left panels*), predicted CPUE (*middle panels*), and predicted probabilities of false zeros (*right panels*) with 95 % prediction intervals across observed standardized TSS for (**a**–**c**) delta smelt, (**d**–**f**) longfin smelt, (**g**–**i**) age-0 striped bass, and (**j**–**l**) threadfin shad

The FMWT survey does follow a fixed station sampling design, which raises the possibility that samples are consistently taken at locations that do not support high localized fish abundance. Additionally, if habitat utilization of fishes in the delta has systematically changed over time in response to morphological alterations of the estuary and/or sustained regimes of ecosystem conditions, differences in CPUE and distribution become confounded. The relatively high spatiotemporal sampling intensity of the FMWT survey may somewhat mitigate these concerns, but the four focal species are schooling pelagic fishes, and thus, variable distributions through time and space should be expected.

The consistency of the model prediction to Secchi depth for all species warrants deeper consideration, especially in the context of false zeros. Feyrer et al. (2007) analyzed raw FMWT survey data to evaluate fish occurrences (presence/absence of delta smelt, age-0 striped bass, and threadfin shad) in relation to various environmental variables and documented an inverse response with Secchi depth. Feyrer et al. (2011) updated that analysis and extended it to derive habitat index values for delta smelt (but see comments provided Manly et al. (2015)). The results of this study generalize the importance of Secchi depth to include CPUE. Feyrer et al. (2007) noted that higher presence/absence of delta smelt at lower Secchi depths could be due to required turbidity for feeding and/or turbidity mediated top-down predation impacts. A third potential explanation is that catchability of the FMWT survey sampling gear changes with Secchi depth. In general, Secchi depth is a coarse measurement of water clarity, and it is not possible to distinguish among constituent groups causing low measurements. If those constituent groups are largely organic material, then a positive fish CPUE response to food availability is possible. Conversely, if those constituent groups are not largely organic, then higher CPUE at lower Secchi depths could be due to compromised foraging impacts of visually oriented piscivores such as larger striped bass (Horodysky et al. 2010). However, all of the fishes in this study are pelagic, planktivorous feeders, and thus, it is reasonable to assume that vision plays a central role in their sensory ecology. Animals could be more effective at gear avoidance under higher Secchi depths than at lower Secchi depths simply because of a larger field of visibility for gear detection.

Although experimentally testing the variable catchability hypothesis is challenging, flume trials to assess gear behavior under various hydrographic conditions, video equipment attached to sampling gear, and coordinated field studies using multiple survey gears designed to quantify relative catchabilities could be informative. Additional modeling efforts may also assist in identifying and quantifying covariate effects on relative catchability. In terms of the bottom-up hypothesis, characterization of water column constituents synoptic with fish stomach content analysis could assist in understanding trophic interactions and prey selectivity, which could aid in determining if the inverse relationship of CPUE and Secchi depth is a response to food availability. Regarding top-down impacts, results of striped bass and other fish predator diet composition studies in the delta have shown very little consumption of delta smelt and longfin smelt, and modest consumption of age-0 striped bass and threadfin shad (Nobriga and Feyrer 2007; Nobriga and Feyrer 2008). However, these studies were temporally abbreviated, and each acknowledged potential biases due to spatial limitation of predator stomach collections. Therefore, systematic temporal and spatial diet composition studies of piscivorous fishes could be helpful in more fully understanding predation impacts of larger fishes.

Annual Covariates

The annualized covariates considered were chosen in an effort to evaluate the effects of hypothesized covariates on fish CPUE that were potentially operating at an annual timescale. The choice to focus on the annual timescale was motivated from the notion that yearly environmental conditions have the potential to impact early life history and thus new year class formation. However, the analytical approach taken here to evaluate annual covariates can be used for variables aggregated across other potentially meaningful scales. For example, biotic or abiotic variables summarized monthly or seasonally could be used to more directly explore drivers of within-year CPUE patterns, and variables could be aggregated spatially to investigated rivers of fish distribution within the delta. Studies of this type represent fruitful areas of future research.

The strong empirical evidence supporting TSS as the best annualized covariate for all species is consistent with the importance of Secchi depth documented in the analysis of sampling covariates. Trends in the model predicted CPUEs and probabilities of false zeros across TSS were analogous to those associated with Secchi depth, with the exception of predicted threadfin shad CPUE which showed a modest decline with TSS. Inspection of the raw threadfin shad CPUE data in relation to TSS showed relatively high frequencies of both zero (>50 % of the tows analyzed) and large CPUE values (>100 fish per tow, 3.9 % of the tows analyzed) at low TSS values when compared to high TSS values. The collective presence of these relatively infrequent large observed CPUEs and numerous observed zero CPUE values likely created the declining predicted CPUE and probability of false zero relationships with TSS (Fig. 7k). The results for the other three species strongly confirm the effect that more turbid water yields higher predicted CPUE and demonstrates that it is also detectable at an annual timescale. As a stand-alone result, the concept that water clarity mediates CPUE keeps the bottom-up, top-down, and variable gear catchability hypotheses in play; however, the strong support for the annualized TSS covariate combined with the lack of empirical support for any of the annualized prey covariates and the aforementioned relative absence of the focal fish species in predator diets may favor the variable catchability hypothesis.

Much of the contemporary understanding regarding covariate effects on fish CPUE in the delta has revolved around flow, particularly outflow and the location of X_2. In this study, X_2 was not considered largely because it is highly variable, often moving significant distances within a single tidal cycle (pers. com., W. Bourez, MBK Engineers, Sacramento, CA) and because it is a proxy covariate directly influenced by flow. Thus, inclusion of the various flow covariates constitutes a more direct evaluation of delta hydrology. CPUE indices of pelagic fishes in the delta have been showed to be positively related to delta outflow (Kimmerer 2002; Sommer et al. 2007), but it is important to note that higher flow regimes lead to higher TSS concentrations. For the data in this study, the historical outflow January–June and March–May time series are each positively correlated with TSS and signficant at the $\alpha=0.07$ level (Pearson's product moment correlations, $\rho_{JJ}=0.32$ [$p=0.058$], $\rho_{MM}=0.31$ [$p=0.067$]). Therefore, higher delta outflow leads to poorer water clarity, which, in turn, could increase survey gear catchability and lead to higher estimated yearly CPUE indices.

If the annualized covariates analysis is restricted to only include the flow covariates, the results indicated that historical outflow averaged January–June received the most support for delta smelt and threadfin shad, and historical inflow averaged January–June and averaged March–May were best supported for longfin smelt and age-0 striped bass, respectively (Table 2). However, there was competing empirical support for historical inflow averaged January–June for delta smelt (ΔAIC=1.3) and for historical outflow averaged January–June (ΔAIC=3.1) for age-0 striped bass. Collectively, these results fail to confirm the effect of a single dominant flow covariate on fish CPUE in the delta, which is arguably not surprising since the underlying dynamics of the focal fish species are likely shaped by intersections of a complex suite of biological, ecological, and environmental processes.

Acknowledgments The significant efforts of the many field and lab personnel responsible for populating the high-quality fish, plankton, water quality, and flow databases for the delta are outstanding. Discussions with D. Fullerton (Metropolitan Water District) about delta fish ecology and W. Bourez (MBK Engineers, Sacramento, CA) about delta hydrology and DAYFLOW data were appreciated. Funding was provided by the Northern California Water Association, and constructive comments were offered by two anonymous reviewers. This is VIMS contribution number 3456.

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Appendix 5

Evaluation
Of
Potential
State Water Resources Control Board
Unimpaired
Flow
Objectives

April 25, 2012

Prepared for: Sacramento Valley Water Users Group
Prepared by: MBK Engineers

EXECUTIVE SUMMARY

This report was prepared to support the Sacramento Valley Water Users in submitting comments to the State Water Resources Control Board (SWRCB) regarding proposed Delta outflow and Sacramento River flow requirements that would be based on percentages of unimpaired flows, and potentially included as water quality objectives in the SWRCB's update and implementation of the Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary (Bay-Delta Plan). This report summarizes the results of a reconnaissance level analysis of the estimated effects that implementation of such requirements would have on water users in the Sacramento River Basin and on CVP/SWP reservoirs and operations.

Initially, an analysis was performed to determine the average percentages of unimpaired Delta outflows that would have occurred in different water-year types if Existing Conditions had been in effect during the entire period of historical record. Consistent with standard hydrological modeling practice, Existing Conditions are defined by today's regulatory requirements, land use, water demands, and facilities and are used to establish how the CVP/SWP currently operates. Existing Conditions percentage of unimpaired Delta outflow is calculated by averaging total modeled Delta outflows for the period of January through June and dividing by the average total unimpaired Delta outflow over that same period. The outflows were not calculated on a month-to-month basis for the initial analysis to determine Existing Conditions percentage of unimpaired Delta outflow. This analysis determined that, under Existing Conditions, average January-June Delta outflow over the period of record is about 50% of unimpaired flows and the critical year average Delta outflow is about 40% of unimpaired flows.

These average percentages of 50% and 40% of unimpaired flows then were modeled, in separate analyses, as minimum monthly Delta flow requirements for each month in the January through June period to estimate the hydrological and related impacts that would result from implementation of such minimum requirements. In other words, this report presents the estimated impacts that would occur if the existing average and average critical year percentages of unimpaired Delta outflows during the January through June period – 50% and 40%, respectively – were imposed as regulatory minimum Delta outflow requirements for each separate month from January through June. The approach of applying a constant percentage of unimpaired flow as a requirement for each month from January through June is consistent with the SWRCB August 2010 Delta flow criteria report and recent analysis performed by SWRCB on certain tributaries to the San Joaquin River as part of its update to the Bay-Delta Plan

The overall conclusions are summarized in the following list, and the detailed analytical results are summarized in this report. The overall conclusions regarding the estimated effects of implementing January-June minimum monthly Delta outflow requirements of 50% and 40% of unimpaired flows are as follows:

- Effects to the CVP and SWP reservoirs and operations would be severe and would result in the inability to maintain viable operations
- Increases in average annual Delta outflows would be:
  - 1,100,000 acre-feet for a 50% of unimpaired flows requirement; and
  - 480,000 acre-feet a 40% of unimpaired flows requirement
- The following reductions and decreases in Sacramento Basin CVP and SWP reservoir carryover storage would occur:

  - Significant reductions in cold water pools would occur under both the 50% and the 40% of unimpaired flows scenarios
  - An average reduction of 2,200,000 acre-feet in reservoir carryover storage would occur under the 50% of unimpaired flows scenario
  - An average reduction of 1,000,000 acre-feet in reservoir carryover storage would occur under the 40% of unimpaired flows scenario
- The following increases in Sacramento Basin groundwater pumping to meet reductions in surface-water deliveries would be necessary:
  - For the 50% of unimpaired flows scenario, groundwater pumping in the Sacramento Basin would have to increase by 250,000 acre-feet per year on average annual basis , and by an average of 1,000,000 acre-feet per year in Critical years
  - For the 40% of unimpaired flows scenarios, groundwater pumping in the Sacramento Basin would have to increase by 100,000 acre-feet per year on average annual, and by an average of 400,000 acre-feet per year in Critical years
- Such increases in groundwater pumping would not be realistic and therefore would not actually occur. Instead, there would have to be reductions in irrigated acreage
- Under both scenarios, there would be increased groundwater overdrafts in the export service area
- The following seasonal changes in river flows and Delta outflows and impacts would occur:
  - Increases in March through June
  - Decreases in July through December
  - Impacts to key instream temperature and habitat
- There would be regular and multiple violations of existing SWRCB standards and ESA Biological Opinion requirements
- There would be severe water supply impacts, including the following:
  - Water-supply impacts to CVP settlement and exchange contractors, and SWP settlement agreement holders, which have water rights senior to the CVP and the SWP
  - Significant reductions in north-of-Delta CVP and SWP water-service contract deliveries.
  - Inability to meet public health and safety water deliveries
  - Reductions in water deliveries to wildlife refuges

UNIMPAIRED FLOW

For hydrological analyses, unimpaired flows are the calculated flows that the Department of Water Resources (DWR) has developed to estimate the flow conditions that would have occurred in the absence of any human alterations of flows. These estimated unimpaired flows have been calculated by taking the stream flow conditions that actually occurred and by subtracting the effects of reservoir storage, water diversions, resulting return flows, and other factors that were caused by human influences on flows.

Unimpaired flow data used for this evaluation were provided by DWR and published in the 2006 report titled: *California Central Valley Unimpaired Flow Data, Fourth Edition*. DWR defines unimpaired flow on page 1 of this report as:

> *"Unimpaired flow is runoff that would have occurred had water flow remained unaltered in rivers and streams instead of stored in reservoirs, imported, exported, or diverted. The data is a measure of the total water supply available for all uses after removing the impacts of most upstream alterations as they occurred over the years. Alterations such as channel improvements, levees, and flood bypasses are assumed to exist."*

The State Water Resources Control Board (SWRCB) has suggested that it may establish new Delta outflow and Sacramento River flow requirements that are based on specified percentages of unimpaired flows. The SWRCB's August 2010 Delta Flow Criteria report suggested that in order to protect aquatic public trust resources in the Delta, 75% of unimpaired Delta outflow would be necessary from January through June, and that 75% of unimpaired Sacramento River flow would be needed for these months, as well as for November and December. The SWRCB has also analyzed the potential imposition of 20%, 40% and 60% unimpaired flow requirements on certain tributaries to the San Joaquin River as part of its update to the Bay-Delta Plan.

The percentages of unimpaired flow that flow into and out of the Delta are highly variable and are influenced by hydrologic conditions, historical development, and regulatory requirements. Fluctuating hydrologic conditions are the dominant factor contributing to variations in the percentages of unimpaired flow that occur over time at various locations in the Delta watershed. Historical development has influenced the percentages of unimpaired flows that have occurred as project reservoirs have been developed. However, it is not possible to ascertain the precise effects of these developments by analyzing historical data, because these data are heavily influenced by changes in hydrologic conditions. Regulatory conditions have also influenced the percentages of unimpaired flow that have occurred, particularly during summer and fall months where regulatory minimum river flow and Delta outflow requirements are greater than the corresponding unimpaired flows.

Because current operating requirements have only been in place for a short period of time, there is not enough available historical data to estimate the Existing Conditions percentage of unimpaired Delta outflow. Therefore standard hydrological modeling practice is to analyze the hydrologic impacts that would occur when current cultural and regulatory conditions – Existing Conditions – are applied to the variable hydrology that has occurred over a period of record. This approach enables projections about what effects existing requirements, or possible new requirements, will have going forward. In this report, to determine the average percentage of unimpaired Delta outflows that would occur, Existing Conditions are applied to a long-term hydrologic period, CalSim II is used to depict streamflows and those modeled streamflows then are compared to DWR's unimpaired flow data to estimate the Existing Conditions percentage of unimpaired Delta outflow. Actual historical flow data are included in this report to provide a historical perspective on the modeled percentages of unimpaired flow over the period of record under Existing Conditions. That comparison demonstrates that the modeled data is sufficiently reliable for analytical purposes.

Figure 1 is a plot of historical average monthly Delta outflows as percentages of average monthly unimpaired Delta outflows for the following periods:

- 1930-1943: Pre-Shasta Reservoir
- 1944-1955: Pre-Folsom Reservoir
- 1956-1968: Pre-Oroville Reservoir
- 1969-2003: Post Sacramento Basin Project Reservoirs
- All years: 1930-2003

During 1969 through 2003, hydrologic conditions varied significantly and regulatory standards became more stringent. Figure 2 is a plot showing average January through June historical Delta outflows during the 1969-2003 period as percentages of unimpaired Delta outflows for the same period of each year. Each data point is labeled with the Sacramento River Basin 40-30-30 index water year type. The average percentages of unimpaired flow for each water year type during the 1969-2003 period are listed in Table 1. Values in Table 1 are calculated by taking the average of total January through June historical flows divided by average total January through June unimpaired flows and is expressed in the following equation:

$$Average\left(\sum January\ through\ June\ historical\ flow\right) \div Average\left(\sum January\ through\ June\ unimpaired\ flow\right)$$

This equation can be used to calculate:(1)average percentage of unimpaired flow for all years; (2) percentages for each year type, as displayed in Table 1; and (3) average percentages based on a comparison of modeled flows over the period of record and DWR's calculated unimpaired flows. As indicated by this table, Delta outflows in wetter years tend to be higher percentages of unimpaired outflows, while Delta outflows in drier years tend to be lower percentages of unimpaired outflows. These differences generally occur because reservoir storage capacity does not change with changes in water year types, and reservoirs therefore are capable of storing a greater percentage of unimpaired flows in drier years than in wetter years.

Figure 1 – Average Historical Delta Outflow as a Percentage of Unimpaired Delta Outflow

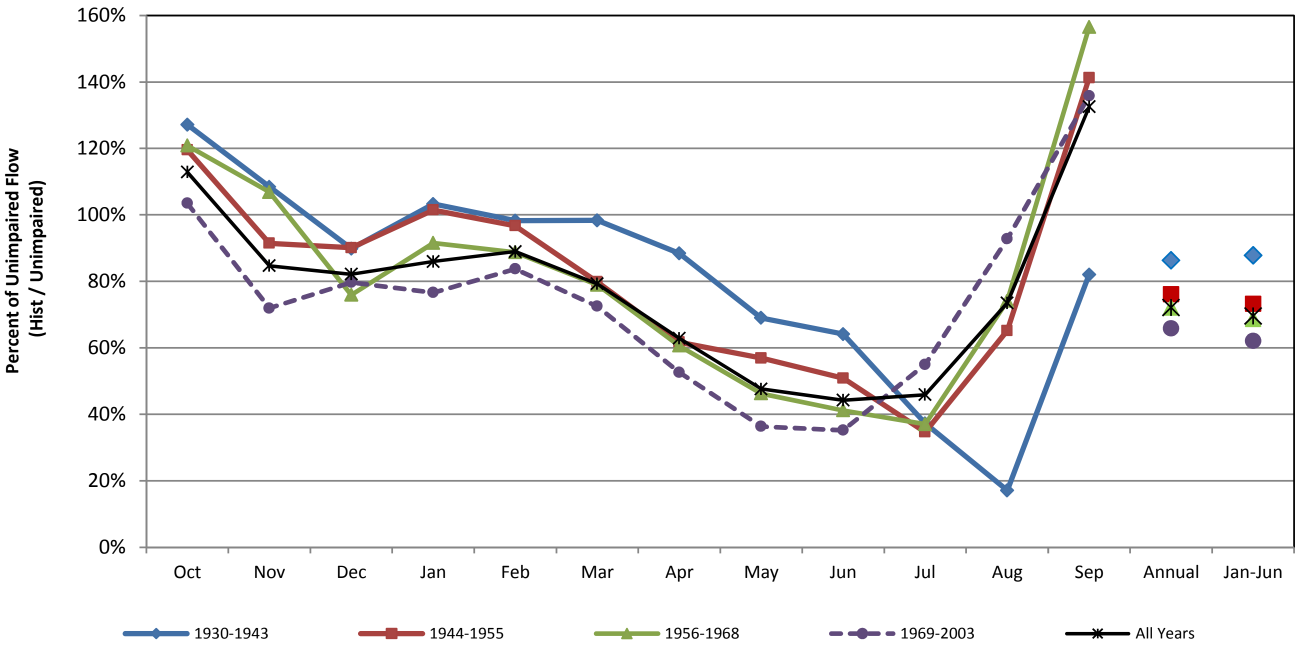


Figure 2 - Historical 1969-2003 Average January through June Historical Delta Outflow as a Percentage of Unimpaired Delta Outflow

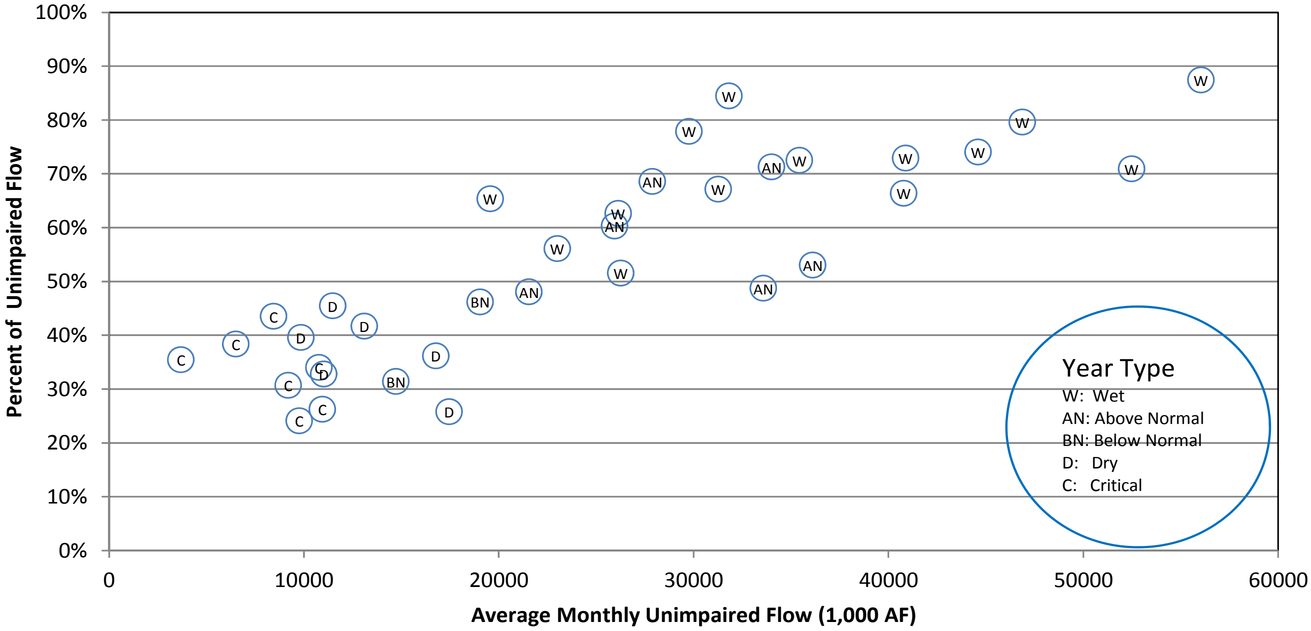


Table 1 - Historical 1969-2003 Average January through June Historical Delta Outflow as a Percentage of Unimpaired Delta Outflow by SRI Water Year Type

Wet	Above Normal	Below Normal	Dry	Critical	All Years
72%	59%	40%	36%	32%	62%

Due to the difficulties in using historical records to determine the average percentage of unimpaired flows that flow into and out of the Delta under Existing Conditions, an evaluation of CalSim II results was performed to estimate what Delta outflows would occur as percentages of unimpaired flows under Existing Conditions, under the variable hydrology that occurred during the 1922-2003 period of record. CalSim II is designed to represent existing CVP/SWP operating and system conditions by using existing operating criteria, facilities, and land use to model the CVP/SWP system and Delta for the 1922-2003 hydrologic period. Using CalSim II to determine the percentage of unimpaired Delta outflows that occur under this Existing Conditions scenario, and then using the average unimpaired outflow percentage developed from this scenario to create new model runs with these average percentage as minimum monthly Delta outflow requirements is the best available method of estimating what might happen if one of these existing percentages were implemented as a minimum Delta outflow requirement.

Figure 3 is a plot showing, by water year type, the monthly average modeled Delta outflows for the 1922-2003 period of record as percentages of monthly average unimpaired Delta outflows over the same period. Because Existing Conditions operating criteria are the same in every year of this CalSim II simulation, variations due to fluctuating hydrologic conditions can be more easily identified under this approach. For example, the percentages that modeled Delta outflows are of unimpaired flows for March vary from 40% in dry years to 78% in wet years. Figure 4 is a plot showing the average January through June modeled Delta outflow percentages of unimpaired Delta outflows for each year. Each data point is labeled with its water year type in this figure. The average percentages that modeled Delta outflows are of unimpaired flows for each water year type are listed in Table 2. In wetter years, modeled Delta outflows tend to be higher percentage of unimpaired outflows, averaging 65%, while in drier years modeled Delta outflows tend to be lower percentage of unimpaired outflow, averaging 40%.

The CalSim II modeling results indicate that over the 1922-2003 period of record, the average modeled Delta outflows under Existing Conditions is 53% of unimpaired outflows for the January through June period; the average percentage for critical years is 40%. To estimate the effects of imposing the existing average January through June percentage of unimpaired flow as a Delta outflow requirement, the value of 50% (rounded down from 53% to ensure that the effects are not overestimated) then is used as a minimum monthly regulatory requirement in further analysis. For the purpose of this further analysis, it is assumed that the 50% of unimpaired flow requirement is applied on a monthly basis from January through June, i.e., for each month from January through June, Delta outflow must be equal to or greater than 50% of unimpaired Delta outflow for that month. A second stage in the further analysis then was performed to estimate the effects of imposing the average January through June critical year Delta outflow percentage of unimpaired flows, 40%, as a minimum monthly regulatory requirement.

Figure 3 - Modeled with CalSim II: Average Delta Outflow as a Percentage of Unimpaired Delta Outflow

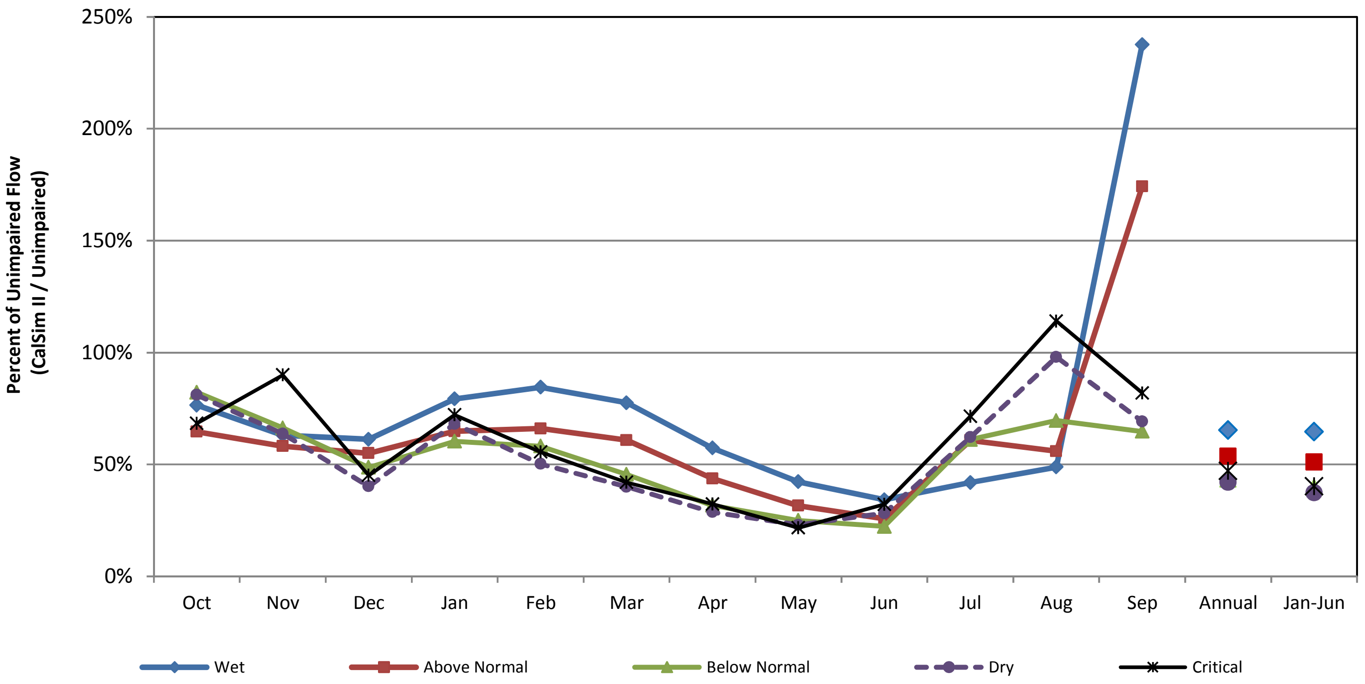


Figure 4 - Modeled with CalSim II: Average January through June Delta Outflow as a Percentage of Unimpaired Delta Outflow

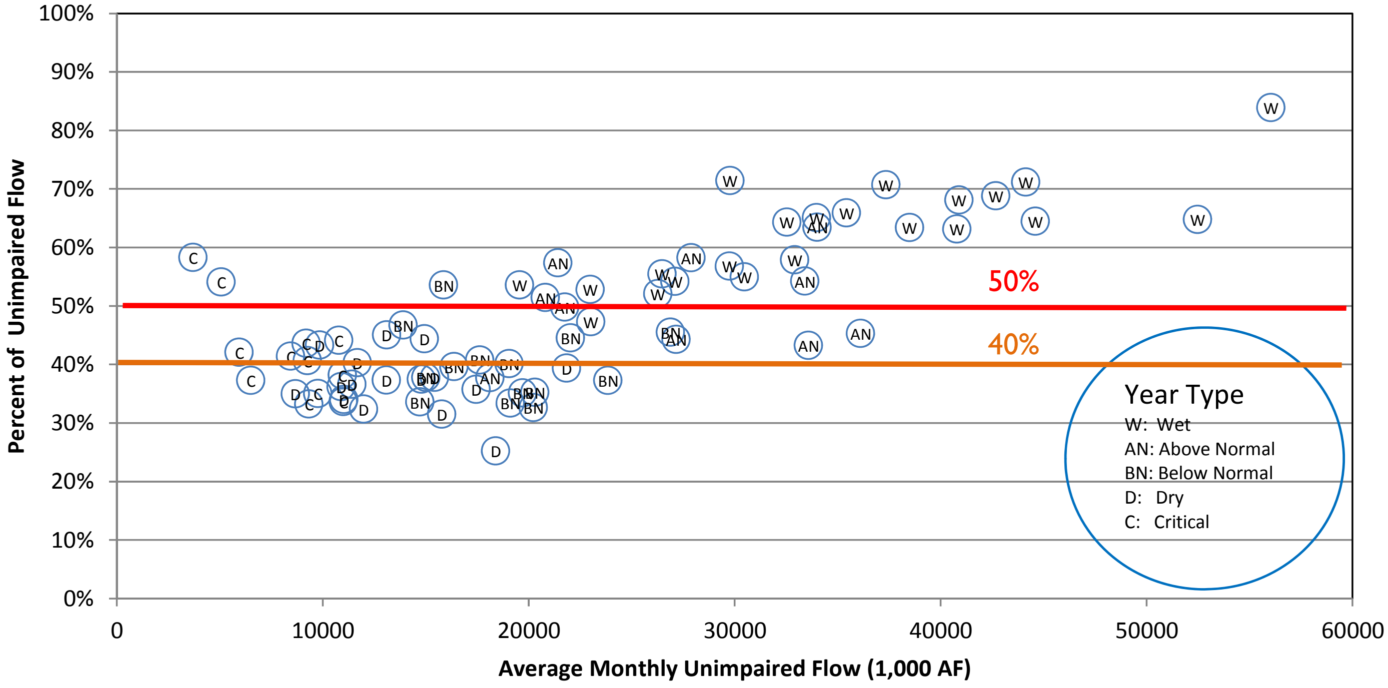


Table 2 - Modeled with CalSim II: Average January through June Delta Outflow as a Percentage of Unimpaired Delta Outflow

Wet	Above Normal	Below Normal	Dry	Critical	All Years
65%	51%	40%	37%	40%	53%

Sacramento River Basin Delta Inflow

Figure 5 is a plot of historical Sacramento River Basin Delta inflows as percentages of unimpaired flows, averaged for the following periods:

- 1930-1943: Pre-Shasta Reservoir
- 1944-1955: Pre-Folsom Reservoir
- 1956-1968: Pre-Oroville Reservoir
- 1969-2003: Post Sacramento Basin Project Reservoirs
- All years: 1930-2003

Although there were hydrologic fluctuations and varying regulatory requirements during the post-1944 period, the January through June averages of Delta inflows as percentages of unimpaired flows into the Delta from the Sacramento River have changed minimally during this almost 70-year period.

During the period from 1969 through 2003, hydrologic conditions varied significantly and regulatory standards became more stringent. The percentage of historical Sacramento River Delta inflows to unimpaired flows for the July through October period have increased through time due to increases in flow and salinity requirements and Delta exports. Figure 6 is a plot showing, for the 1969-2003 period, average January through June historical Sacramento River Basin flows to the Delta as percentage of unimpaired flows for each year. Each data point is labeled with the year type. The average percentages of Sacramento River Delta inflows to unimpaired flows for each water year type are listed in Table 3. In wetter years, Sacramento River inflows tend to be higher percentage of unimpaired outflows, while in drier years these percentage tend to be lower.

Figure 7 contains a chart showing monthly average Sacramento River Basin Delta inflows as percentages of unimpaired flows by water year type for the 1922-2003 period. Based on the CalSim II baseline, the average percentage of Sacramento River Basin Delta inflows to unimpaired flows for the January through June period is 78%; the average of these percentages for critical years is 67%. Although Sacramento River Basin inflows to the Delta are a higher percentage of unimpaired flows (69%) than are Delta outflows (50%), the percentage of Delta outflow to unimpaired flows is applied as a minimum flow requirement for Sacramento River inflows to the Delta for this analysis. This assumption will estimate less adverse effects to the Sacramento River Basin than would occur with a 78% minimum flow requirement.

Figure 5 - Average Historical Sacramento Basin Delta inflow as a Percentage of Unimpaired Sacramento Basin Delta Inflow

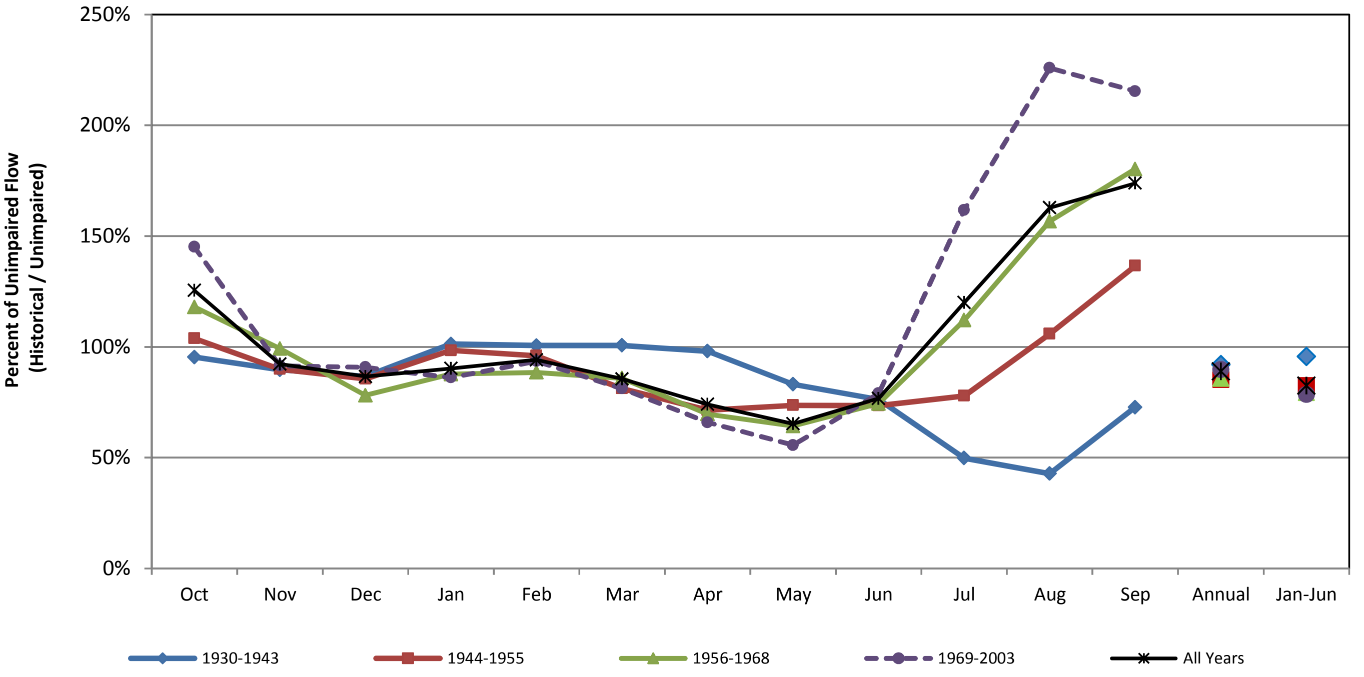


Figure 6 - Historical 1969-2003 Average January through June Sacramento Basin Delta inflow as a Percentage of Unimpaired Sacramento Basin Delta Inflow

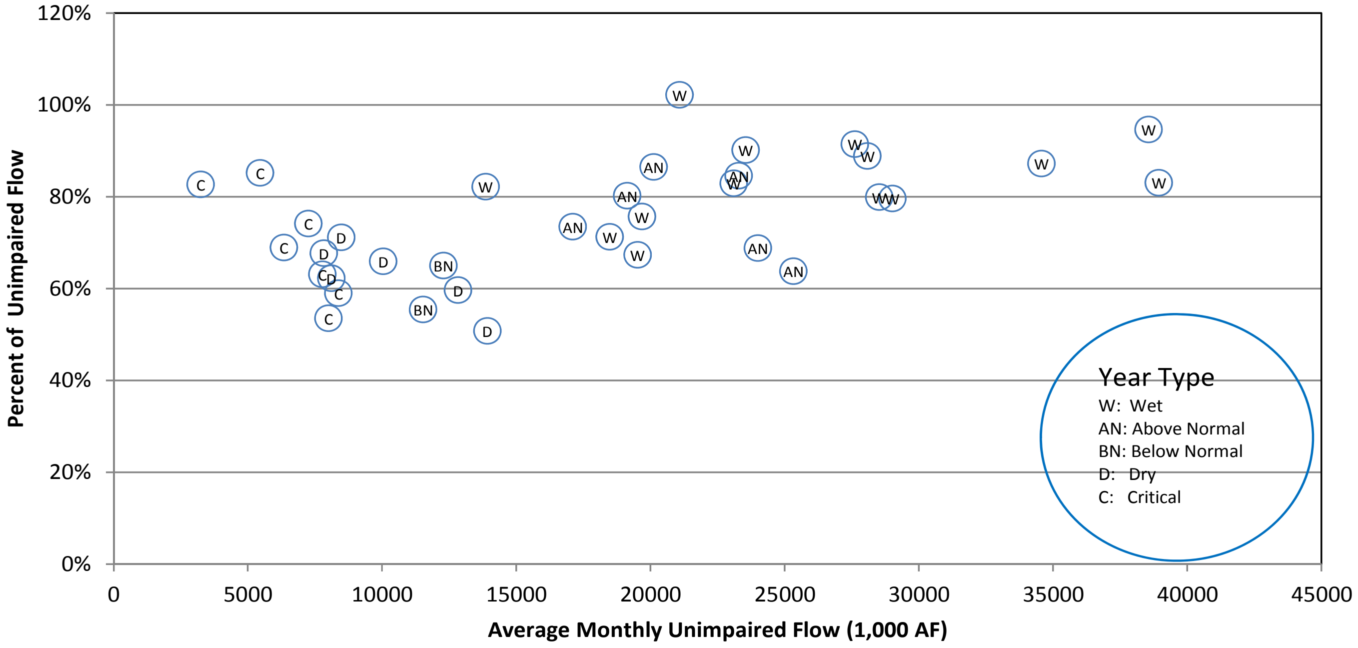


Table 3 - Historical 1969-2003 Average January through June Historical Sacramento Basin Delta Inflow as a Percentage of Unimpaired Sacramento Basin Delta Inflow by SRI Water Year Type

Wet	Above Normal	Below Normal	Dry	Critical	All Years
85%	76%	60%	62%	67%	78%

Figure 7 - Modeled with CalSim II: Average Sacramento Basin Delta Inflow as a Percentage of Unimpaired Sacramento Basin Delta Inflow

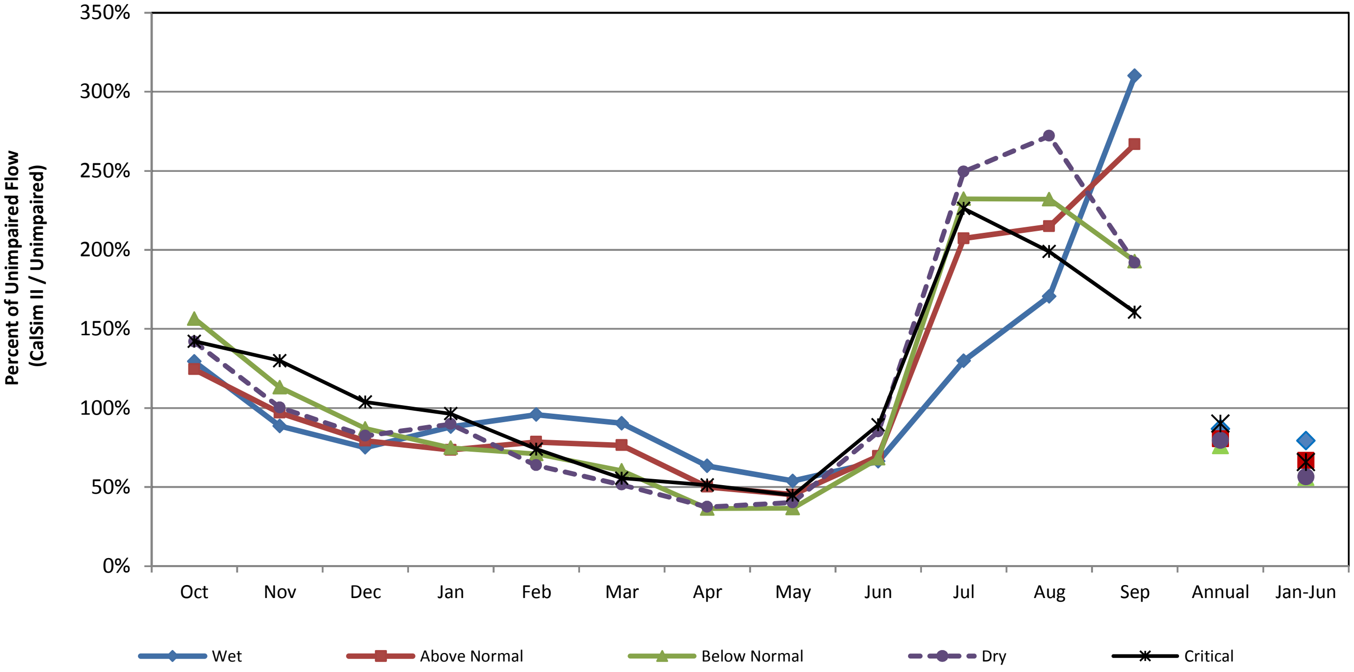


Table 4 - Modeled with CalSim II: Average January through June Sacramento Basin Delta Inflow as a Percentage of Unimpaired Sacramento Basin Delta Inflow

Wet	Above Normal	Below Normal	Dry	Critical	All Years
79%	67%	56%	56%	65%	69%

MODELING ASSUMPTIONS AND LIMITATIONS

The primary analytical tool used for this effort is the latest publically available version of the CalSim II model. The CalSim II model simulation used to support the State Water Project Delivery Reliability Report (SWP DRR) is the best available modeling tool and latest public release of the model. The DRAFT Technical Addendum to SWP DRR 2011, titled January 2012 of the SWP DRR, describes the CalSim II modeling assumptions. For this analysis, CalSim II was used to assess changes in CVP / SWP storage, river flows, water deliveries, and Delta conditions. The SWP DRR may be found at the following web location: http://baydeltaoffice.water.ca.gov/swpreliability/2011DraftDRR012612.pdf.

The Delta outflow requirements based on 50% and 40% of unimpaired flows described above were inputted into the CalSim II Existing Conditions model simulation to develop two new model simulations, which estimate how the system would operate with such Delta outflow requirements. Two CalSim II model simulations were developed to perform this analysis: one with a 50% of unimpaired Delta outflow requirement and a 50% of unimpaired Sacramento River flow requirement from January through June, and the other with a 40% of unimpaired Delta outflow requirement and a 40% of unimpaired Sacramento River flow requirement from January through June. These two model simulations were then compared to Existing Conditions to estimate the changes to the water system that would occur with the new Delta outflow requirements. The applicable Delta outflow requirement for each simulation then was applied as an average monthly net Delta outflow requirement, and the Sacramento River Basin requirement was applied as a minimum requirement for the sum of Sacramento River flow at Freeport plus the Yolo Bypass inflow to the Delta.

The SWRCB's 2010 Delta flow criteria report suggests that its proposed criteria that are stated in percentages of unimpaired flows could be implemented as 14-day running averages. The CalSim II model, however, simulates on a monthly time step and does not provide daily or hourly results and, therefore, simplifies the hydrologic diversity that exists in reality. Accordingly, when using the CalSim II model – which is the best available model -- it is difficult to predict how requirements that are based on a percentage of the unimpaired flows would be implemented or operated on 14-day average basis. Modeling using the CalSim II model probably understates the real impacts of implementing the proposed Delta outflow and Sacramento River flow requirements as percentage of unimpaired flows on a time-step less than one month, as suggested by the proposed Delta flow criteria in the SWRCB's 2010 report.

In addition, the CalSim II model primarily simulates operations of the CVP and SWP Systems. The SWRCB's 2010 Delta flow criteria report suggests that the SWRCB would seek to spread the impacts of implementing the proposed Delta outflow and streamflow requirements over all upstream users, but no integrated model with this capability currently exists. Therefore, the CalSim II model for the SWP/CVP was used for this analysis as a surrogate for the kinds of impacts that may be observed if Delta outflow and Sacramento River flow requirements based on percentage of unimpaired flows were implemented as minimum outflow and flow requirements.

The water supply impacts that would result from 50% and 40% of unimpaired flow requirements for Delta outflow and Sacramento River flow would be extreme and would go far beyond what CalSim II is designed to evaluate. If these requirements were implemented, then SWP and CVP reservoirs would be at the "dead pool" levels by the end of summer in many years, CVP and SWP settlement contracts would be violated due to the lack of adequate water supplies, and existing temperature and water quality standards could not be met much of the time due to exhaustion of water supplies in the reservoirs. None of these events are consistent with how the CVP and SWP actually would be operated. For this reason, to more accurately model the effects of such requirements, a new in-basin depletion analysis would need to be constructed, and this analysis necessarily would have to simulate the additional reductions in water supplies that would result from implementation of such requirements. The CalSim II modeling described in this evaluation was used to evaluate the order of magnitude of water system impacts. However, because of these limitations in the CalSim II model, the results discussed in this evaluation are underestimates of the impacts that actually would occur from implementing these Delta outflow and Sacramento River flow requirements.

OBSERVATIONS

When a 50% of unimpaired Delta outflow requirement and a 50% of unimpaired Sacramento River Basin inflow to the Delta requirement from January through June are imposed on the Existing Conditions scenario, the average annual Delta outflow increases by 1,057,000 AF. The model results show that the 50% of unimpaired flow requirement for Sacramento River inflows to the Delta normally would not govern CVP/SWP operations because the more onerous Delta outflow requirement would control in all but 3 monthly time steps in the 82-year simulation. The model results indicate that, to meet a Delta outflow requirement based on 50% of unimpaired flows, Sacramento River Basin inflows to the Delta would increase by an average of 331,000 AF annually, Delta exports would decrease annually by 703,000 AF, and other Delta diversions (including the North Bay Aqueduct) would decrease by 23,000 AF annually. The CalSim II modeling estimated that the increased Sacramento River Basin inflows to the Delta of 331,000 AF would require increased imports from the Trinity River Basin of 91,000 AF, increased Sacramento River Basin groundwater pumping of an annual average of 248,000 AF, and other average annual changes of 8,000 AF. Figure 8 shows these estimated average annual flow changes by water year type.

When a 40% of unimpaired Delta outflow requirement and a 40% of unimpaired Sacramento River Basin to Delta flow requirement from January through June are imposed on the Existing Conditions scenario, the average annual Delta outflow increases by 484,000 AF. The model results show that the 40% of unimpaired flow requirement for Sacramento River inflows to the Delta normally would not govern CVP/SWP operations because the more onerous Delta outflow requirement would control in all months of the simulation. The model results indicate that, o meet a Delta outflow requirement based on 40% of unimpaired flows, Sacramento River Basin inflows to the Delta would increase an average of 136,000 AF annually, Delta exports would decrease annually by 333,000 AF, and other Delta diversions (including the North Bay Aqueduct) would decrease by 15,000 AF annually. The CalSim II modeling estimated that the increased Sacramento River Basin inflows to the Delta of 136,000 AF would require increased imports from the Trinity River Basin by 32,000 AF, increased Sacramento River Basin groundwater pumping of an annual average of 99,000 AF, and other changes of 7,000 AF. Figure 9 shows these estimated average annual flow changes by water year type.

Imports from the Trinity River Basin

The requirements of 50% and 40% of unimpaired flows are outside the operational parameters that CalSim II was designed to model. The CalSim II logic that balances Trinity and Shasta Reservoir storage amounts properly for Existing Conditions therefore may not be suitable for modeling the operations that would be necessary to satisfy these outflow and flow requirements. In particular, desired increases in releases from Trinity Reservoir to the Trinity River may be inconsistent with the CalSim II modeled operations that would be triggered by these requirements based on 50% and 40% of unimpaired flows. Additional modeling logic that isolates Trinity operations from the Sacramento River Basin operations therefore may need to be developed. Because imports from the Trinity River Basin actually might not increase as much as is indicated by the CalSim II modeling done for this evaluation, the model results described in this report probably underestimate the impacts within the Sacramento River Basin that actually would occur with implementation of these requirements.

Figure 8 - Annual Average Changes in Flow by Water Year Type
50% Unimpaired Flow Requirement

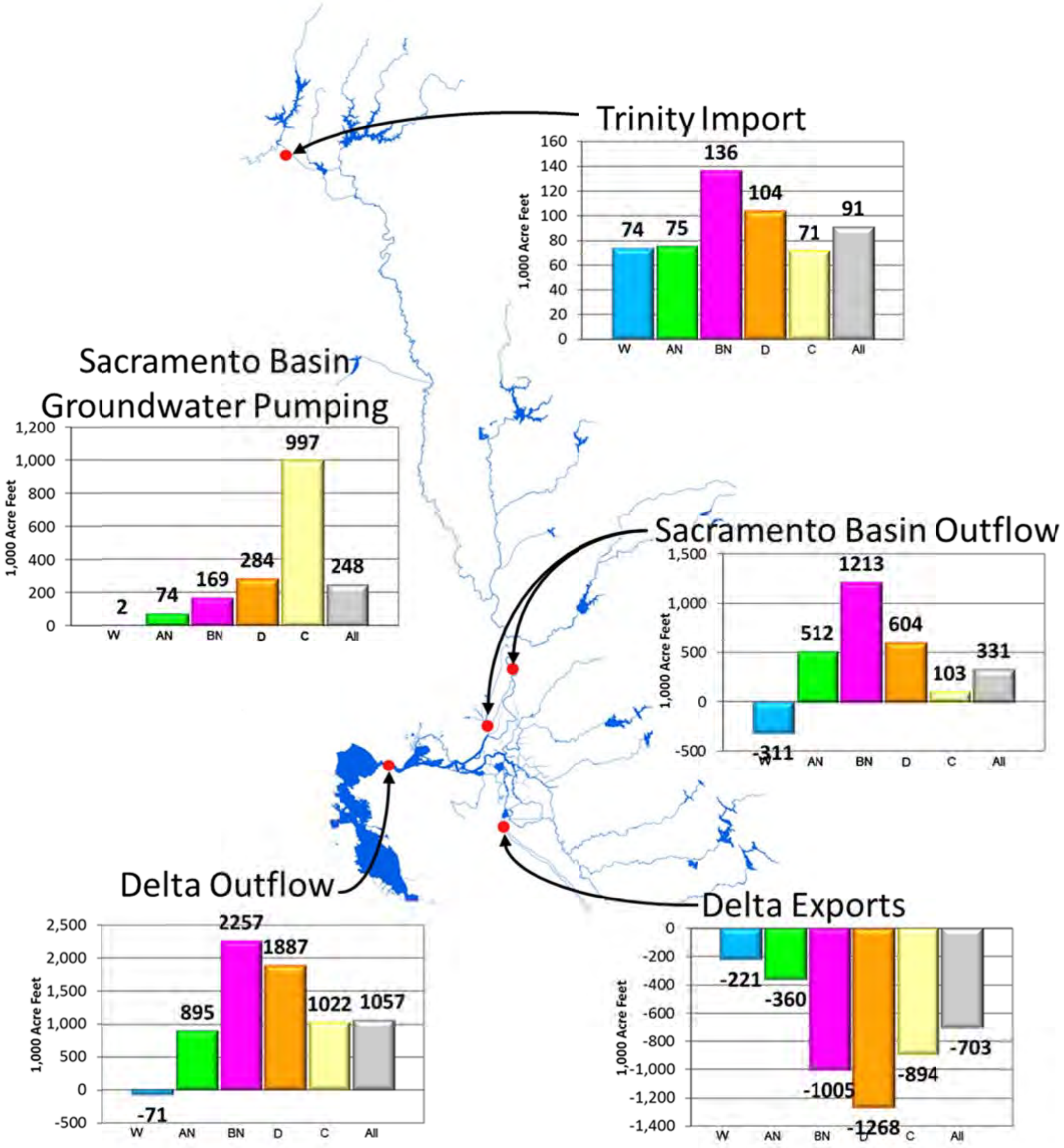
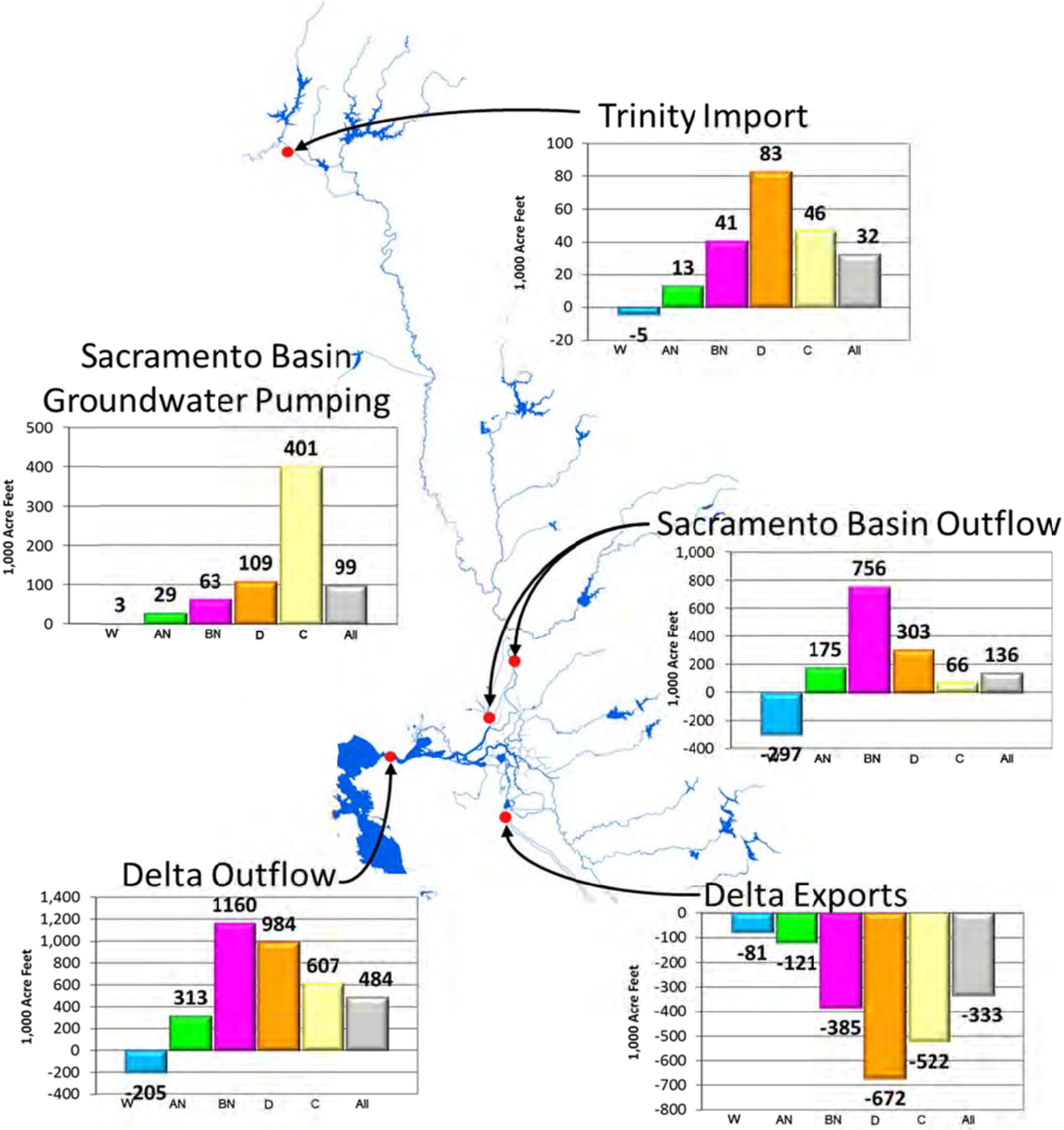


Figure 9 - Annual Average Changes in Flow by Water Year Type
40% Unimpaired Flow Requirement



Groundwater and land fallowing

As noted above, water supply impacts of the requirements that are 50% and 40% of unimpaired flows would exceed what the existing CalSim II model can readily assess. For example, when a CalSim II modeling scenario does not have enough water to meet in-basin demands, the model simply assumes that groundwater in the Sacramento Valley will be pumped to make up the shortage. However, the groundwater pumping that would be necessary to make up for the water supply losses to water users in the Sacramento River Basin with implementation of requirements that are 50% and 40% of unimpaired flows would not be physically possible or sustainable. Figures 10 and 11 show the added groundwater pumping that would be needed to meet in-basin demands that would be necessary to make up for the losses in surface water supplies that would occur with implementation of these requirements.

Although the CalSim II modeling for these requirements assumes that groundwater pumping would increase as necessary to make up for all losses in surface-water supplies in the Sacramento River Basin, in reality this would not be possible, so, in reality, there probably would be reductions in total crop acreage and wildlife refuge water supplies. Also, any increases in actual groundwater pumping probably would result in lower groundwater levels and increases in groundwater recharge (similar in magnitude to the increases in pumping). These increases in recharge would result in decreases in stream flows, which would cause additional needs for groundwater pumping, reservoir releases, and crop fallowing. Decreases in groundwater levels also probably would cause adverse impacts to major surface water systems and ephemeral stream habitat (by inducing greater recharge through streambeds) and to urban wells. There are a large number of factors affecting the interrelationships between groundwater levels and pumping, stream-groundwater interactions, deep percolation of applied water, percolation of precipitation, and natural recharge, all of which make it difficult to speculate how much additional pumping, recharge, and fallowing would occur if these requirements were implemented.

Figure 10 – Required Groundwater Pumping Due to 50% Unimpaired Flow Requirement

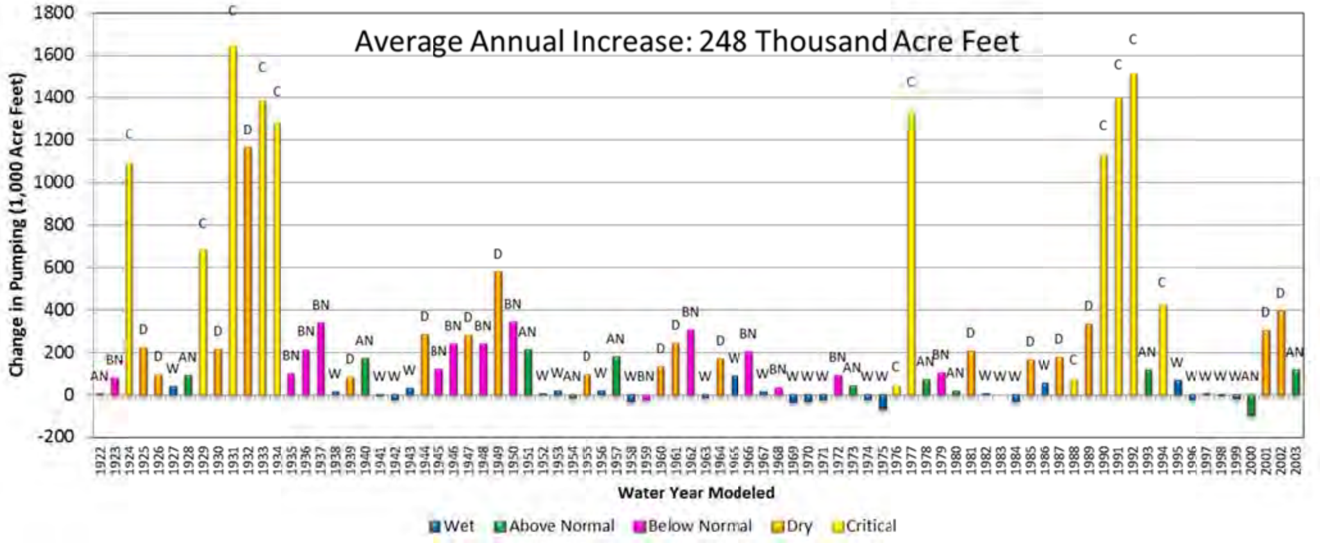
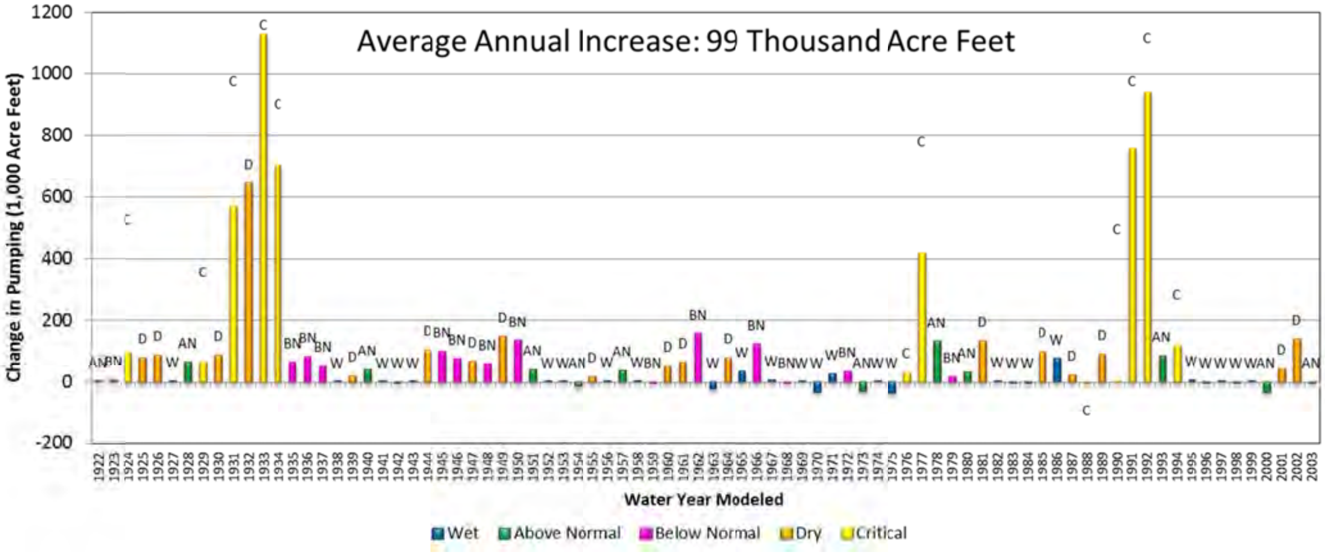


Figure 11 – Required Groundwater Pumping Due to 40% Unimpaired Flow Requirement



Project Reservoir Storage

Figure 12 and Figure 13 show the expected CVP and SWP reservoir levels that would occur at the end of September with implementation of requirements of 50% and 40% of unimpaired flows. The 50% of unimpaired flow requirements would cause Trinity, Shasta and Folsom Reservoirs to be at the dead pools (effectively empty) by the end of September in 20% of all years, and Oroville Reservoir to be at its minimum pool in 40% of all years. In contrast, under current operating rules, such dead pool levels would occur only rarely. With implementation of the 50% of unimpaired flow requirements, average carryover storage reductions for the major project reservoirs would be :

- Trinity Reservoir: - 460,000 AF
- Shasta Reservoir: - 960,000 AF
- Oroville Reservoir: - 620,000 AF
- Folsom Reservoir: - 150,000 AF

The total reduction in upstream carryover project storage that would be caused by implementing a 50% of unimpaired flow requirement would be about 2.2 million AF, and the carryover reduction would be even greater in drier years. These reductions in carryover storage, coupled with substantially increased groundwater pumping, would result in water supply deficits in the Sacramento Valley that would be greater than 2 million AF in below normal, dry, and critical years. Under these conditions, the CVP and SWP reservoir storage levels required by in the National Marine Fisheries Services' 2009 salmon Biological Opinion (BO) could not be maintained. In addition, the cold-water pools in these reservoirs that are necessary to meet temperature conditions downstream for salmon survival and reproduction would be completely depleted in 20% of years, and would be greatly reduced in other years. These depletions and reductions would make it virtually impossible for CVP and SWP operations to achieve acceptable temperature requirements in the rivers downstream of these reservoirs. With implementation of these requirements, maintaining acceptable storage levels in these reservoirs throughout summer months may not be possible, even with severe reductions in agricultural diversions. Reducing reservoir releases by 2 million AF from July through September would result in violations of applicable instream flow requirements and would make it difficult or impossible to meet applicable instream temperature requirements.

Implementation of the 40% of unimpaired flow requirements would result in Trinity, Shasta, Folsom Reservoirs being at their dead pools (effectively empty) by the end of September in roughly 10% of all years, and in Oroville Reservoir being at its minimum pool in 30% of all years. With implementation of the 40% of unimpaired flow requirements, average carryover storage reductions for the major project reservoirs would be:

- Trinity Reservoir: - 200,000 AF
- Shasta Reservoir: - 423,000 AF
- Oroville Reservoir: - 390,000 AF
- Folsom Reservoir: - 79,000 AF

The total reduction in upstream carryover project storage that would occur with implementation of the 40% of unimpaired flow requirement would be about 1.1 million AF. Although such reservoir deficits would be about half of the reservoir deficits that would occur with implement of the 50% of unimpaired flow requirement, there still would be similar types of impacts. Reducing upstream reservoir releases by 1 million AF from July through September would result in violations to the applicable instream flow requirements and would make it difficult or impossible to meet the applicable instream temperature requirements.

This extensive loss of carryover reservoir storage would have significant impacts to hydropower, recreation, lake fisheries, and downstream fisheries. During multiyear droughts, project reservoirs would be at minimum or dead pool levels throughout the drought period, which would lead to adverse conditions for fisheries in many consecutive years. Figures 14 through 17 show monthly storage in Trinity, Shasta, Oroville, and Folsom Reservoirs respectively for the 1922-2003 CalSim II simulation period for Existing Conditions and the 50% and 40% of unimpaired flow requirements. By comparing Existing Conditions storage to the 50% and 40% of unimpaired flow storage prolonged reductions in storage due to unimpaired flow requirements are noticeable, particularly in dryer conditions. These prolonged reductions in storage would result in adverse conditions that could persist for several years.

Figure 12 - Project Reservoir Carryover Storage

50% Unimpaired Flow Requirement

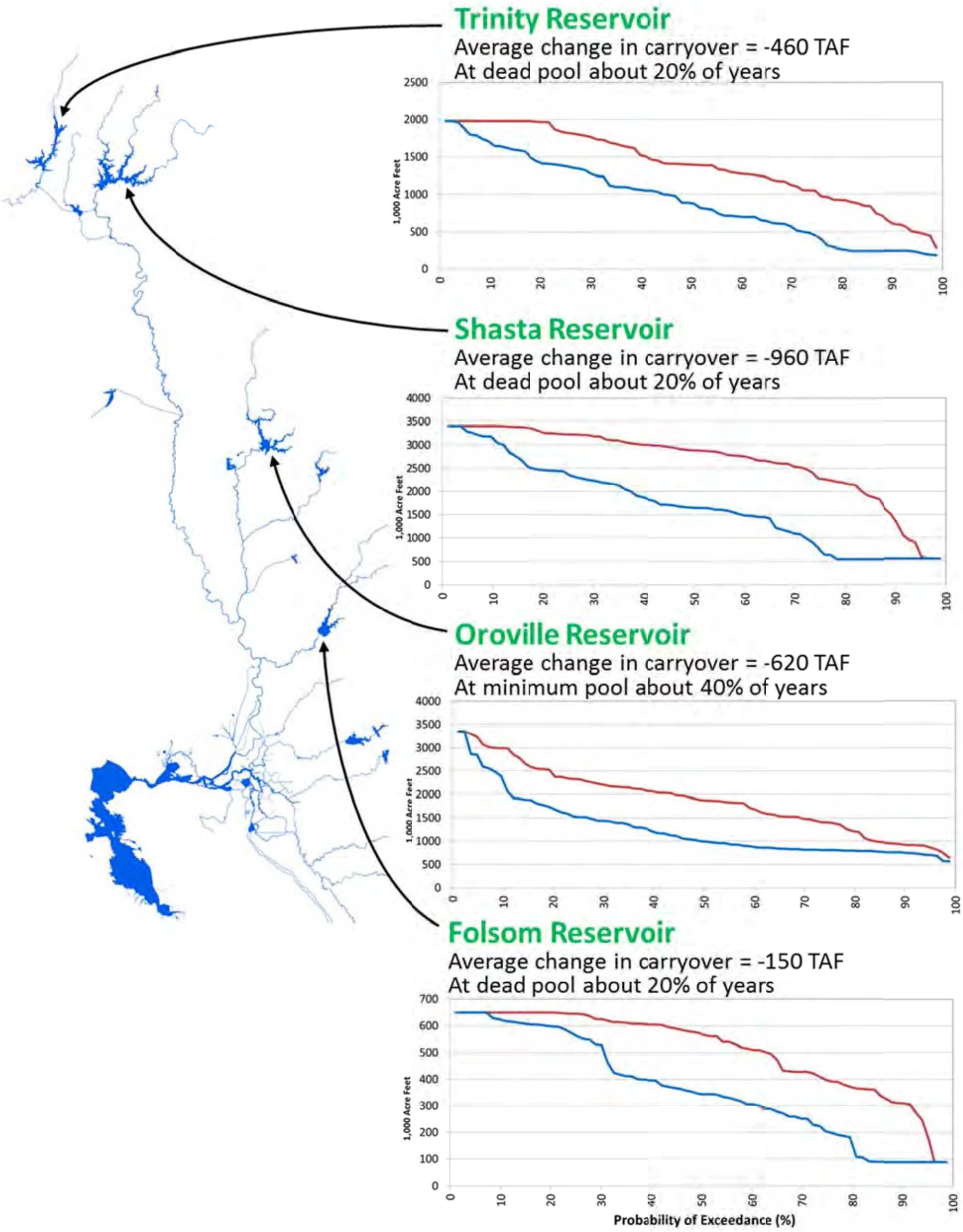
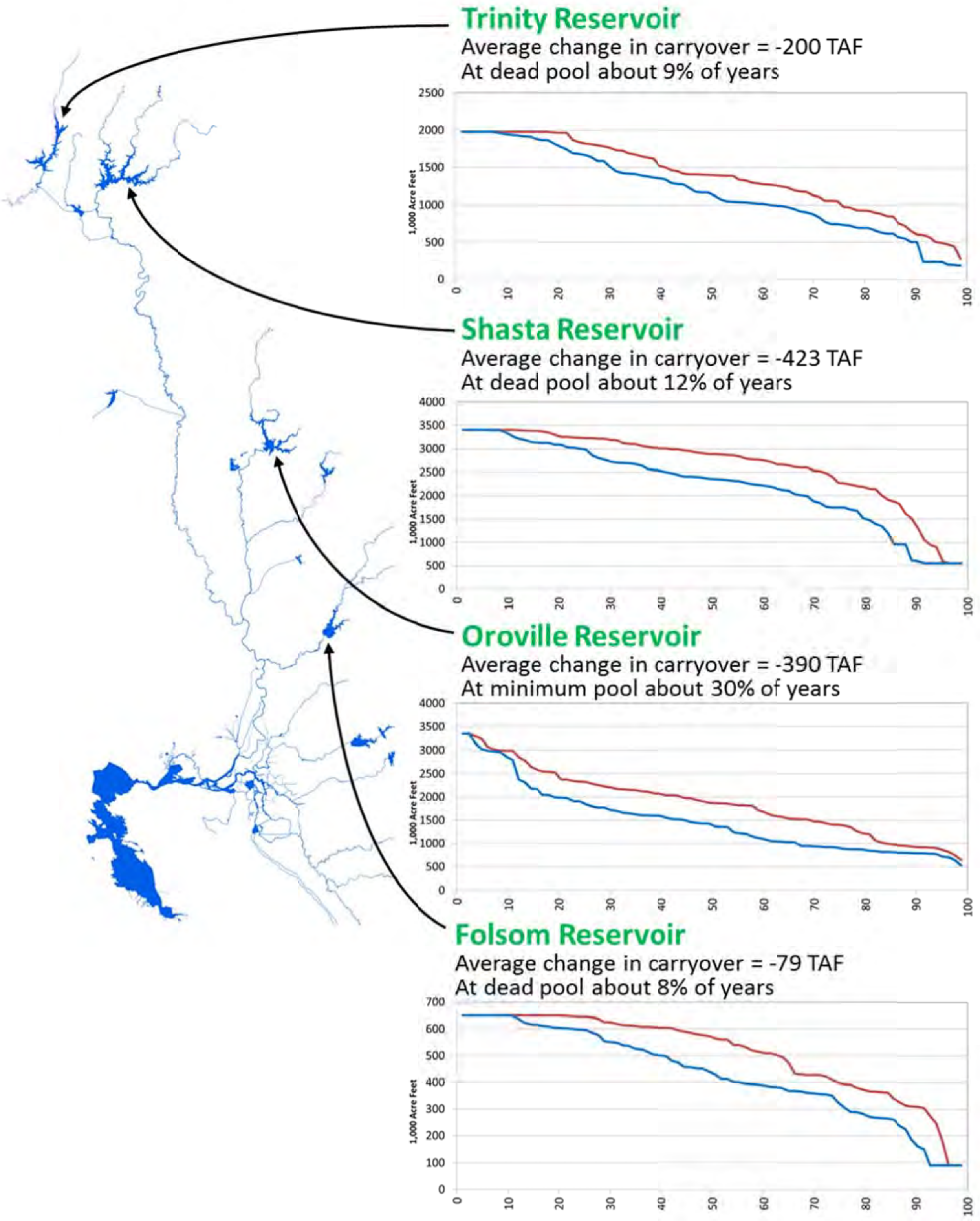


Figure 13 - Project Reservoir Carryover Storage
40% Unimpaired Flow Requirement



Trinity Reservoir
Average change in carryover = -200 TAF
At dead pool about 9% of years

Shasta Reservoir
Average change in carryover = -423 TAF
At dead pool about 12% of years

Oroville Reservoir
Average change in carryover = -390 TAF
At minimum pool about 30% of years

Folsom Reservoir
Average change in carryover = -79 TAF
At dead pool about 8% of years

Figure 14 - Monthly Trinity Reservoir Storage
50% and 40% Unimpaired Flow Requirement

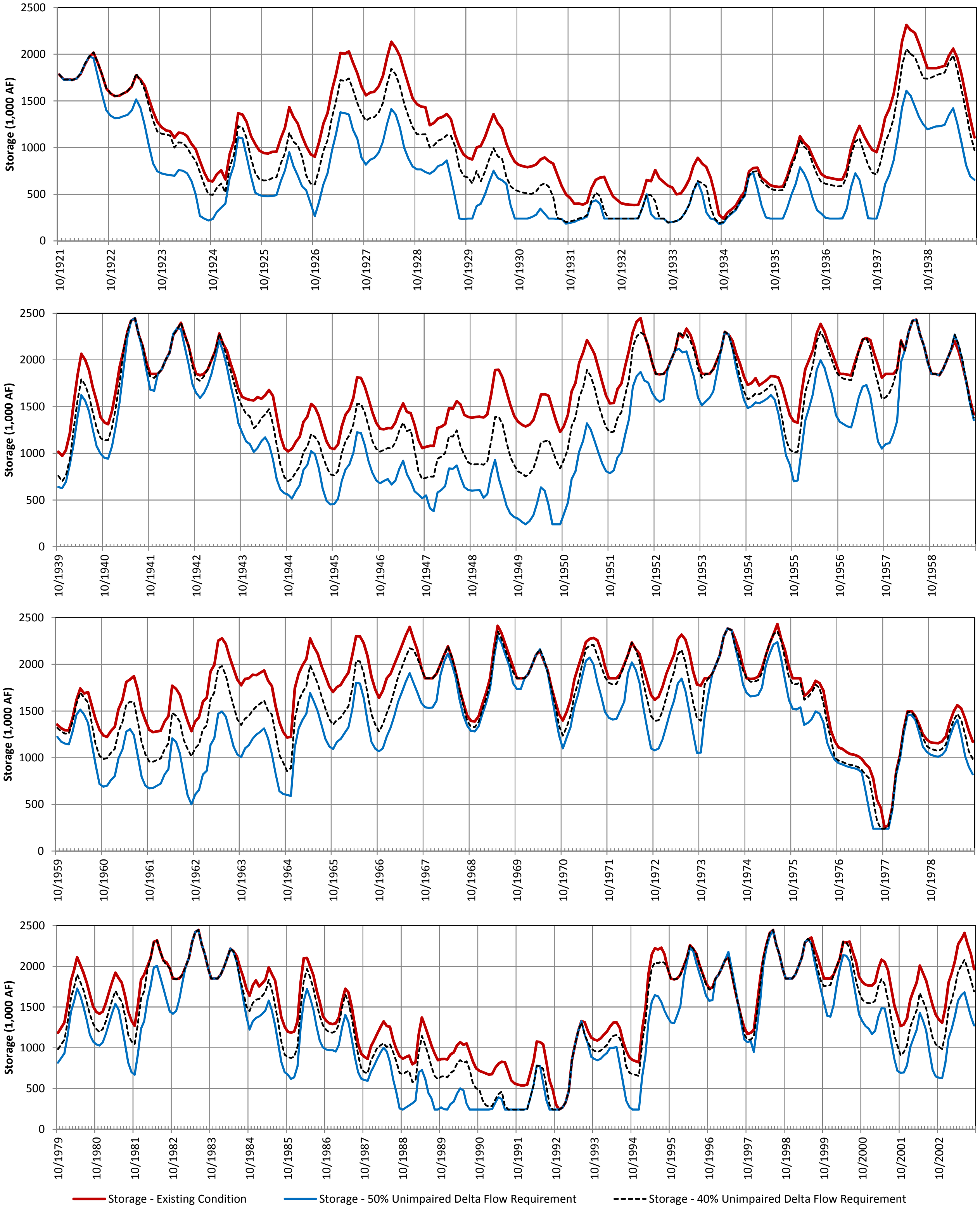


Figure 15 - Monthly Shasta Reservoir Storage
50% and 40% Unimpaired Flow Requirement

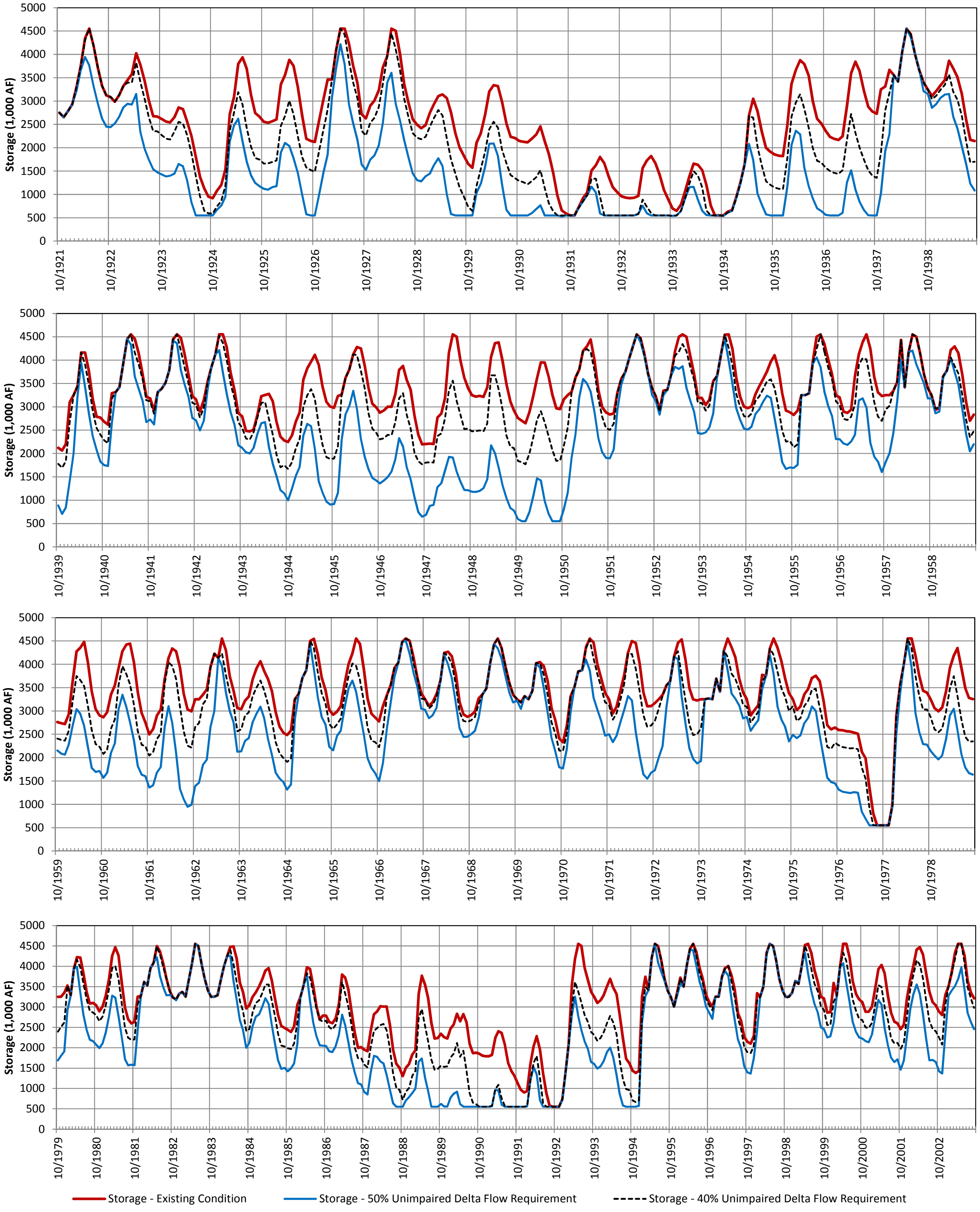


Figure 16 - Monthly Oroville Reservoir Storage
50% and 40% Unimpaired Flow Requirement

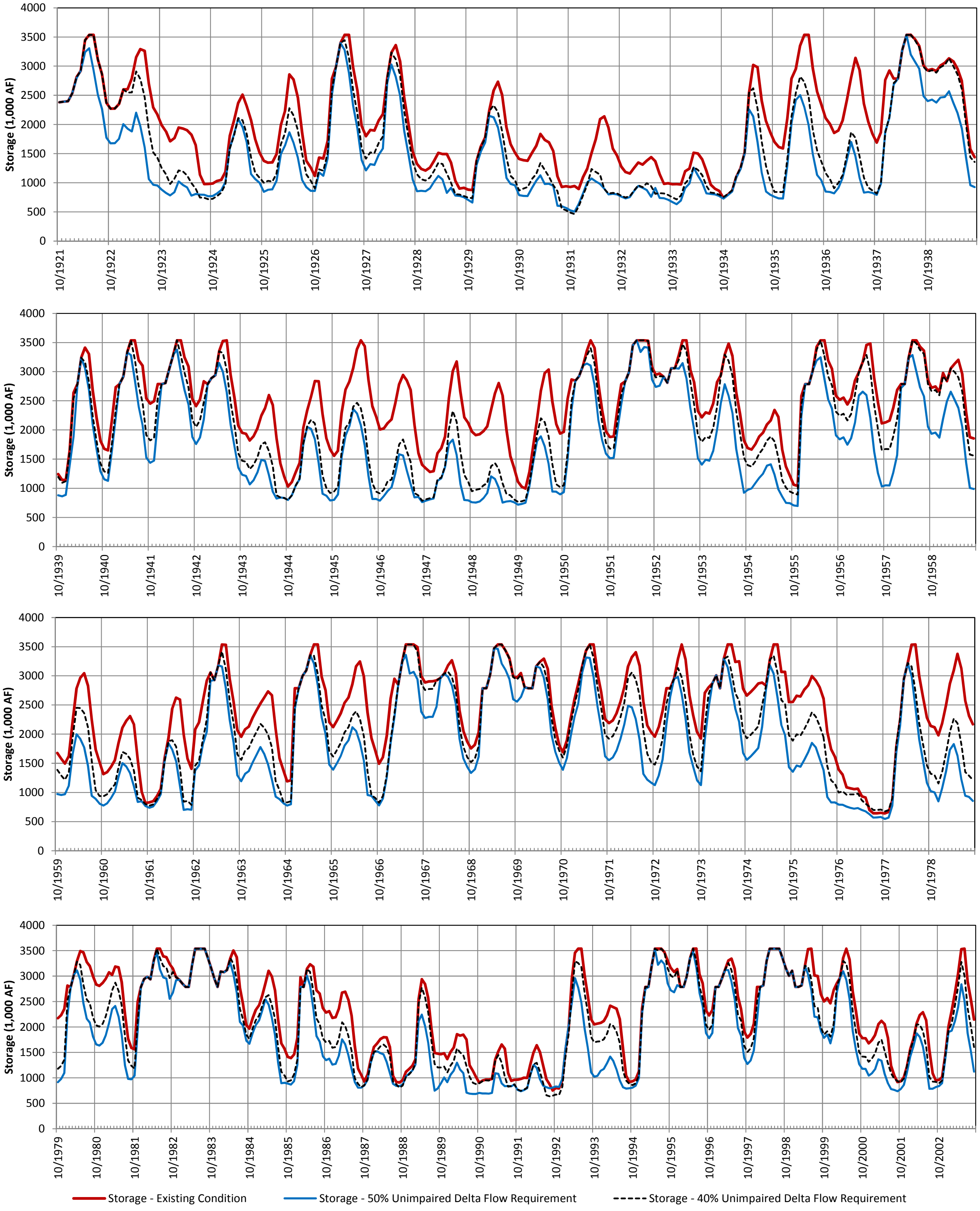
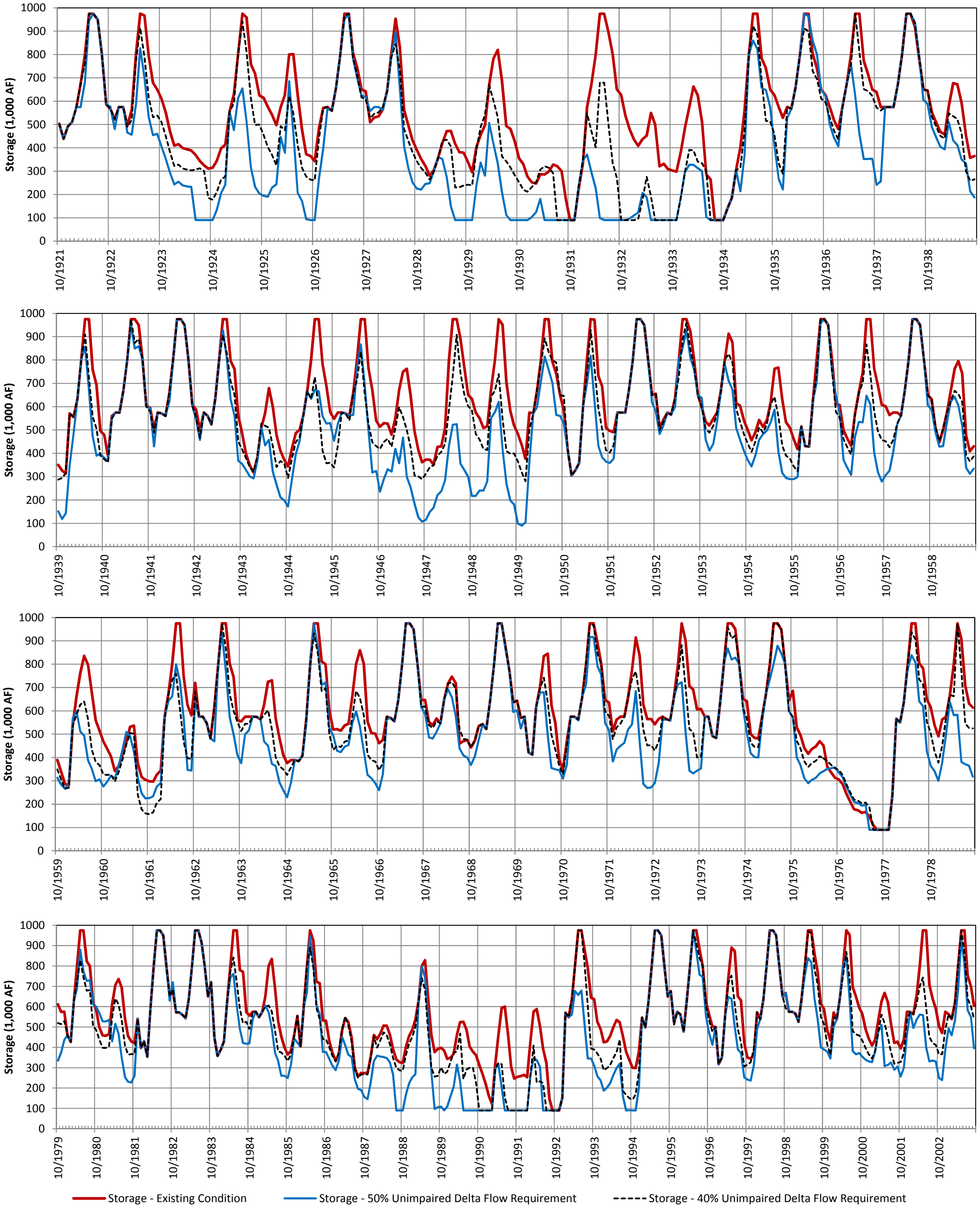


Figure 17 - Monthly Folsom Reservoir Storage
50% and 40% Unimpaired Flow Requirement



Changes in Flow Patterns

Figure 18 and Figure 19 provide summaries of the kinds of changes in the monthly flow patterns that would occur in rivers below the major CVP and SWP reservoirs with implementation of the 50% and 40% of unimpaired flow requirements. These river flows would typically be higher in the months of March, April, and May, and in some Junes, but would be lower in the other months, especially the summer months. Also, as mentioned in the above discussion of impacts to project reservoirs, the changes in river flow patterns that are estimated by CalSim II are underestimates of the impacts that actually would occur. Moreover, reductions in summer river flows would be much greater if reservoir releases were decreased further, to meet reservoir carryover requirements in order to maintain cold-water pools.

These decreased flows, and the resulting increased residence times, would cause the warmer water released into rivers to increase in temperature during the summer, when air temperatures are high. Effects below Oroville and Folsom Reservoirs would be equally dramatic.

These changes in flow patterns would impact hydropower generation as well. There would be increases in generation during spring months when hydropower is already abundant, and there would be decreases in generation during summer months when the State’s power demand is greatest.

Figure 18 - Changes in Key River Flow
50% Unimpaired Flow Requirement

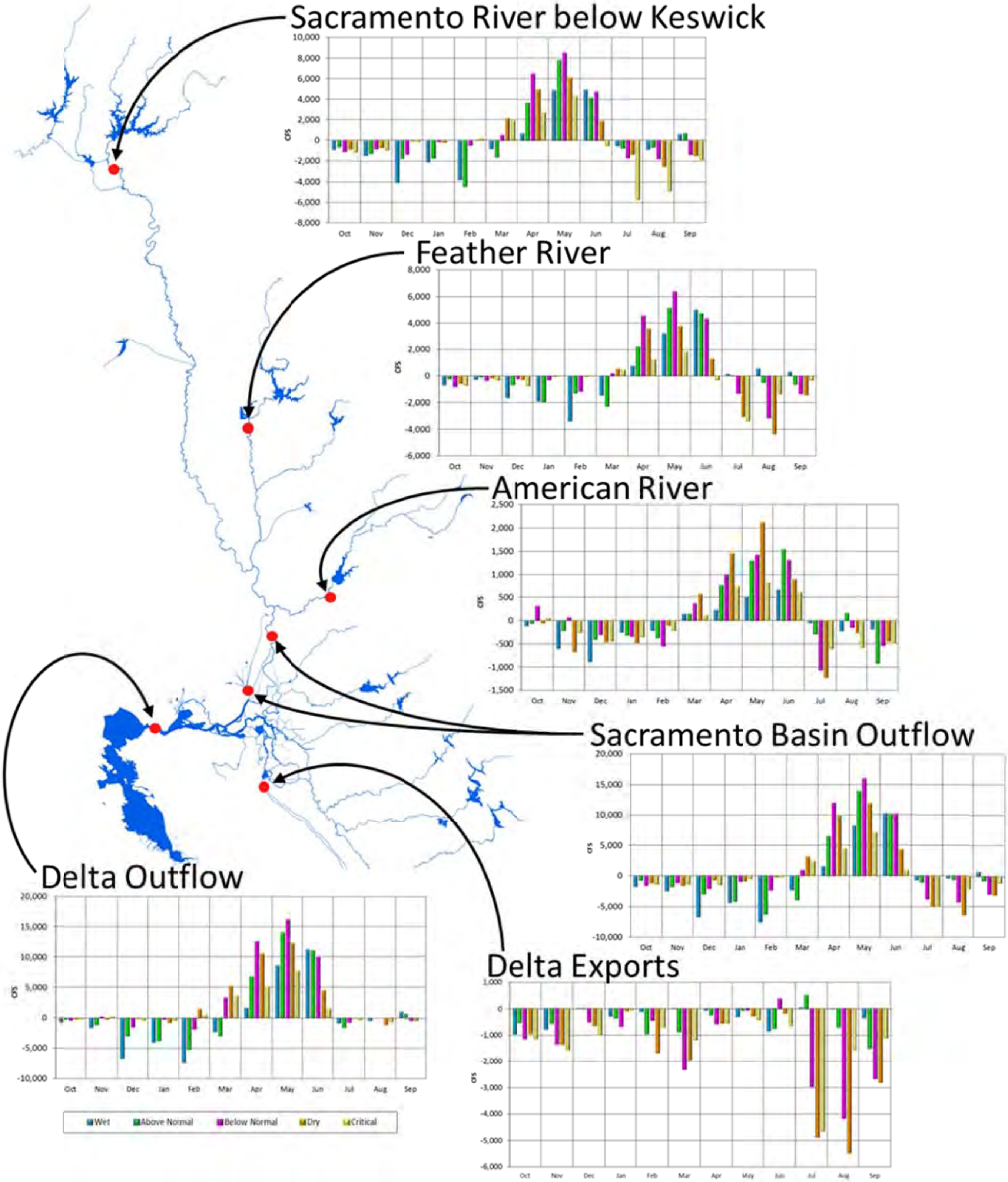
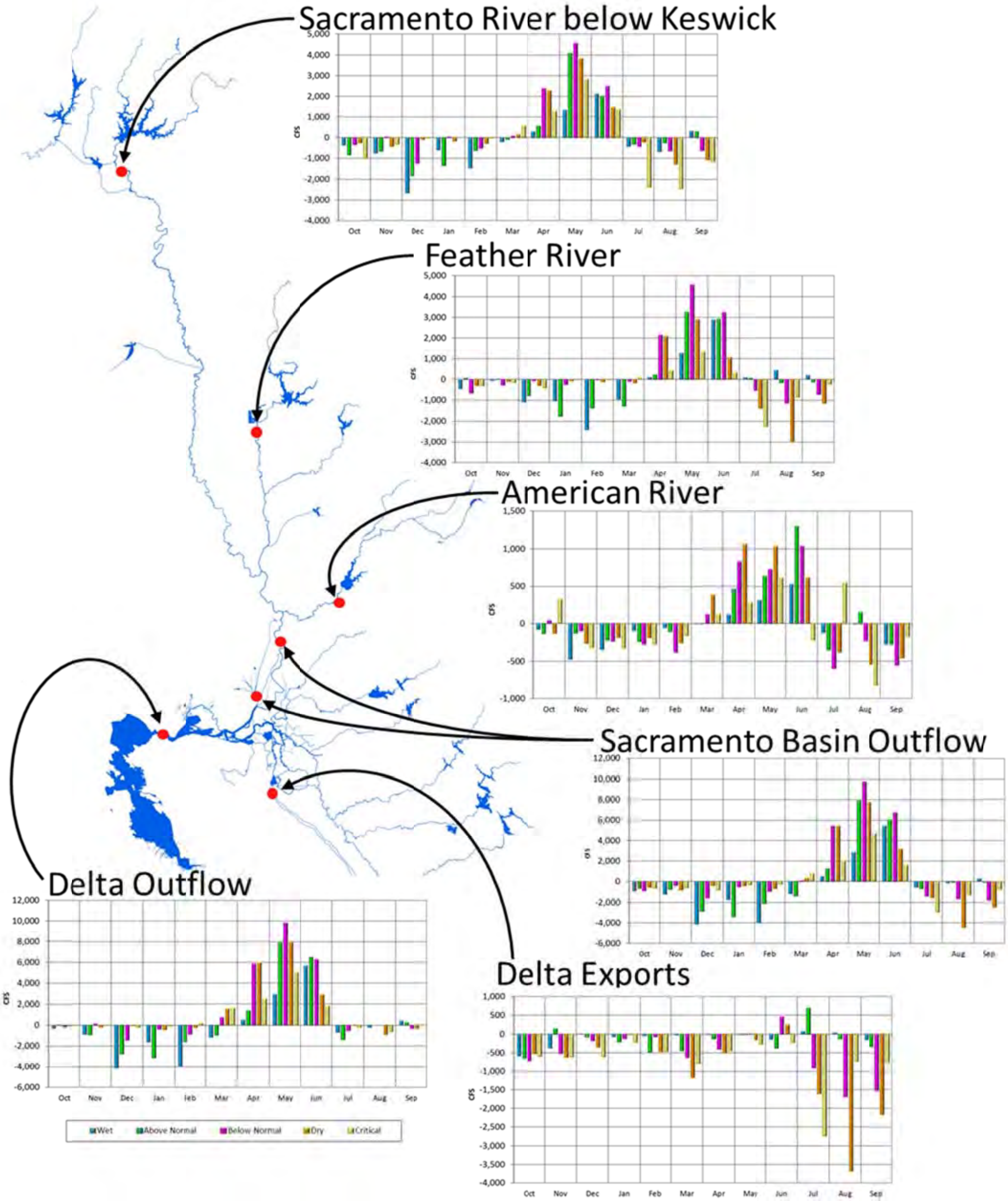


Figure 19 - Changes in Key River Flow
40% Unimpaired Flow Requirement



Violations of Existing Instream flow, Bay-Delta Plan, and ESA Biological Opinion Requirements

The increases in Delta outflows and Sacramento River flows that would occur during the January through June period with implementation of the 50% or 40% of unimpaired flow requirements would result in reduced river flows and Delta outflows in the July through December period. When the CalSim II model is run with these January through June percentage of unimpaired flow requirements, the model assumes that water would be released to satisfy the requirement during a specific month, even if the model then indicates that the reservoir would run out of water in the following month. For the 50% and 40% unimpaired requirement model runs, the model indicates that the CVP and SWP reservoirs would run out of water in about 20% of years. This situation would results in the inability of the CVP and SWP to comply with existing SWRCB requirements. In addition to the inability to comply with SWRCB requirements, there would be an inability to satisfy the requirements specified in the National Marine Fisheries Services' 2009 salmon biological opinion.

Figures 20 and 21 contain charts showing the monthly violations of SWRCB D-1641 requirements for the Sacramento River at Rio Vista that would occur under the 50% and 40% of unimpaired flow CalSim II model runs. In both unimpaired flow scenarios these violations would be larger than 1,000 cfs and typically would occur in drier years. There also would be a potential that D-1641 Delta water quality standards would be violated; however, this issue has not yet been analyzed.

Figure 20 - Violations in D-1641 Flow Requirement at Rio Vista – 50% Unimpaired Flow Requirement

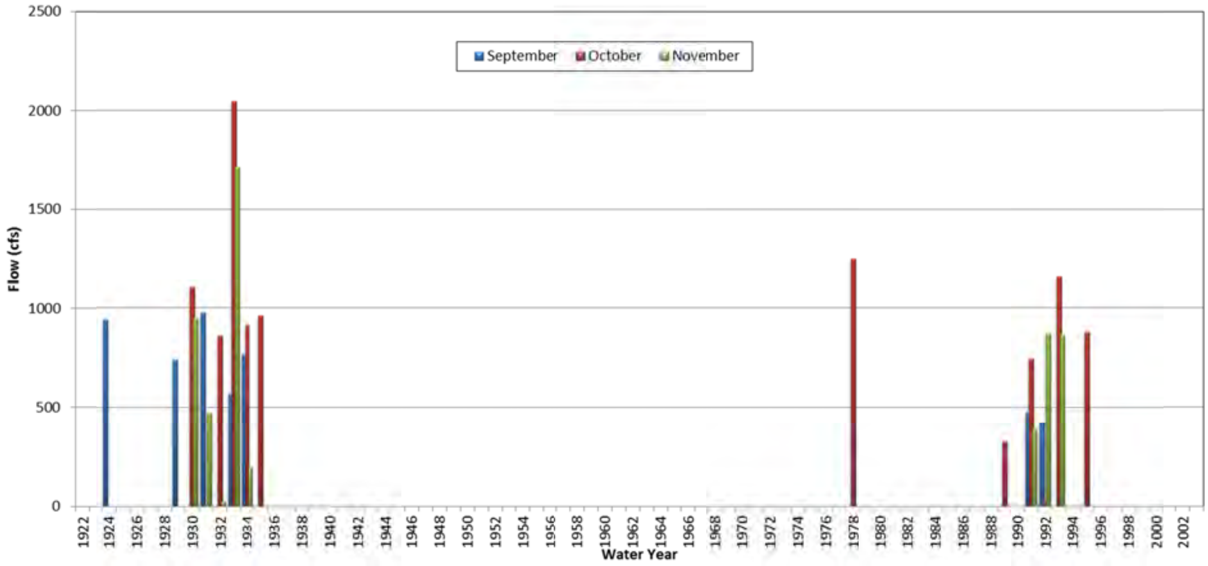
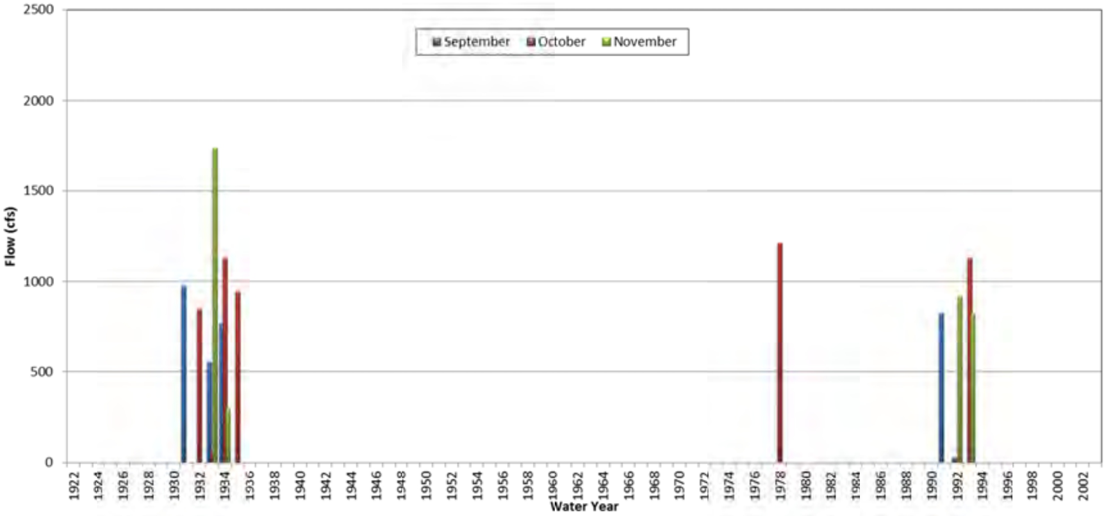


Figure 21 - Violations in D-1641 Flow Requirement at Rio Vista – 40% Unimpaired Flow Requirement



Figures 22 and 23 contain charts showing the monthly violations in Delta outflow requirements that would occur under the 50% and 40% of unimpaired flow CalSim II model runs. Delta outflow requirements include those contained in D-1641, the Delta smelt Biological Opinion, and the unimpaired flow requirement. In many years of the CalSim II model simulations there is not enough water to satisfy both the unimpaired flow requirement and existing Delta outflow requirements.

Figure 22 - Shortage in Minimum Required Delta Outflow– 50% Unimpaired Flow Requirement

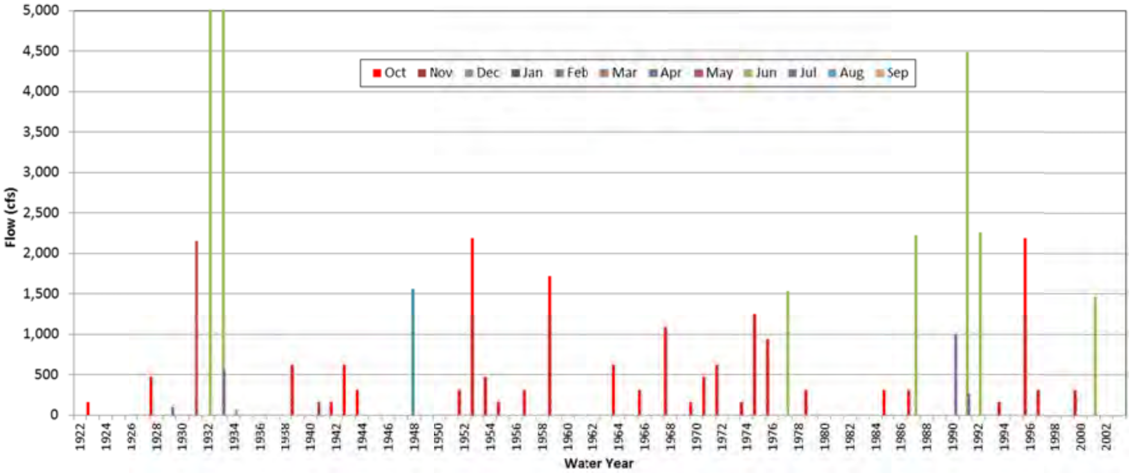
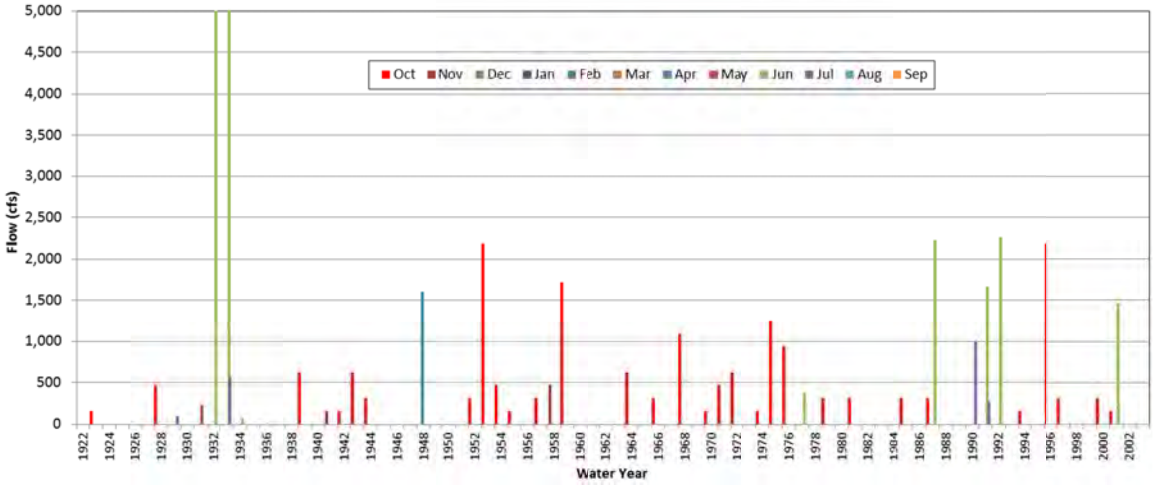


Figure 23 - Shortage in Minimum Required Delta Outflow– 40% Unimpaired Flow Requirement



The CalSim II model assumes that flows in the Sacramento River below Keswick Dam would be reduced when Shasta Reservoir reaches dead pool. The simulation modeling the 50% and 40% of unimpaired flow requirements, indicate that, with implementation of these requirements, Sacramento River flow below Keswick Dam would drop below the minimum flow requirement of 3,250 cfs. Figures 24 and 25 contain monthly exceedance plots of the Sacramento River flows below Keswick Dam that would occur under the 50% and 40% unimpaired flow scenarios. These figures indicate that violations would occur from July through November in the 50% of unimpaired flow scenario and from August through November in the 40% of unimpaired flow scenario. If the 50% or 40% of unimpaired flow requirement model runs were adjusted to maintain required carryover reservoir storage levels, then there would need to be additional dry year reduction of about 2 million AF in the 50% scenario and 1 million AF in the 40% scenario in reservoir releases from July through September; these reductions would require Keswick releases to be reduced from July through September to levels below the applicable flow standards.

Figure 24 – Monthly Exceedance plots of Sacramento River Flow below Keswick
50% Unimpaired Flow Requirement

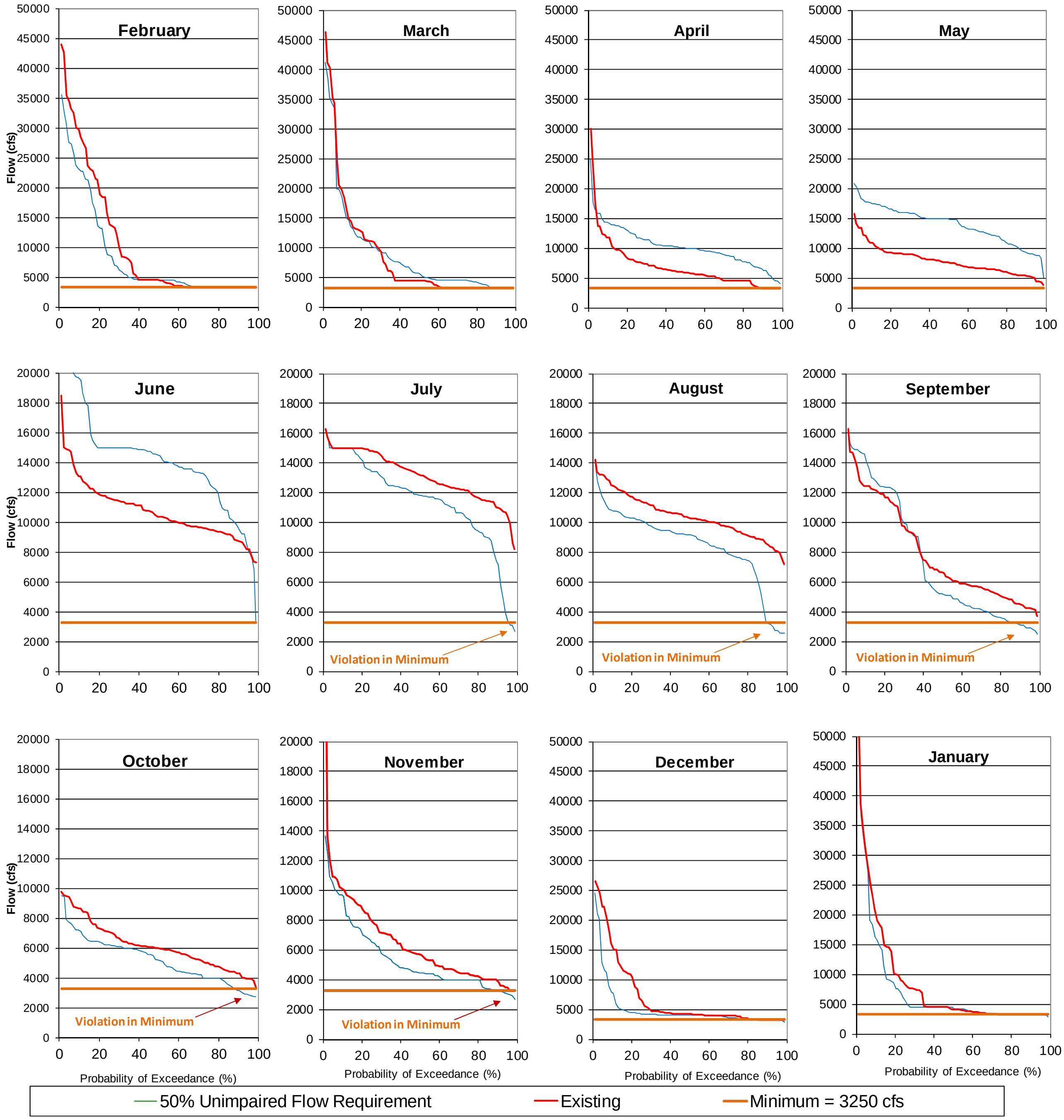
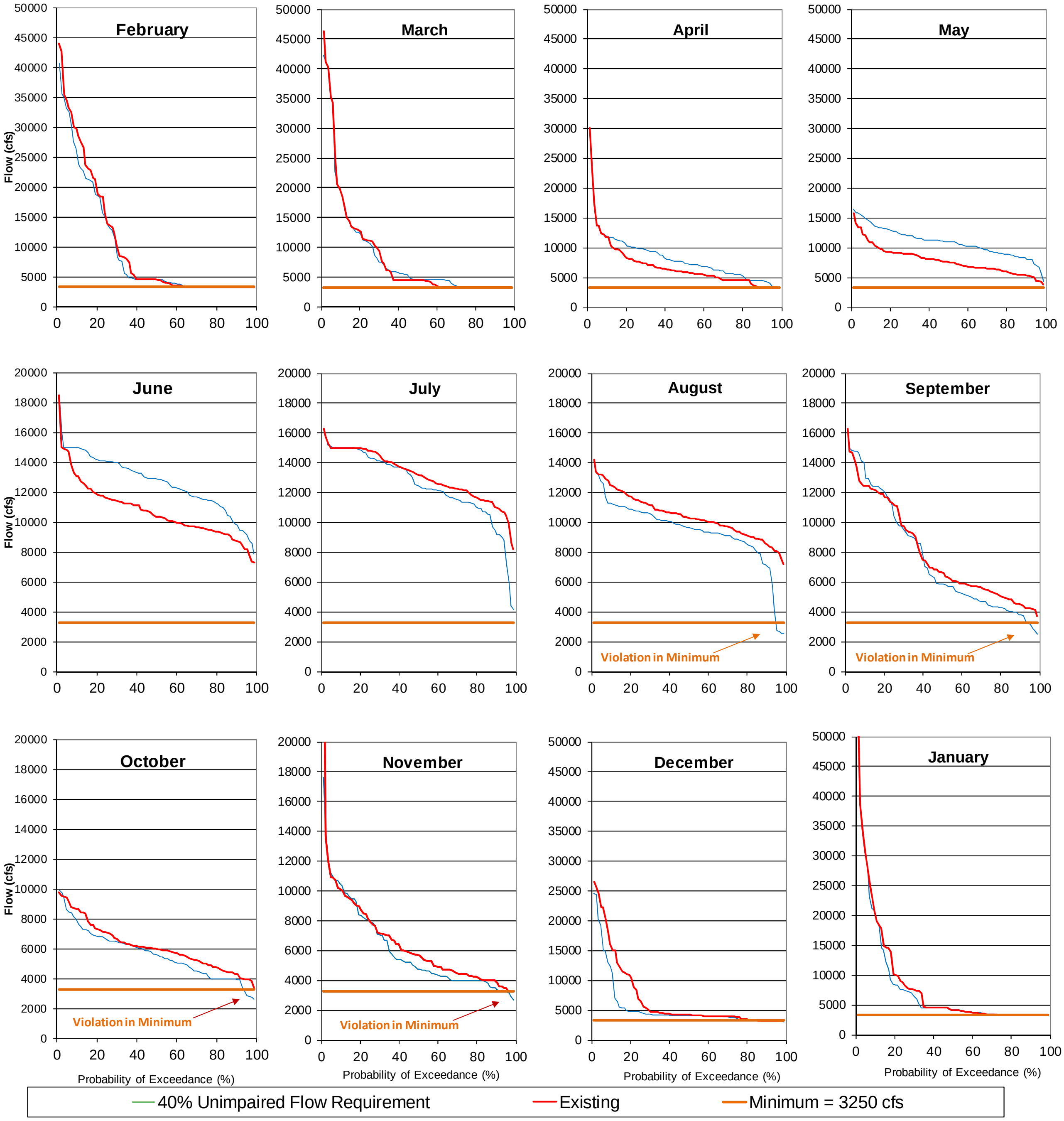


Figure 25 – Monthly Exceedance plots of Sacramento River Flow below Keswick
40% Unimpaired Flow Requirement



Water Supply Impacts

This analysis assumes that the CVP and SWP reservoirs will be operated to meet the 50% and 40% of unimpaired flow requirements; therefore, the analysis assumes that all water supply impacts would be on the CVP and SWP. As discussed above, all of the estimated water supply impacts are underestimates of the actual water supply impacts that would occur from implementation of these requirements. This is because although rules governing CalSim II's simulations of the CVP / SWP system have been developed to produce meaningful operations under a wide range of alterative scenarios, simulation of the 50% and 40% of unimpaired flow requirements requires simulation of operating conditions that would be outside of the range of CalSim II's existing rules. Nevertheless, modeling under CalSim II is the best available method of estimating the impacts of implementing such flow requirements. Additional features would need to be incorporated into the CalSim II model to estimate the full range of impacts to the water system that implementation of the 50% and 40% of unimpaired flow requirements would cause.

Table 5 contains summaries of estimated average annual water deliveries to CVP contractors under Existing Conditions and under the 50% unimpaired flow requirement, and a summary of the differences. Average annual North of Delta (NOD) deliveries would be reduced by 172,000 AF and South of Delta (SOD) would decrease by 346,000 AF. Average critical year reductions NOD would be 542,000 AF and reductions SOD would be approximately 368,000 AF. Table 6 contains summaries of estimated average annual water deliveries to CVP contractors under Existing Conditions and under the 40% unimpaired flow requirement, and a summary of the differences. Average annual North of Delta (NOD) deliveries would be reduced by 74,000 AF and South of Delta (SOD) would decrease by 140,000 AF. Average critical year reductions NOD would be 216,000 AF and reductions SOD would be approximately 172,000 AF. It is important to note that the model assumes that diversions by settlement and exchange contractors would be curtailed, both NOD and SOD, and that the model does not contain any adjustment to maintain these contractors' water diversion priorities. The model results also indicate that municipal and industrial (M&I) deliveries north and south of Delta would be reduced to levels such that public health and safety water supply needs would be difficult or impossible to satisfy.

The model results indicate that water deliveries to wildlife refuges would be reduced to extents that could have effects on the Pacific Flyway. The water supply reductions to agriculture in both the Sacramento and San Joaquin Valleys would also result in water supply reductions to wildlife refuges in these areas. Additionally, the loss of rice production acreage in the Sacramento Valley would affect the Pacific Flyway due to the loss of fall flood-up habitat.

Tables 7 and 8 contain a summary of estimated annual water deliveries to SOD SWP contractors under the Existing Conditions and 50% and 40% of unimpaired flow requirements scenarios, and a summary of the differences. The estimated average annual reductions in SOD SWP contractor deliveries is 352,000 AF in the 50% of unimpaired scenario and 191,000 AF in the 40% of unimpaired scenario. Estimated dry and critical year delivery reductions are 863,000 AF and 460,000 AF, respectively in the 50% of unimpaired flow scenario and 516,000 AF and 299,000 AF, respectively in the 40% of unimpaired flow scenario.

Figure 26 contains exceedance probability plots of CVP water supply allocations for CVP NOD agricultural service contractors, CVP SOD agricultural service contractors, CVP NOD M&I contractors, and CVP SOD M&I contractors for the Existing Conditions and 50% of unimpaired flow scenarios. Figure 27 contains this information for the 40% of unimpaired flow scenario. Under the 50% of unimpaired flow scenario, both NOD and SOD agricultural service contractors would receive no water supplies in 20% of all years, and would experience significant reductions in allocations in most years. Under 50% of unimpaired flow scenario, both NOD and SOD M&I contractors would receive 50% allocations in 20% of all years, which would result in difficulties in meeting public health and safety water needs. There would be difficulty in satisfying public health and safety water needs in the 40% of unimpaired flow study, but not to the degree of the 50% of unimpaired flow scenario. In addition to reduced water supply allocations, when project reservoirs would reach dead pool, most M&I water supply deliveries would be further reduced, and in many months would be zero.

Figures 28 and 29 contain exceedance probability plots of SWP SOD water supply allocations under both of these scenarios. The plots indicate that, in 60% of all years, SWP SOD water supply deliveries would be significantly reduced with implementation of the 50% of unimpaired flow requirements and in 50% of all years with implementation of the 40% of unimpaired flow requirements.

Table 5 - CVP Delivery Summary (1,000 AF)

50% Unimpaired Flow Requirement

	AG NOD	AG SOD	Exchange	M&I NOD	M&I SOD	Refuge NOD	Refuge SOD	Sac. Setlmnt	CVP NOD Total	CVP SOD Total
Existing										
All Years	226	879	852	85	117	68	296	1840	2219	2326
W	318	1380	875	93	136	70	305	1837	2318	2879
AN	286	962	802	85	113	65	279	1696	2131	2325
BN	220	717	875	86	112	70	305	1881	2257	2192
D	159	605	864	81	108	69	300	1876	2184	2061
C	53	233	741	68	87	56	252	1740	1917	1492
50% Unimpaired Flow Requirement										
All Years	150	592	836	75	99	65	287	1758	2048	1980
W	303	1278	875	92	131	71	304	1836	2301	2772
AN	206	686	802	78	105	65	279	1695	2045	2040
BN	78	233	865	70	88	70	301	1859	2077	1660
D	29	125	847	64	79	68	293	1833	1994	1506
C	17	84	664	51	56	35	206	1272	1375	1124
Difference										
All Years	-75	-286	-17	-10	-18	-3	-9	-83	-172	-346
W	-15	-103	0	-1	-4	0	0	0	-16	-107
AN	-80	-277	0	-6	-8	0	0	0	-86	-284
BN	-142	-484	-10	-15	-24	0	-3	-22	-180	-532
D	-130	-479	-17	-17	-30	-1	-8	-43	-190	-554
C	-36	-149	-77	-16	-31	-22	-45	-468	-542	-368

Table 6 - CVP Delivery Summary (1,000 AF)

40% Unimpaired Flow Requirement

	AG NOD	AG SOD	Exchange	M&I NOD	M&I SOD	Refuge NOD	Refuge SOD	Sac. Setlmnt	CVP NOD Total	CVP SOD Total
Existing										
All Years	226	879	852	85	117	68	296	1840	2219	2326
W	318	1380	875	93	136	70	305	1837	2318	2879
AN	286	962	802	85	113	65	279	1696	2131	2325
BN	220	717	875	86	112	70	305	1881	2257	2192
D	159	605	864	81	108	69	300	1876	2184	2061
C	53	233	741	68	87	56	252	1740	1917	1492
40% Unimpaired Flow Requirement										
All Years	190	756	850	80	110	66	292	1809	2145	2186
W	313	1346	875	92	135	70	304	1837	2312	2843
AN	256	896	802	82	113	65	279	1695	2099	2258
BN	158	500	875	80	104	70	305	1881	2188	1968
D	88	375	860	72	99	68	300	1850	2079	1816
C	31	144	730	59	68	47	230	1565	1701	1320
Difference										
All Years	-36	-123	-2	-5	-6	-1	-4	-32	-74	-140
W	-5	-34	0	-1	-1	0	-1	0	-6	-36
AN	-29	-67	0	-2	0	0	0	0	-32	-67
BN	-63	-217	0	-6	-7	0	0	0	-69	-225
D	-71	-229	-4	-9	-9	0	0	-26	-106	-244
C	-22	-88	-11	-9	-19	-9	-21	-176	-216	-172

Table 7 - SWP South of Delta Delivery Summary (1,000 AF)

50% Unimpaired Flow Requirement

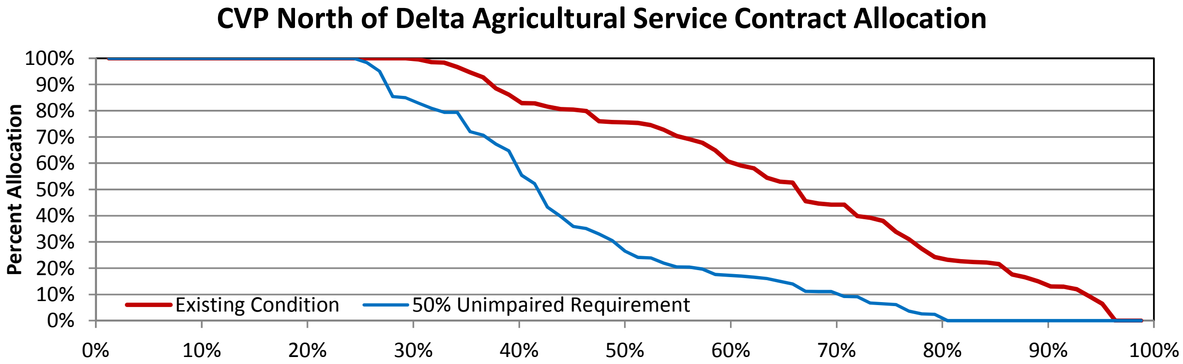
	MWD	"Other" M&I	AG SOD	Art. 56	Art 21	M&I	Table A	Total
Existing								
All Years	1037	610	596	303	71	1647	2242	2616
W	1186	713	738	393	140	1899	2637	3169
AN	1065	606	601	222	60	1671	2271	2554
BN	1121	641	618	376	31	1762	2380	2788
D	1001	582	535	225	39	1583	2118	2382
C	551	348	298	196	21	899	1196	1414
50% Unimpaired Flow Requirement								
All Years	906	540	521	232	66	1446	1967	2264
W	1202	711	738	328	120	1913	2651	3099
AN	1067	605	600	148	113	1672	2272	2533
BN	968	578	521	297	41	1546	2067	2404
D	619	387	334	168	11	1006	1339	1519
C	388	243	210	107	6	631	841	954
Difference								
All Years	-131	-70	-75	-71	-5	-201	-275	-352
W	15	-1	0	-65	-19	14	14	-70
AN	2	-1	-1	-74	53	1	0	-21
BN	-154	-62	-98	-80	10	-216	-314	-384
D	-383	-195	-201	-56	-28	-578	-779	-863
C	-163	-105	-88	-89	-16	-268	-356	-460

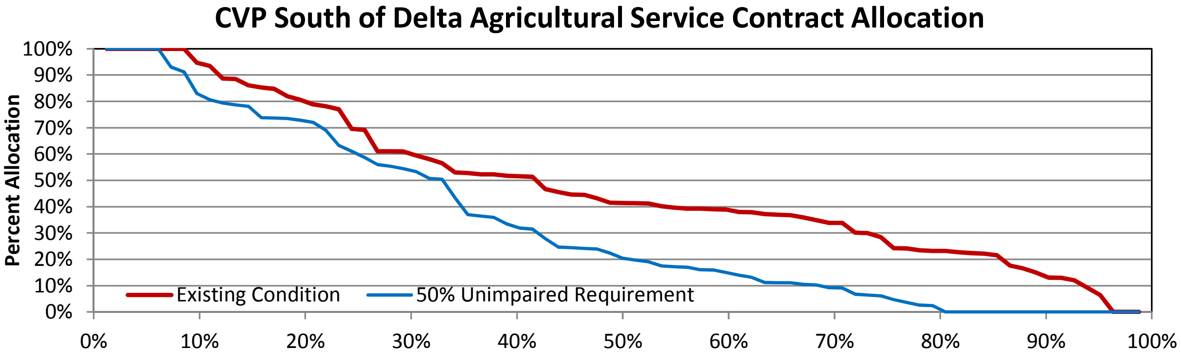
Table 8 - SWP South of Delta Delivery Summary (1,000 AF)

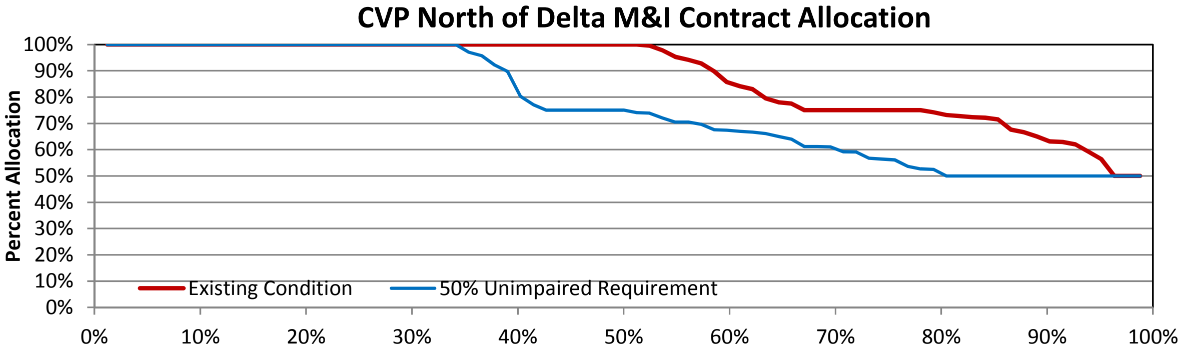
40% Unimpaired Flow Requirement

	MWD	"Other" M&I	AG SOD	Art. 56	Art 21	M&I	Table A	Total
Existing								
All Years	1037	610	596	303	71	1647	2242	2616
W	1186	713	738	393	140	1899	2637	3169
AN	1065	606	601	222	60	1671	2271	2554
BN	1121	641	618	376	31	1762	2380	2788
D	1001	582	535	225	39	1583	2118	2382
C	551	348	298	196	21	899	1196	1414
40% Unimpaired Flow Requirement								
All Years	968	571	555	265	65	1539	2094	2425
W	1194	712	738	356	142	1906	2644	3142
AN	1064	601	598	211	69	1666	2263	2543
BN	1096	619	586	317	41	1715	2301	2659
D	777	475	419	189	7	1251	1671	1866
C	438	278	237	155	6	717	954	1115
Difference								
All Years	-69	-39	-41	-37	-6	-107	-148	-191
W	7	-1	0	-36	2	7	7	-28
AN	0	-5	-3	-11	9	-5	-8	-10
BN	-25	-22	-33	-59	10	-47	-79	-129
D	-225	-107	-116	-35	-33	-332	-448	-516
C	-113	-69	-61	-41	-15	-182	-243	-299

Figure 26 – CVP Water Supply Allocation
50% Unimpaired Flow Requirement







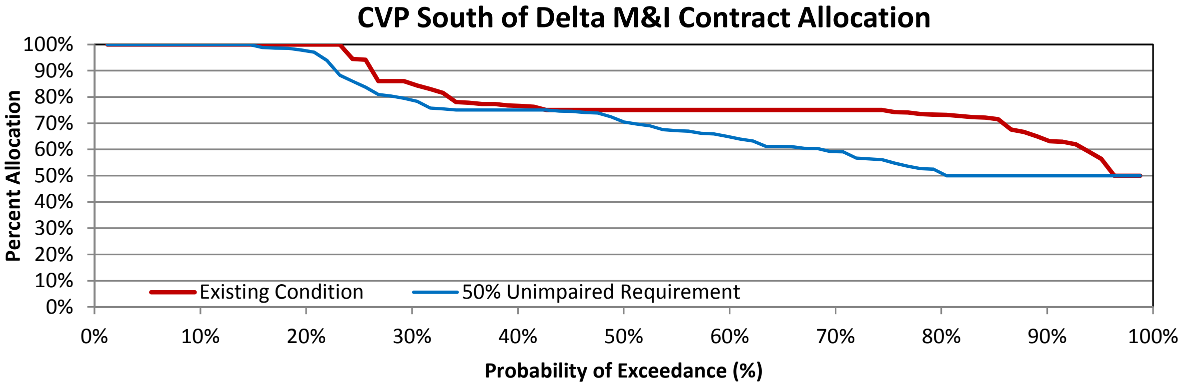
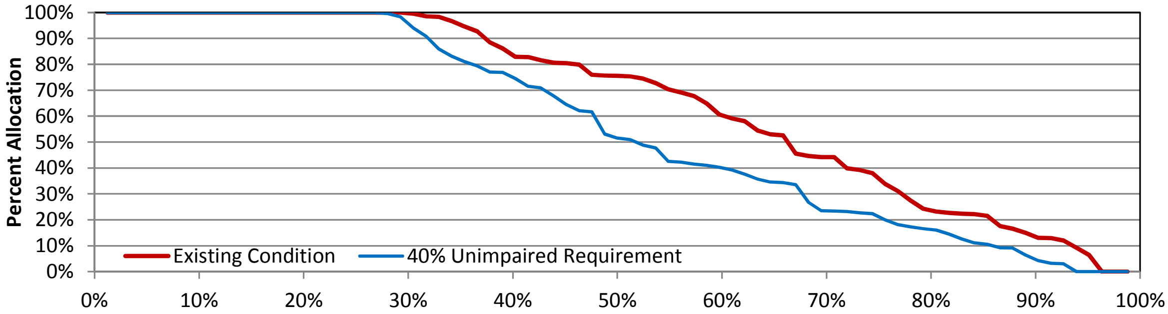
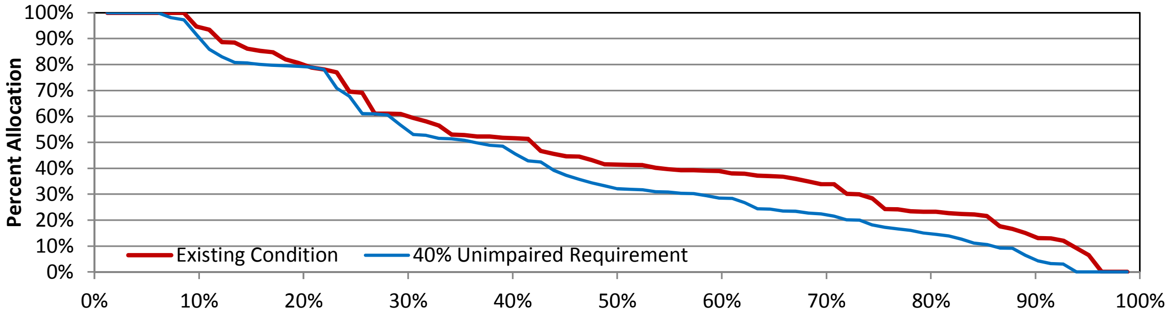
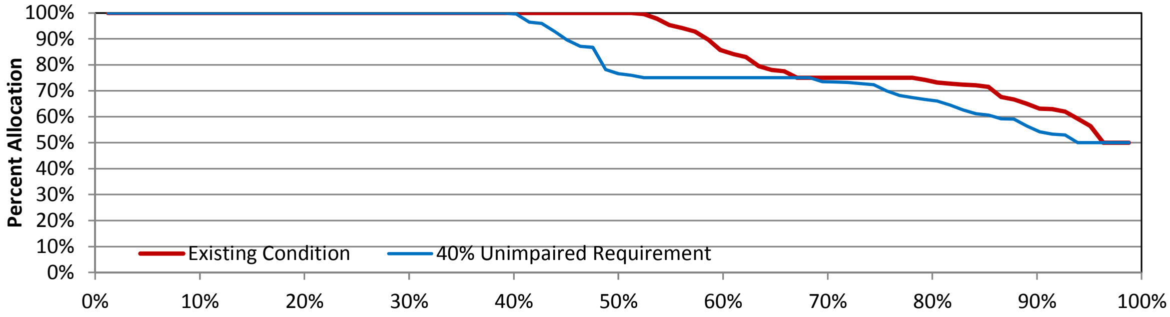


Figure 27 – CVP Water Supply Allocation

40% Unimpaired Flow Requirement


CVP North of Delta Agricultural Service Contract Allocation


CVP South of Delta Agricultural Service Contract Allocation


CVP North of Delta M&I Contract Allocation

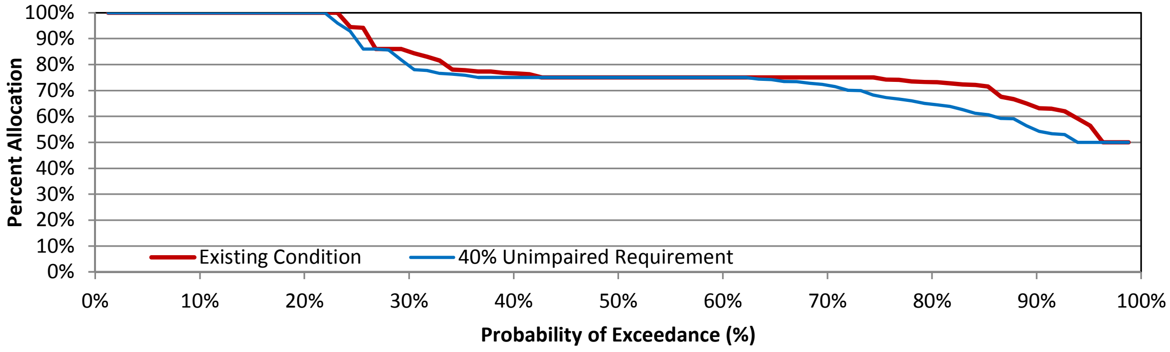

CVP South of Delta M&I Contract Allocation

Figure 28 – SWP Water Supply Allocation
50% Unimpaired Flow Requirement

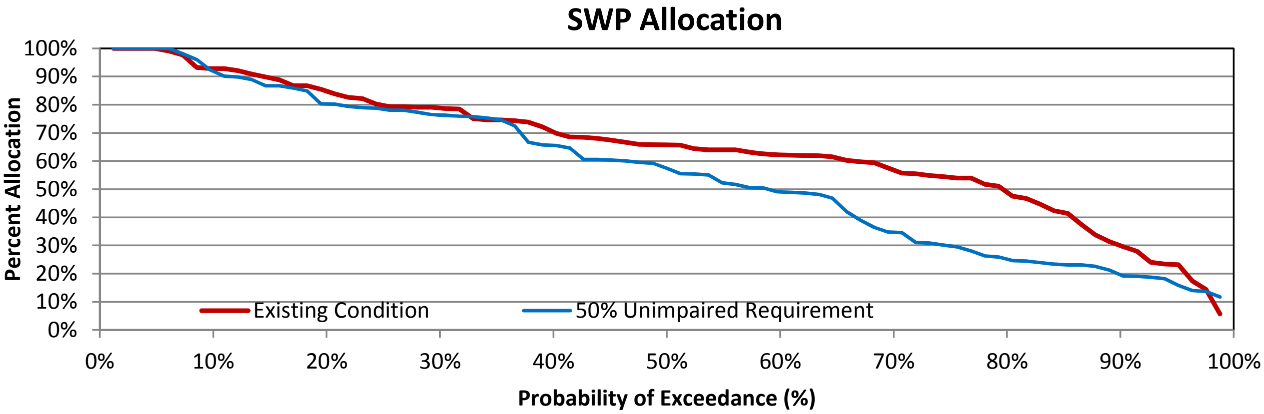
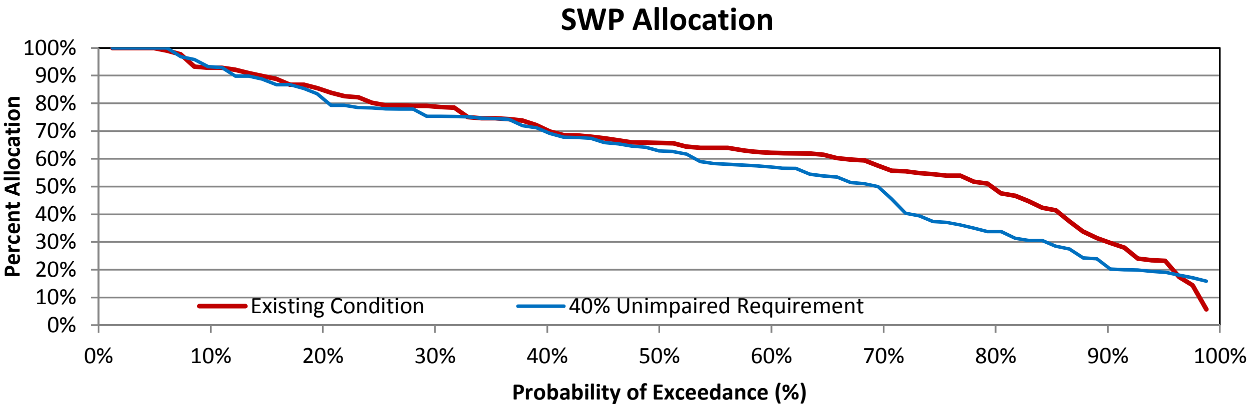


Figure 29 – SWP Water Supply Allocation
40% Unimpaired Flow Requirement



Appendix 6

Sustainable Groundwater Management:

What We Can Learn from California's Central Valley Streams

Reference

This publication is a summary of detailed report:

The Nature Conservancy. 2014. Groundwater and Stream Interaction in California's Central Valley: Insights for Sustainable Groundwater Management.

Available at: http://www.scienceforconservation.org/

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for The Nature Conservancy

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WATER
FOUNDATION

Photo on cover: Seasonal vernal pools surface amidst lush grasslands and blue oak woodlands at Dye Creek Preserve, part of the Lassen Foothills project where restorative land management and conservation-compatible ranching techniques are administered by The Nature Conservancy on behalf of the state of California. © Ian Shive

Introduction

Groundwater is intimately connected to surface water, which has profound implications for sustainable water resource management. California has historically overlooked this important interaction and as a consequence, decisions about groundwater extractions have generally failed to address the resulting impacts to surface flows and aquatic ecosystems such as rivers, wetlands and springs. This has contributed to a loss of approximately 95 percent of the historical wetlands and river habitat in California's Central Valley.[1]

With the passage of the Sustainable Groundwater Management Act (SGMA), groundwater sustainability agencies across the state will soon be required to manage groundwater resources to avoid causing undesirable results to groundwater levels and interconnected groundwater and surface water. These groundwater levels and areas of interconnection support groundwater-dependent ecosystems[2] (GDEs). Therefore, an important first step in sustainable groundwater management is to understand how groundwater pumping impacts surface water, including streams, and GDEs.

To build the case for ecosystem protections now found in SGMA, The Nature Conservancy completed a study in 2014 to illustrate how groundwater pumping is affecting streams and rivers in California's Central Valley. The report, entitled *Groundwater and Stream Interaction in California's Central Valley: Insights for Sustainable Groundwater Management*[3]*,* uses an integrated hydrologic model to reconstruct the historical impacts of groundwater use on groundwater levels and stream flow conditions. The results from that detailed study are summarized here.

Our study focused on the state's Central Valley because of its importance in California's overall water supply. We used a model developed by the Department of Water Resources (DWR) to simulate the Central Valley's hydrologic conditions during the years from 1922 to 2009. Across the Tulare Basin, San Joaquin Basin and Sacramento Valley these changes have differed in magnitude, but share a similar trend. In areas with hydraulic connection between groundwater and surface water, increases in groundwater extraction continue to cause declines in groundwater levels that reduce stream flow.

Our report found that as groundwater production grew threefold, surface water was seriously depleted in the Central Valley. This region, which accounts for 20 percent of all groundwater pumping in the United States, has now lost nearly all of its wetlands and river habitat. Our modeled results indicate that over 80 percent of the valley's rivers lose more water today than they did in their relatively natural state. By the end of our study period, the valley's rivers were losing almost 1.5 billion gallons of water each day—that is enough water to supply 2.5 times the water needs of Los Angeles. In addition, groundwater aquifers contain 6.5 trillion gallons less water now than they did at the start of the study period.

The results of our study pre-date the extended drought that began in 2011 and it is likely that the drought has exacerbated stream depletions. In addition, our study illustrates that the effects of groundwater pumping can take years—even decades—to recover. This means that the full extent of the impacts of groundwater pumping during the drought will continue to plague us for many years.

These findings have troubling implications not only for the health of our ecosystems, but also for the surface water right holders. If groundwater pumping continues to increase, it will become even more challenging to ensure that surface water is available for the cities, industries, agriculture and plants and animals that rely on surface water systems.

Sustainable groundwater management requires that we acknowledge the critical connection between groundwater and surface water. In addition, in managing this connection, we must acknowledge the protracted time period it can take for groundwater extractions to impact stream flow. The best tools we have to sustain our important groundwater supplies are to proactively manage and monitor groundwater use and to invest heavily in groundwater recharge. Implementation of SGMA provides the impetus to change our approach and to integrate management of groundwater and surface water.

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[1] The Bay Institute (1998) *From the Sierra to the Sea: The Ecological History of the San Francisco–Bay Delta Watershed.*

[2] Groundwater dependent ecosystems are "terrestrial, aquatic and coastal ecosystems that require access to, replenishment or benefit from, or otherwise rely on subsurface stores of water to function or persist." Howard and Merrifield (2010) Mapping Groundwater Dependent Ecosystems in California. PLoS ONE 5(6): e11249. doi:10.1371/journal.pone.0011249
Available at: http://www.scienceforconservation.org/

[3] The Nature Conservancy. 2014. *Groundwater and Stream Interaction in California's Central Valley: Insights for Sustainable Groundwater Management*. Available at: *www.scienceforconservation.org*

Background

The Interconnection between Groundwater and Stream Flow

Most of California's groundwater occurs in material deposited by streams, called alluvium. Alluvium consists of coarse deposits, such as sand and gravel, and finer-grained deposits such as clay and silt. The coarse and fine materials are usually coalesced in thin lenses and beds that were deposited by streams. In this environment, coarse materials such as sand and gravel deposits usually provide the best source of water and are termed aquifers; the finer-grained clay and silt deposits are relatively poor sources of water and are referred to as aquitards. California's groundwater basins usually include one or a series of alluvial aquifers with intermingled aquitards. DWR has delineated more than 500 alluvial groundwater basins and sub-basins across California, the largest of which are the Sacramento Valley, San Joaquin Basin and Tulare Basin that underlie the Central Valley.

Streams and rivers in the Central Valley typically flow over sediments that are connected to underlying aquifers. Because the sediments that make up the bottoms of these stream channels are porous, water can flow back and forth between the streams and the underlying aquifer.

A range of groundwater–surface water interconnections are found in basins in the Central Valley. When groundwater levels in the surrounding sediments are high relative to the streams, groundwater flows from the aquifer into the streams, contributing to the stream flow. This condition is known as a gaining stream—streams gain surface flows from high groundwater levels. In some cases, this groundwater inflow keeps

FIGURE 1: Groundwater and Stream Interaction in Alluvial Aquifers

Groundwater basins in California are predominately alluvial or "valley-fill" groundwater aquifers. These aquifers are made up of unconsolidated or loosely-cemented sediments that have been deposited over long periods of time in valleys. These deposits, sometimes thousands of feet deep, are usually underlain by more solid, and less permeable, rocks that make up the geologic floor of the valley and the surrounding hills or mountains. The sediments that make up the valley-fill are deposited in interwoven layers and veins that vary widely in particle size, from cobbles and gravel, to sands, to clay. The water in these aquifers resides in, and moves through, the pore spaces between the sediment particles. Water moves more easily through sediments of larger particles, and moves very slowly, if at all, through sediments of finer particles, like clays.

Gaining Stream—Where rivers or streams run across valley floors underlain by valley-fill aquifers, there will inevitably be exchange of water between the streams and the underlying and surrounding aquifers. If surrounding groundwater levels are higher than the water levels in the river, the river will "gain" water from the surrounding groundwater. This is called a **"gaining" reach of stream**. This groundwater inflow is often a large portion of the flow in streams after precipitation events have passed. This is often the natural condition of streams, since streams are commonly the major discharge location for groundwater flow.

Losing Stream—Pumping of groundwater draws down the groundwater levels near the pumping well, and multiple wells can lower groundwater levels over large regions of the aquifers. If groundwater levels are drawn down, by pumping or by natural processes, to levels lower than the stream, water will flow from the stream into the aquifer sediments below. In this condition, the stream segment is said to be a **"losing" reach of stream**.

Gaining Stream—Groundwater flows into the stream, increasing surface flows

Losing Stream—Stream flows depleted by outflows to groundwater streams flowing in the dry seasons, even when there is no rain or snow to maintain them. This is referred to as base flow. When groundwater levels drop, the amount of groundwater flow into the stream is correspondingly reduced.

When groundwater elevations in the surrounding basin sediments are lower than the water level in the stream, the flow direction is reversed and water from the stream leaks or seeps through the streambed sediments, flowing into the surrounding aquifer, recharging the groundwater basin. This seepage or leakage of stream flow into the groundwater basin reduces the flow in the stream. This condition is called a losing stream—streams lose surface flows to groundwater recharge.

In short, what is a gain for the groundwater is a loss for the stream. The loss of flow in streams due to groundwater pumping is formally known as "stream depletion," meaning groundwater pumping ultimately comes at the expense of surface waters—from depleting surface flows. This stream-aquifer relationship can change seasonally or annually between gaining and losing conditions based on the flows in the river and the status of the groundwater system.

Because of the interaction between stream flow and groundwater in alluvial systems, pumping water from wells essentially diverts surface water, with the aquifer functioning as a large storage facility for water that comes from surface flows. Deep wells in confined portions of the aquifers, and wells distant from streams are similarly connected to streams; they simply take longer to impact rivers and streams. Groundwater pumping is therefore only sustainable to the extent that it can be replenished by surface water systems and also to the degree that we are willing to compromise ecosystems and established surface water rights.

Study Approach

Recognition of the groundwater–surface water connection in the Central Valley is especially critical in managing California's water supply because of the importance of Sacramento and San Joaquin river flows and underlying groundwater in meeting local and statewide water supply needs.

Our study describes how groundwater pumping over the past century has changed conditions in the Central Valley using DWR's integrated groundwater and surface water model, the California Central Valley Groundwater-Surface Water Simulation Model (C2VSim). The model covers the hydrologic, land use and water use conditions in the Central Valley for the period of 1922 to 2009. While the model is not a perfect representation of the natural system, it represents the clearest comprehensive picture available for the Central Valley hydrologic and water use conditions and the interaction between streams and groundwater system.

Salamander at small freshwater stream on The Nature Conservancy's Mueller Ranch located in the Arroyo Seco River and Uplands Conservation Areas of Monterey County, California Central Coast Ecoregion, California. © Mark Godfrey/TNC

One of the biggest challenges in understanding the status of groundwater conditions is the lack of reliable data on pumping rates, since measuring or reporting of groundwater pumping volumes has not historically been required in California. Consequently, pumping volumes must be estimated. This is done within C2VSim by dynamically calculating crop water demands, allocating contributions of water from precipitation, soil moisture, and surface water diversions (which are reported), and then estimating the amount of groundwater pumping required to meet remaining demand. Experts generally agree that the C2VSim model provides some of the best estimates of agricultural water demand, and therefore groundwater pumping to meet agricultural demands for the Central Valley because estimates are based on water budgets developed for various management areas, considering various crop mixes, soil conditions, irrigation practices, rainfall, surface water supplies and variation in both space and time throughout the valley.

In addition to illuminating historical conditions and current trends in groundwater–surface water conditions, we used the C2VSim model to illustrate possible future conditions that could result from water management scenarios. These scenarios include a groundwater substitution transfer and development of new irrigated lands using groundwater.

Observations and Results

The following are some general observations drawn from the C2VSim simulations. More details on each of these can be found in the full technical report.

Declining Groundwater Levels

Water development and use within the Central Valley increased dramatically in the 1900s as new irrigated agricultural land was progressively brought into production. Combined surface water and groundwater use rose from about 9 million acre-feet per year in the 1920s to about 22 million acre-feet per year in 2009, with groundwater production rising from about 3.3 to 10 million acre-feet per year over this same period.

The proportion of groundwater use to total water use in the Central Valley averaged about 45 percent between 1922 and 2009, with the actual amount varying year to year depending on rainfall. In 1977, a severe drought year, groundwater provided nearly 70 percent of the supply for this area, with pumping totaling nearly 16 million acre-feet. In 1983, an extremely wet year, groundwater provided only 30 percent of the supply, totaling only 7 million acre-feet. The Tulare Basin accounts for as much groundwater production as the other regions combined.

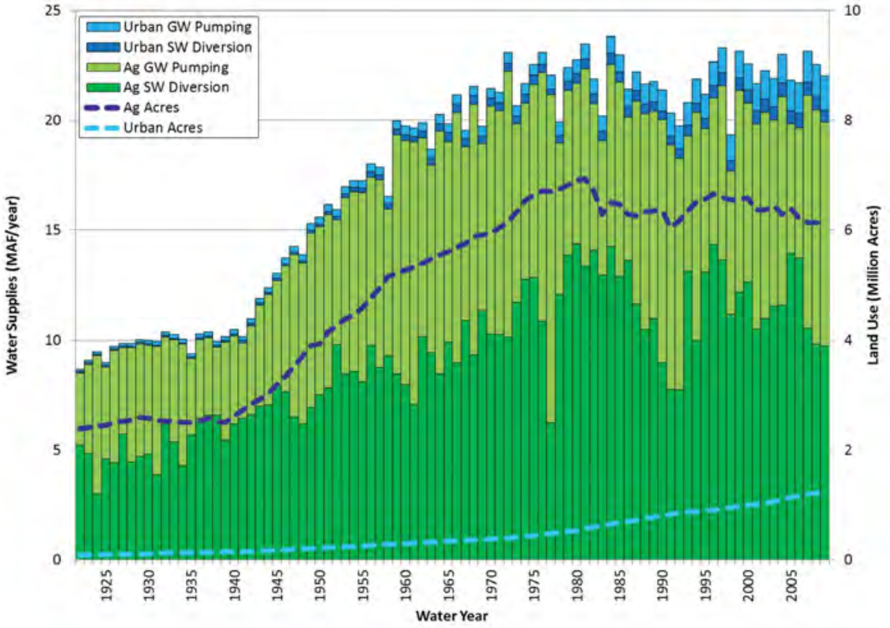
Increases in groundwater pumping resulted in lower groundwater levels throughout most of the Central Valley in 2009 relative to the 1920s. These lower water levels correspond to a decrease in stored groundwater, meaning more water was pumped from the aquifer than was recharged. Estimated stored groundwater in the Tulare Basin region underwent a dramatic decline, with total pumping exceeding recharge by more than 120 million acre-feet. Over the same period in the San Joaquin Basin, the estimated reduction in storage was more than 20 million acre-feet. Meanwhile in the Sacramento Valley, a similar though less dramatic trend can be seen, with less than 5 million acre-feet estimated reduction in storage.

Assuming the existing land use and water use conditions continue in the future, model simulations suggest that groundwater storage could potentially decline by an additional 75 million acre-feet through the year 2083.

Resulting Stream Depletion

As described above, when groundwater levels decline in alluvial aquifers, the flow in the overlying streams that have some level of hydraulic connection with groundwater is affected. The historical effects of increased groundwater pumping on stream flow between 1922 and 2009 are clearly evident from the results of the C2VSim simulations. As groundwater

Figure 2: Historical Land Use and Water Supplies in the Central Valley.



extractions tripled, groundwater discharge to streams gradually decreased. In fact by the end of our study period, major Central Valley rivers were being depleted at a rate of 1.5 billion gallons per day. This is 2.5 times the amount of water needed to support Los Angeles each day.

Streams in the San Joaquin and Sacramento Valley hydrologic regions were gaining water overall in the 1920s, while streams in the Tulare were already losing flows to groundwater. Streams in the San Joaquin largely converted in the 1960s, at which time they began to lose more water than they gained. While these findings do not indicate that all streams reversed from gaining to losing rivers—or that any particular river became disconnected—the results clearly show that the general relationship between groundwater and stream flow has been significantly altered.

Up north in the Sacramento Valley, the model simulation indicates that streams reached their tipping point by 2009, losing more flow to groundwater than they gained. The Sacramento River and its tributaries were net-gaining streams in the early 1900s, but now they

Figure 3: Cumulative Change in Groundwater Storage, by Region.

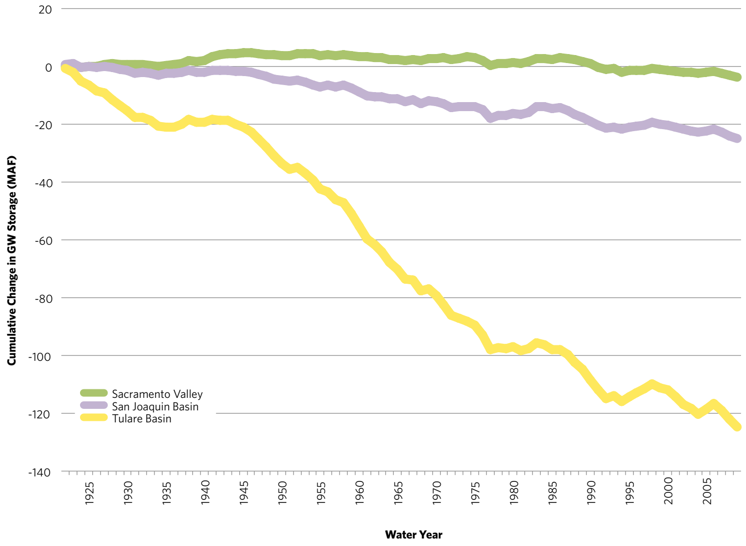
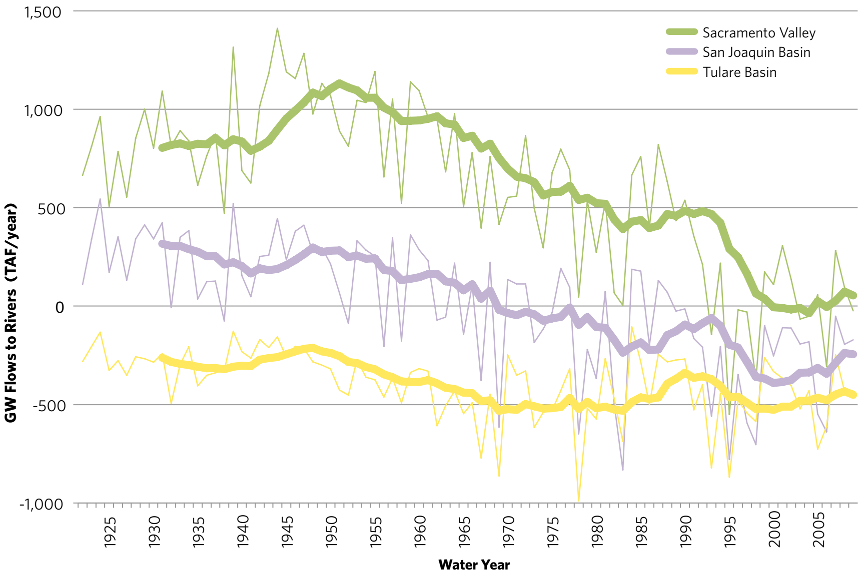


Figure 4: Net Historical Groundwater Discharge to Rivers, with 10-Year Moving Average.



Lush, riparian forest surrounds Dye Creek in the Dye Creek Preserve, part of the Lassen Foothills project where restorative land management and conservation-compatible ranching techniques are administered by The Nature Conservancy on behalf of the state of California. © Ian Shive

are estimated to be gaining much less or even net losers of water overall due to increases in groundwater pumping. These stream flow depletions in the Sacramento Valley occurred as groundwater level declined as little as 25 feet over most of the valley.

Compromised Groundwater Dependent Ecosystems

The reduction in stream flows has degraded the plants, animals and ecosystems that rely on rivers and streams, as well as the ability to maintain water quality, stream temperature and other beneficial uses. As a result, there has been a drastic decrease in the extent of wetlands and river habitats, drying of seeps and springs, and an interruption of the dry season stream flow needed for passage of salmon and for the health of other aquatic species. Some of these declines in ecosystem health have resulted in listing of species under the Endangered Species Act and/or California Endangered Species Act, in some cases forcing regimented water system operations that could be avoided if the rivers or wetlands were restored to functional levels.

In addition to declines in groundwater storage and degradation of GDEs, increased groundwater pumping in the San Joaquin and Tulare Basins has resulted in some of the world's most extreme examples of subsidence—a condition where the land surface slowly loses elevation due to the compaction of sediments—in some cases by more than 30 feet

Our study reflects impacts up to 2009. Since then, California entered a drought that increased groundwater pumping and exacerbated stream depletions, habitat losses and subsidence.

Scenario 1: Groundwater Substitution Transfer

During times of drought, transferring water from areas with relatively abundant water supplies to areas of shortage is often a means to reduce supply constraints in the state. One form of this is called a "groundwater substitution transfer." This occurs when water users forgo their surface water entitlement for transfer and substitute groundwater pumping to meet their irrigation needs.

Our study modeled a scenario to isolate the impact of a single year of a groundwater substitution transfer. It assumed a transfer from the Sacramento Valley to an area south of the Delta, with pumping of 186,000 acre-feet.

This scenario resulted in groundwater levels declining at locations of increased pumping, with varied affects on the surface water system. The groundwater level declines are less in pumping areas close to the major river systems, and more at greater distances from the rivers, indicating that rivers are major sources of recharge to the groundwater system.

These groundwater level declines persist for years to decades, resulting in long-term depletion of stream flow. Our modeling analyses indicate that over this period, the total stream depletions approach the 186,000 AF volume of water pumped for the substitution.

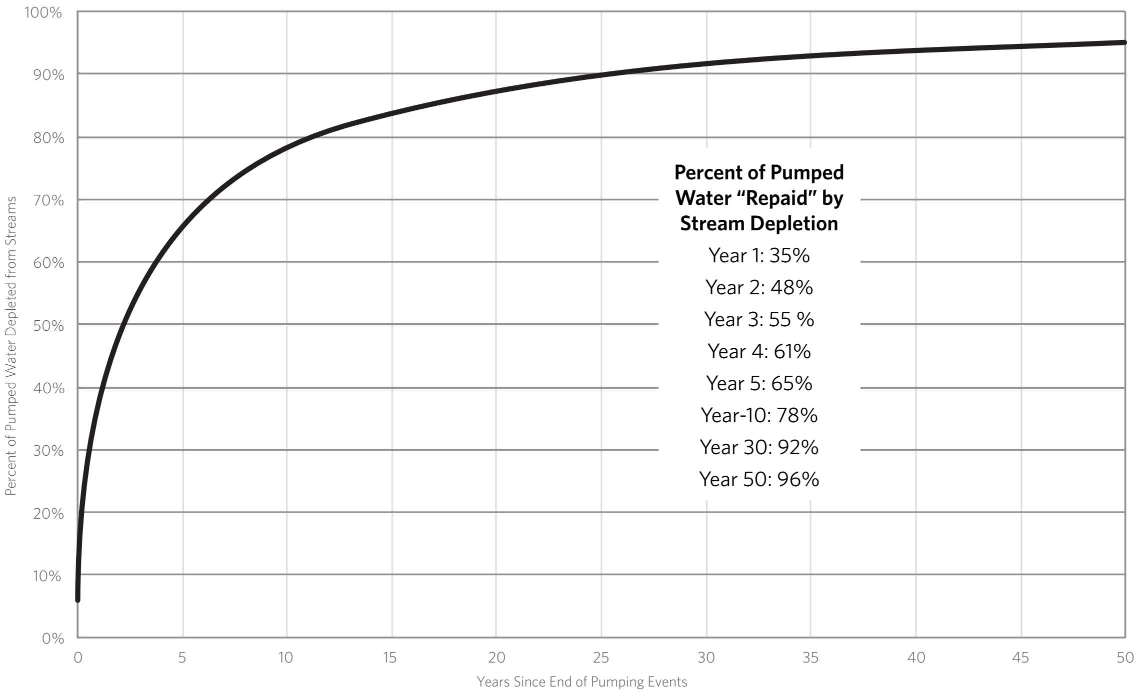
Scenario 2: Stream Flow Impacts from Development of New Irrigated Lands

Recent years have seen significant levels of new agricultural development in the Central Valley, where previously non-irrigated lands are being irrigated using groundwater. To estimate the impacts of new pumping on stream flow in the Central Valley, we simulated a hypothetical case of 10,000 acres of new irrigated lands being brought into production on the northwest side of the Sacramento Valley using groundwater as the water supply.

Our modeled scenario assumed a groundwater pumping need of 30,000 acre-feet per year. Since a portion of the irrigation (~5,000 acre-feet per year) returns to the groundwater through deep percolation from irrigation applied water, we assumed a net new-groundwater use of approximately 25,000 acre-feet per year.

The additional groundwater use resulted in a reduction in groundwater levels that inevitably led to new stream depletions. Once the new pumping is initiated in the area, it takes approximately 25 to 30 years for a “new equilibrium” to be reached in the groundwater levels and for all the stream depletions to fully develop. Eventually, however, all of the net new groundwater use, 25,000 acre-feet per year, is reflected as reduced stream flows.

Figure 5: Sacramento Valley Stream Depletion and Groundwater “Repayment” Curve.



Conclusions

Our report illustrates how increased groundwater pumping in the Central Valley has resulted in stream depletions, essentially reversing the historical interconnection where streams gained flows from groundwater. The result of these stream depletions includes loss of surface water supplies as well as declines in the health of plants and animals that depend on surface water and sufficient groundwater levels. These impacts are significant because the volumes of lost groundwater are frequently replaced by corresponding depletions in stream flow, and because these stream losses can persist for many years—even decades.

As California implements the Sustainable Groundwater Management Act, our study provides clear lessons learned that should inform sustainable management:

- **Groundwater withdrawals result in surface water depletions.** In many areas of California's Central Valley, groundwater and surface water resources are intimately interconnected. As groundwater production tripled in the 20th century, many portions of the Central Valley's rivers and streams converted from systems that gained flows from groundwater to systems that lost surface flows to groundwater.
- **Conditions are worsening in the Sacramento Valley.** While groundwater overdraft has long been recognized in the southern parts of the Central Valley, conditions in the Sacramento Valley region have, until recently, been reasonably stable. Our study indicates that groundwater conditions in the Sacramento Valley are worsening and, as a result, adverse impacts to surface flows are increasing.
- **Stream flow impacts from pumping may be delayed by decades.** Although the effects of groundwater pumping on stream flow may be fairly immediate when the pumping location is close to the stream, the effects of groundwater pumping miles away from a stream or deeper in the aquifer will lead to stream depletion that is not fully expressed for years or even decades.
- **Small changes in groundwater levels can make a big difference.** Because it can take decades to recover groundwater levels, even small groundwater level declines can lead to potentially significant stream depletion when aggregated over time.
- **Without action, Central Valley groundwater conditions will continue to decline.** Our modeling results show that groundwater storage in the Central Valley has declined by about 150 million acre-feet since the early 1920s. Assuming the existing land use and water use conditions continue in the future, model simulations suggest that groundwater in storage could potentially decline by an additional 75 million acre-feet through the year 2083.
- **Groundwater substitution transfers affect stream flow.** Modeling results clearly indicate that supplies for groundwater substitution transfers initially comes from groundwater. Although pumped groundwater for transfers initially comes from groundwater in storage, eventually it is balanced by an equivalent amount of stream depletion that occurs over many years or even decades. While groundwater transfers may be a useful drought mitigation measure, such measures need to be designed and implemented with full recognition of long-term impacts to streams and surface water rights.
- **Expanding irrigated agriculture means lower groundwater levels and less flow in streams.** Increased agricultural development in the Central Valley supplied by groundwater will result in further declines in groundwater levels. These declines will ultimately result in stream depletion similar in amount to the consumptive use of the new crops. Stream depletion impacts from this new groundwater pumping may take years to decades to fully develop.

While our study focuses on the Central Valley, the same hydrologic and physical principles apply where streams and rivers flowing over alluvial aquifers are pumped for water supply across California. Sustainable groundwater management requires recognizing and understanding how declining groundwater levels lead to stream depletions. Stated simply, groundwater pumping in alluvial aquifers as just another way of diverting surface water. When viewed in this way, it is clear that groundwater pumping is only sustainable to the degree that we accept associated impacts to surface water rights and plants and animals.

Over the next few decades, we will learn much more about groundwater dependent ecosystems and the connection between groundwater and stream flows. But today, one lesson is clear: healthy rivers are strong indicators of effective and sustainable groundwater management.

Photo on back cover, clockwise from top: Cattle graze along the Shasta River on the Conservancy's recently acquired Shasta Big Springs Ranch near Shasta, California. Heavy grazing on the ranch has seriously degraded the river, damaging this crucial salmon habitat. The Conservancy purchased the ranch as part of a major project to restore the river habitat and protect the salmon fishery. The upper reaches of the Shasta River hold the best hope for restoring salmon populations in the Klamath Basin of northern California and southern Oregon. The 4,136 acres Shasta Big Springs Ranch (formerly, Busk Ranch) contains large cold water springs that support over 80% of the coho salmon found rearing in the Shasta. Protecting this ranch and restoring its river habitat is a major link in restoring the salmon habitat in California. © Bridget Besaw; Wetland at Lost Slough Wetland in the California Cosumnes River Preserve. © Harold E. Malde; Riparian forest line the banks of a slough along the Sacramento River in California. ©Harold E. Malde; Pond with mountains in the background and trees and grasses on the side in the Sequoia Foothills, near Three Rivers. The Sequoia Foothills region supports the greatest biodiversity of native vegetation and the 2nd highest concentration of rare and endemic plants in the Sierra Nevada. TNC's Sequoia Foothills Project began due to the principal threat to the natural habitats and native species of the area driven by population growth. The project area covers just under 1 million acres within Tulare County. © Gary Crabbe/Enlightened Images Photography




Appendix 7

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Functional Flows in Modified Riverscapes: Hydrographs, Habitats and Opportunities

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Building on previous environmental flow discussions and a growing recognition that hydrogeomorphic processes are inherent in the ecological functionality and biodiversity of riverscapes, we propose a functional-flows approach to managing heavily modified rivers. The approach focuses on retaining specific process-based components of the hydrograph, or functional flows*, rather than attempting to mimic the full natural flow regime. Key functional components include wet-season initiation flows, peak magnitude flows, recession flows, dry-season low flows, and interannual variability. We illustrate the importance of each key functional flow using examples from western US rivers with seasonably predictable flow regimes. To maximize the functionality of these flows, connectivity to morphologically diverse overbank areas must be enhanced in both space and time, and consideration must be given to the sediment-transport regime. Finally, we provide guiding principles for developing functional flows or incorporating functional flows into existing environmental flow frameworks.*

Keywords: hydrology, river ecology, water resources, land-use management, geology

During the past three decades, flow management of regulated rivers has increasingly considered downstream effects on the environment. Early approaches to defining stream flows that benefit the environment (hereafter called *e-flows*) focused on quantifying a single minimum instream flow sufficient to maintain aquatic species during crucial low-flow periods. These recommendations did not address the role of stream flow in maintaining species during other periods—or in habitat maintenance and formation—and riparian ecosystem needs (Petts 1996). However, consideration of the impacts of different aspects of the flow regime on the entire river ecosystem was first proposed by Hill and colleagues (1991), who described the various ecological links associated with different flow magnitudes: low flows, bankfull flows, overbank flows, and extreme valley-inundating floods. Petts (1996), Richter and colleagues (1996), and Poff and colleagues (1997) introduced ecological and geomorphological relationships to other attributes of the flow regime, including the timing, duration, frequency, and rate of change of flows. Following these and other advances in river science, an "e-flows imperative" to sustain healthy river ecosystems (Petts 2009) emerged at the beginning of the twenty-first century. Today, resource managers and river scientists recognize the importance of the natural flow regime (Poff et al. 1997), the role of flow variability as a driver of ecosystem processes (Naiman et al. 2008), and the inherent interplay among river structure, physical processes, and ecological patterns (Fremier and Strickler 2010, Wohl 2012).

The early twenty-first century has seen expansion in the variety of approaches to implementing e-flows (Arthington 2012). These advances have ranged from simple prescriptions applicable to rivers where few baseline data are available to complex data-driven approaches, such as the Ecological Limits of Hydrologic Alteration (ELOHA) framework (Poff et al. 2010). The former approaches include strategies such as limiting withdrawals to a fixed proportion of the natural flow (Richter et al. 2012) and downscaling the entire flow regime by reducing flow magnitudes but sustaining the normal seasonal pattern of flow variations (Hall et al. 2011). The latter approaches specifically advocate that flow recommendations be based on the mechanistic relationships between flows and ecological outcomes. However, in heavily modified riverscapes (*sensu* Ward 1998, Fausch et al. 2002), restoring a natural flow regime is a particular challenge because of competing water demands (Acreman et al. 2014). Mimicking a natural flow regime in modified riverscapes will not yield successful ecological outcomes unless such flows trigger functional processes. For example, the

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restoration of peak flows will not regenerate habitats if the river is starved of sediment or if the river channel is highly confined (Wohl et al. 2015). Given these constraints, we propose that a more effective approach is to identify and restore aspects of the flow regime that support key ecosystem functions and drive geomorphological and ecological processes.

Riverine ecosystems and their species are adapted to processes and patterns that stem from not only the flow regime but also the associated disturbance regime, which promotes ecological feedbacks between biological and physical processes (Lytle and Poff 2004). It is well recognized that functioning river systems exhibit temporal variability in flow (Naiman et al. 2008), sediment flux, and channel morphology (Beechie et al. 2010), and these physical dynamics interact with biological communities at multiple scales (Petts 2009). Simply stated, the design of a more natural flow regime without consideration of the implications for sediment transport and channel–floodplain geomorphology is likely to have limited success in river management and restoration.

Here, we build on the latest e-flows science to propose a functional-flows approach to managing rivers in highly modified riverscapes. We expand consideration of e-flows to not only address the ecological function of particular flows (Acreman et al. 2014) but also to explicitly emphasize sediment erosion, transport, and deposition to maintain and rehabilitate geomorphologically important instream and floodplain habitats, as was advocated most recently by Wohl and colleagues (2015). We suggest that e-flow design and implementation should focus on specific functional flows (*sensu* Escobar-Arias and Pasternack 2010) that support natural disturbances, promote physical dynamics, and drive ecosystem functions (Arthington et al. 2010). We define these functional flows, discuss their geomorphic implications in the context of floodplain connectivity and sediment mass balance, suggest how they might be combined into a functional flows framework or incorporated into existing e-flow frameworks, and provide several guiding principles for the flow management of highly modified rivers. We illustrate our approach with examples from rivers throughout western North America that have marked flow seasonality, widely variable sediment supply regimes, and variable sensitivity to hydrological change, typically exhibiting relatively short relaxation times for channel morphology response to flow regulation (Petts and Gurnell 2013)—thereby providing examples applicable to other rivers worldwide.

What is a highly modified riverscape?

We consider *highly modified rivers* to be those that (1) have a high proportion of their total length converted to reservoirs, (2) have a high proportion of their total annual stream flow diverted and/or managed for societal uses, (3) have a high proportion of their total annual stream flow stored in reservoirs, and/or (4) have a large proportion of their total length channelized or lined by levees. These four characteristics rarely occur in the same river, but even one of these characteristics can greatly affect the riverscape, particularly in terms of sediment transport and floodplain extent, and constrain e-flow implementation and ecosystem restoration potential. For example, the Columbia River meets the first criterion, and e-flows can only be applied to the remaining reaches of the channel network. In these short river reaches, specific flow regimes, specific target species, and particular life-history habitat requirements can be relatively easily linked to limited e-flow allocations, because fewer demands are placed on these short reaches. In contrast, the Colorado River meets the third criterion, with reservoirs that can store many times the annual average runoff and long river segments between reservoirs. Here, e-flow recommendations must be balanced with the interests of multiple stakeholders concerned about different river resources in different parts of the river. Extensive e-flows negotiations over several decades have been implemented, debated, and revised in order to meet these competing demands (Melis et al. 2012). Opportunities for e-flow implementation are particularly constrained on the lower Colorado River, where all of the stated criteria for a highly modified river are met. In fact, no flow typically occurs downstream from Morelos Dam in Mexico, and the Colorado River rarely flows into the Gulf of California. In each of these types of highly modified rivers, the limited availability of water to support e-flows makes it impossible to restore a full natural flow regime, suggesting that the restoration of key flow components that drive geomorphological and ecological functions may be a more efficient and effective strategy.

The functionality of flows in the riverscape

Variable flow regimes that transport differing sediment sizes at multiple discharges produce dynamic habitat mosaics that change in space and time (Stanford 2006) but can remain consistent in terms of overall abundance and area of habitat types (Ward et al. 2002). Temporally variable flow regimes interact with spatially variable river channel and floodplain forms to support high biodiversity (Ward 1998, Wohl 2012). When these dynamic spatiotemporal interactions are limited by flow alterations, blocked by channel levees, or perturbed by sediment deficit or surplus, rivers can become homogenous, and biodiversity decreases (Moyle and Mount 2007, Wohl et al. 2015).

In large alluvial rivers, the extended residence time of floodwaters within riparian wetlands diversifies the vegetative structure and increases primary productivity (Ahearn et al. 2006), whereas increased shoreline complexity can provide greater diversity of fish habitat (Moore and Gregory 1988). Such conditions require both the flows to produce the necessary timing of connectivity, as well as the space for the development of geomorphic configurations (figure 1). Only when interactions between flow and the riverscape are maintained can these diverse ecological processes be sustained over time (Fausch et al. 2002). However, these morphologic attributes and related physical processes are often the first to be lost when floodplains are confined by levees and channels are simplified.

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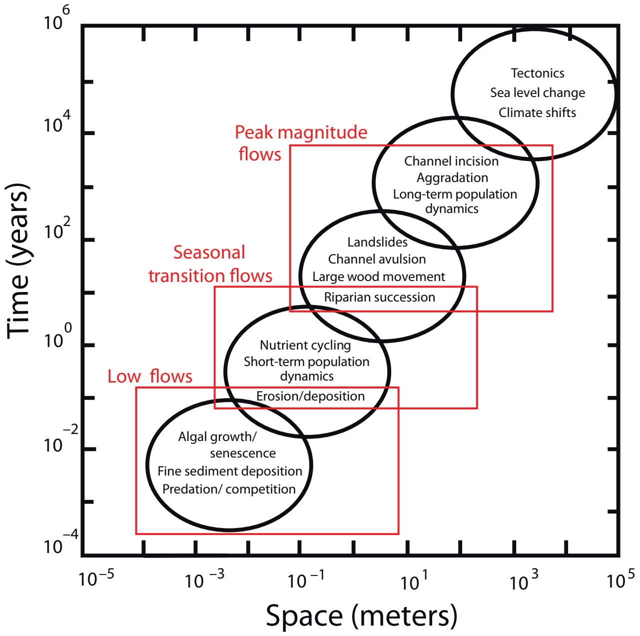

Figure 1. Examples of interrelated physical and ecological riverine processes at varying spatial and temporal scales. Key functional flows supporting specific processes are shown in boxes.

Hydrogeomorphic processes are not only influenced by active floodplains but also by the balance between the sediment supplied from the watershed and the ability of the river to move the sediment (Lane 1955). Channels differ in form because of differences in sediment transport capacity and sediment supply (Wohl et al. 2015), as well as variations in riparian vegetation, the presence of coarse legacy substrate and bedrock, floodplain extent, and large woody debris (Petts and Gurnell 2013). In headwater areas, geomorphic diversity is primarily driven by the mobilization of coarse bed material in various aquatic habitats; therefore, the magnitude of stream flow and the availability of sediment are key factors. However, as one moves downstream in the drainage network, the proportion of fine sediment and the total bed material load typically increases, and consideration of bed material mass balance becomes key (Church 2002). Here, geomorphic diversity and aquatic habitats can only be maintained if the duration of high flows is sufficient to maintain the flux of bed material supplied from further upstream.

In regulated rivers with large dams, the upstream sediment supply is typically trapped behind the dams, creating a sediment mass balance deficit downstream. If the relationship between flood duration, which correlates with total transport capacity, is not in balance with the limited sediment available below the dam, subsequent scour and bed degradation can occur, such as in the immediate 25 kilometers (km) downstream from Glen Canyon Dam on the Colorado river (Grams et al. 2007). Conversely, if a regulated river has large sediment inputs from unregulated tributaries or lacks transport capacity because of large flow diversions, such as in the Rio Grande in the Big Bend region of Texas and Chihuahua (Dean and Schmidt 2013), the sediment mass balance may be perturbed into surplus. Short duration floods are insufficient to transport large volumes of residual sediment downstream, limiting the geomorphic diversity and maintenance of associated instream channel habitats.

Achieving greater river functionality in highly modified riverscapes requires the enhancement of dynamic spatiotemporal interactions. Recent emphasis on process-based restoration has drawn attention to the connections between hydrologic and geomorphic dynamics (Beechie et al. 2010, Wohl et al. 2015). In general, greater floodplain benefits accrue when physical habitat restoration, sediment transport, and flow regimes are considered together. In some locations, levee setbacks or reclaimed farmland adjacent to the channel have been coupled with e-flows to restore floodplain dynamics (e.g., Greco and Larsen 2014). In other cases, coarse sediment has been added to the river to promote sediment transport and redistribution of bed material to create instream habitat diversity (e.g., Gaeuman 2014). Incorporating a process-based view of how flows interact with the riverscape is more likely to produce a self-sustaining and resilient river ecosystem (Beechie et al. 2010). Furthermore, a process-based view allows for future climate or land use changes to be taken into account versus empirical approaches that rely on assumptions of stationarity and static management prescriptions (Null and Viers 2013).

In many contemporary riverscapes, opportunities for process-based restoration may be found at tributary junctions along the drainage network, locations where the valley morphology naturally widens, where access to the historic floodplain is politically possible, or where sediment can be actively recruited into the channel, creating a diversity of bed material sizes. Considered "biological hotspots" (Benda et al. 2004), tributary junctions are zones of geomorphological and hydraulic diversity with enhanced channel dynamics, increased channel width, increased local sediment supply, and low-energy backwater habitats with thermal upwelling benefits. Similarly, areas with channel widening that promote local deposition and bar development or areas with local sediment inputs that provide coarse substrate in a fine-grained channel bed can provide hotspots of habitat diversity within a more uniform river reach (Yarnell 2008). These various types of hotspots may be seen as loci of core populations and assemblages that can buffer aquatic and riparian metacommunities against environmental change, providing stable sources of dispersers to recolonize peripheral habitats following a major disturbance. In highly modified rivers with complex water demands and limited "room for the river" (Warner and van Buuren 2011), functional flows maximize the benefits from limited environmental flow allocations. This may be achieved by focusing on the ecological and geomorphological functionality of particular aspects of the flow regime, considering geomorphic context and emphasizing spatiotemporal diversity at key locations

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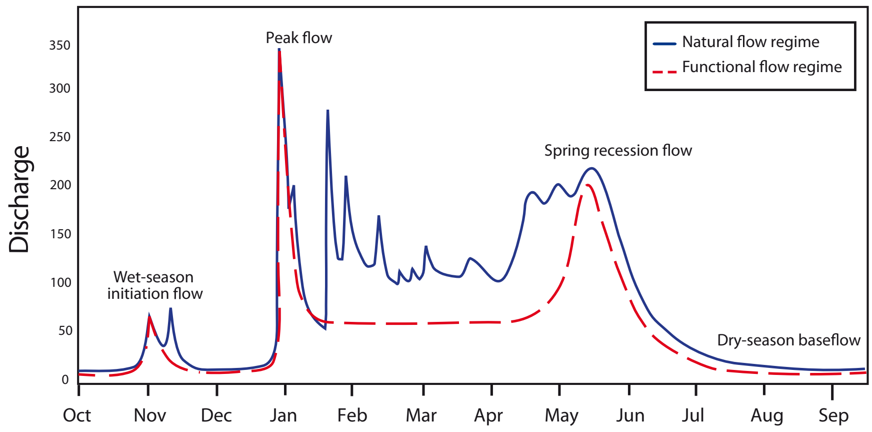

Figure 2. Natural and functional flow regimes in a Mediterranean–montane climate, where spring occurs April to June. Peak flows are typically rain-driven events in winter, whereas a pronounced snowmelt pulse occurs in spring. The functional flow regime retains key components of the natural hydrograph that support physical and ecological processes across the riverscape.

in the riverscape, such as adjacent floodplains or tributary junctions.

Defining functional flows

A *functional flow* is a component of the hydrograph that provides a distinct geomorphic or ecological function (*sensu* Escobar-Arias and Pasternack 2010). These functions may include geomorphic processes (Escobar-Arias and Pasternack 2010), ecological processes (Ward et al. 2002), or biogeochemical processes (Vidon et al. 2010). Such processes in rivers and associated biotic interactions operate in three dimensions—longitudinally, laterally, and vertically—and are intimately tied to the timing, duration, and frequency of natural flows. Therefore, functional flows must attempt to reflect the natural patterns of flow variability.

Most rivers in the western US have a distinct season of high-magnitude flow, with low flows dominating the remainder of the year. In Mediterranean-montane environments of the Pacific region, winter precipitation events create rain-driven floods at low and moderate elevations and spring snowmelt floods from high elevation snowpack. Streams draining the Rocky Mountains into the Missouri and Colorado Rivers have a well-defined spring snowmelt flood season, whereas the southern Rocky Mountain and southwest mountain regions have a pronounced spring snowmelt season and a later summer flood season associated with the North American monsoon. For many native species adapted to these cyclic flow regimes, high flows present significant abiotic pressures (e.g., high main-stem velocity, high turbidity), whereas intermediate and low flows present significant biotic pressures (e.g., competition, predation) (Lytle and Poff 2004, Yarnell et al. 2010). However, flood and drought cycles, their seasonal transitions, and their associated temperature changes provide breeding, migration, and other life-history cues for most endemic species.

Recognizing that e-flow recommendations mimicking the full natural flow regime are not likely to be implemented in highly developed rivers where societal demands are well established, we attempt here to identify the most essential functional flows that support physical and biotic processes, emphasizing their timing, duration, rate of change, and frequency (figure 2). Below, we delineate five key components of the flow regime that drive ecosystem processes and should be incorporated into the existing environmental flow framework.

Wet-season initiation flows. Whether the onset of high flows begins with the first substantial rains of late fall in the Pacific region or with the first substantial melting of the winter snowpack, as in the Rocky Mountains, the transition from dry season to wet season signals the start of a dramatic annual shift in riverine conditions. The first high flows of the season typically have higher suspended sediment concentrations as sediments accumulated on hillslopes and in channels during the dry season are flushed downstream. In some landscapes, these "initiation flows" kick-start ecological processes such as nutrient cycling (Ahearn et al. 2006) and provide key ecological cues for native species, such as upstream migration in the Pacific region (Sommer et al. 2011, Kiernan et al. 2012) and spawning in semiarid rivers (Propst and Gido 2004). The timing of these first high flows is essential for life-history cues, whereas the magnitude and duration are important for revitalizing the riverscape by reconnecting channel–riparian–floodplain habitats, flushing organic matter and fines from gravel spawning beds, increasing soil moisture, and reactivating exchanges with the hyporheic zone (Stubbington 2012).

The timing of wet-season initiation flows should coincide, to the degree possible, with the onset of wet-season precipitation or initial snowmelt runoff. For many native species, this first turbid flow event provides a key life-history cue to migrate upstream and begin spawning. In the California Delta, at the confluence of the Sacramento and San Joaquin Rivers, the endangered Delta smelt (*Hypomesus transpacificus*) is a short-lived endemic minnow that resides in the Delta estuary and relies on "first flush" pulses of more turbid, lower salinity, colder water in the fall to cue their upstream migratory response (Sommer et al. 2011). Similarly, the Colorado pikeminnow (*Ptychocheilus Lucius*) in the Colorado River initiates migration for spawning in response to the flow and temperature cues associated with the initial increase of the spring snowmelt pulse (Schmidt and Brim-Box 2004). Alterations to the timing of or complete lack of this key flow event can be detrimental to the life-history strategies of these native species.

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The magnitude of an initiation flow should be such that connectivity with the riparian zone is established and organic matter can be flushed from the channel substrate. The buildup of organic material and fines can impede the success of salmonid spawning in gravel beds (Kemp et al. 2011) and over time can contribute to increased vegetation encroachment and decreased substrate diversity in the main channel. On many rivers, such flushing flows that remove sand from riffles and organic fines from pools and riparian edgewaters can be effective at or above 60% bankfull depth. The duration of flushing flows should be adequate to cue species migration or initiate nutrient exchange in floodplains. In California's Cosumnes River floodplain, for example, Ahearn and colleagues (2006) observed that the timing and intensity of the first flushing flow of the season, which typically lasted only a few days, determined water chemistry patterns throughout the watershed.

On some rivers, wet-season initiation flows can be accomplished by simply letting the first sediment-laden flood of the season or the initial rise of the snowmelt flood pass through reservoirs to reflect the natural passage through the watershed. This may be more easily accomplished in rivers with small storage reservoirs that are quickly filled, but even in highly regulated rivers, where large reservoirs can store the full annual flow, wet-season initiation pulse flows can be designed to match unregulated reference conditions. In Putah Creek, California, a more natural flow regime was implemented that included fall pulse flows at the start of the wet season designed to initiate migration of native fish species (Kiernan et al. 2012). In combination with elevated spring spawning flows, the new flow regime resulted in an increase in native species abundance and a reduction in nonnative species throughout the upper 20 km of the 30-km stream.

Peak magnitude flows. Large-magnitude peak flows during the annual flood season typically transport a significant portion of the annual sediment load and restructure the channel and floodplain landforms, which create the habitat template of the river corridor ecosystem. These large-scale disturbances serve to reset natural processes such as succession (Ward 1998); to redistribute large volumes of sediment through scour and fill, creating channel bed, bank, and floodplain variability (Florsheim and Mount 2002); and to cause the mortality of exotic species not adapted to the disturbance regime (Kiernan and Moyle 2012). Channel-filling and overbank flows initiate nutrient cycling within the floodplain (Ahearn et al. 2006), scour vegetation encroaching the channel, and disperse seeds and wood fragments to rejuvenate riparian vegetation (Petts and Gurnell 2013). As such, peak flows serve as a primary driver for ecosystem processes that maintain habitat diversity over the long term.

The magnitude of a peak flow should be large enough to mobilize bed material and maintain in-channel bar forms, connect to overbank areas and floodplains, and occur with a frequency of 1–3 years depending on regional climate conditions. Very large magnitude peak flows that cause extensive floodplain scour and fill and reset floodplain vegetation succession naturally occur every 10–20 years; however, such geomorphologically effective floods are typically incompatible with highly modified rivers, where the alluvial valley is developed for agriculture and residential communities. Without space within the river corridor for lateral channel migration, inundation of floodplain depressions, and backwater channels, the geomorphic functionality of peak flows is limited. Therefore, connections to the floodplain (e.g., levee breaches) and the expansion of overbank areas (e.g., levee setbacks) should be enhanced and maintained wherever possible.

The timing of a peak magnitude flow should occur within the natural season of high flows when native species have life-history strategies to survive and even capitalize on these large-scale floods. In California, native amphibians retreat to protected riparian areas during winter floods, whereas native juvenile fish occupy shallow low-velocity overbank habitats and avoid high-velocity conditions in the main channel (Yarnell 2008; Kiernan et al. 2012). Peak flows can provide ecologic cues for migration and spawning, as well as the flow volume needed to create a migration corridor. For example, Columbia River salmon use high spring snowmelt flows to migrate upstream to small streams suitable for spawning. Shifts in the timing of peak flows, particularly to seasons that naturally might be dominated by low flows, can be detrimental to the life-history strategy of these native species.

The duration of peak flows should allow ecologic processes such as floodplain activation, species migration, and spawning to occur. For example, Ahearn and colleagues (2006) showed that as flood pulse flows inundate the Cosumnes River floodplain, wetted soil promotes a bloom of phytoplankton, which in turn drives the secondary production of zooplankton. Juvenile Chinook salmon (*Oncorhynchus tshawytscha*) rearing in the floodplain feed on the zooplankton, leading to high growth rates (Jeffres et al. 2008). Simultaneously, native splittail (*Pogonichthys macrolepidotus*) use the inundated floodplain habitat for breeding, with larval fish emerging within several weeks. These ecological processes and cues are dependent on the sustained floodplain inundation of a minimum of three weeks and periodic connectivity between the topographically heterogeneous floodplain and the river.

Although the duration of a peak flow should also be sufficient to facilitate desired geomorphic processes, such as floodplain deposition, pool scour, or channel bar formation, the duration should not be longer than the time needed to transport the annual available supply of bed material. Particularly in rivers perturbed into sediment deficit, extended duration floods are likely to further erode sediment deposits that are already infrequent and can result in net erosion of the channel unless sediment supplies are augmented naturally by access to historic floodplains or artificially by gravel augmentation. For example, in the Colorado River,

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controlled floods have been released from Glen Canyon Dam to mobilize the small amounts of sand supplied from unregulated tributaries and transfer the sediment to eddy sandbars that are of recreational and ecological importance (Melis et al. 2012). These floods have short durations of 2–7 days and are half the magnitude of the pre-dam annual flood in an effort to limit erosion of the remaining pre-dam fine sediment and redistribute only the sand supplied from the tributaries. In contrast, in rivers perturbed into sediment surplus, the flood duration must be sufficiently long to transport the annual accumulation of sediment and limit channel infilling. In the Rio Grande River along the US–Mexico border, sediment surplus conditions exacerbate the problems of fine sediment accumulation, particularly during short-duration flood pulses that attenuate quickly and rapidly deposit their sediment load, inducing the vertical aggradation of the floodplain and channel narrowing (Dean and Schmidt 2013).

The management of the magnitude, timing, and duration of peak flows is easier in rivers where reservoir volume is relatively small and natural high flows can spill downstream, where dams have the capacity to release high flows via controlled outlets or spillways, and where water-supply demands can be met. Challenges occur when reservoirs are large and rarely spill, when hydropower or water supply demands are highly seasonal and out of phase with the natural runoff, or when the infrastructure to release high flows is limited. In the Yuba River in California, peak winter runoff and spring snowmelt flows are captured for agricultural water supply during the low-flow summer season. Environmental flow negotiations have resulted in the release of spring high flows in all but the driest years, designed to support the rejuvenation and maintenance of Chinook salmon–spawning conditions on gravel–cobble bars (5 April 2015; *www.yubaaccordrmt.com*). In contrast, in the Colorado River basin, the annual snowmelt peak historically occurred in May and June, but the demands for hydropower—and therefore high flows from the powerhouses—are largest in December–January and July–August. Controlled floods to redistribute sediment are now scheduled (2012–2014) during the historically low-flow period in November to mobilize newly deposited sediments supplied from the unregulated tributaries. Although these controlled floods provide some geomorphic functionality to the Colorado River in Grand Canyon by rebuilding channel bars, the timing is out of phase with the natural flow regime.

Spring recession flows. The spring flow transition from high flow to low flow is often identified as a part of the hydrograph from which stream flows can be extracted without significant geomorphic and ecological effect (Schmidt and Potyondy 2004). However, the spring flow recession is predictable in its timing and rate of flow change and therefore provides distinctive annual cues for the reproduction and movement of native species (Yarnell et al. 2010), particularly in regions with highly seasonal climates. These cues are primary ecologic drivers in population dynamics such that changes in the timing or shape of the flow recession can alter aquatic community composition and limit reproductive success (Marchetti and Moyle 2001). Gradually receding flows can also be a key factor in redistributing sediments mobilized by high peak flows (Yarnell et al. 2010). When sediments are recruited and entrained at high flows, slowly receding flows allow for continued sediment movement in deeper channel locations and gradual deposition throughout shallow channel habitats.

The initial magnitude of recession flows is typically associated with the spring snowmelt peak, and the rate of declining flow should mimic the natural gradual recession rates shown to provide suitable habitat conditions for native species (Yarnell et al. 2010). The character of water storages—ice, snow, groundwater, lake—determines the typical flow recession curve for each river basin. In the Sierra Nevada mountain range of California, daily spring flow recession rates were found to be consistent across latitude, elevation, and watershed area, with flows decreasing from 4–8% per day across the entire spring season (Yarnell et al. 2013). These recession rates are slow enough that suitable spring spawning habitat for native species, such as the riffle sculpin and the foothill yellow-legged frog, persists for two to four weeks in any one channel location, allowing the emergence from eggs before the habitat disappears as flows continue to decrease (Yarnell et al. 2013). In southwestern US rivers, the recruitment-box model for cottonwood germination suggests spring flow recession rates should not exceed 2.5 centimeters per day in order for cottonwood (*Populus* spp.) to germinate and young sapling roots to follow the receding water level (Mahoney and Rood 1998). These recession rates are such that the duration of receding flows sustains the persistence of various aquatic habitats used by native species for successful reproduction and therefore should be replicated in regulated rivers to the extent possible.

The timing of recession flows should coincide with natural climatic conditions (e.g., during spring snowmelt) when temperatures and precipitation regimes are changing. For many native spring spawners, the flow recession provides a cue that appropriate higher-flow spawning conditions will soon transition into warm, low-velocity habitats suitable for early life stages. The foothill yellow-legged frog (*Rana boylii*) is a river-breeding amphibian native to California and southern Oregon highly adapted to the natural seasonal flow regime (Yarnell 2008). Individuals breed annually in early spring following the start of the snowmelt recession, timing their reproduction to minimize the risk of egg scour from late-spring storms, and to maximize tadpole growth during summer low flows. Similarly, successful cottonwood recruitment requires not only an appropriately slow recession flow rate but also the appropriate timing to coincide with seed dispersal (Mahoney and Rood 1998). In order to successfully reproduce, the endangered Rio Grande silvery minnow (*Hybognathusamarus*) requires access to suitable floodplain habitat for spawning in late April and May and a

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gradual flow recession with lateral connectivity to the main channel (Medley and Shirey 2013). In regulated rivers with altered spring and summer flow regimes, these native species populations have been extirpated or persist in very low numbers. The prescription of a flow regime that gradually ramps down from a spring high-flow event by appropriately mimicking the rate and timing of natural spring snowmelt recessions will provide the greatest opportunity for the successful reproduction of these and other native species.

The implementation of spring recession flows in regulated rivers is limited primarily by the system's infrastructure. If high spring flows are the result of spill over the dam, control valves or lower-level outlets must be used to appropriately ramp down flows from spill to baseflow. In some instances in the northern Sierra Nevada in California, this has required modifications to spill gates or changes in the low-level outlets of the dam (Yarnell et al. 2013). Although there can be potential costs to hydropower generation by extending spring flow releases in a recession, if the flows are timed appropriately to coincide with naturally occurring higher spring flows, the costs can be minimal or recouped by storage downstream (Rheinheimer et al. 2013). In rivers with a sediment surplus, the design of a flow recession should include consideration of the volume of sediment supplied by upstream reaches, whereas in rivers where sediment is limited, consideration of augmentation to local sediment sources may be needed to promote redistribution of sediment throughout the channel.

Dry-season low flows. The duration and magnitude of dry-season low flows are important drivers of riverine ecosystems, because most native species are adapted to survive these biologically stressful periods. The magnitude and duration of low flows dictate the extent and quality of physical habitat, thereby affecting the composition and distribution of riverine biota. As low flows restrict the connectivity of instream habitat, ecological-niche partitioning can occur with native species using low-flow refugia or exhibiting adaptive life-history strategies (Lee and Suen 2012). Artificially high baseflows can maintain connectivity, but often to the benefit of nonnative species that are not adapted to the limiting conditions of natural low-flow periods (Kiernan and Moyle 2012). Extended constant base flows can also lead to silt accumulation in the channel bed, reducing instream channel diversity and species diversity (Moyle and Mount 2007).

Although the prescribed magnitude of low flows or minimum instream flows in regulated rivers is a well-studied and extensively debated topic (e.g., Jowett 1997), we suggest that the magnitude of low flows should be low enough to produce naturally limiting habitat conditions, such as floodplain disconnection, but still maintain natural stream characteristics, such as perenniality or ephemerality. On the lower Santa Clara River in southern California, geological controls on groundwater historically created an alternating pattern of perennial and intermittent reaches such that a heterogeneous mosaic of mesic and xeric riparian communities occurred in close proximity (Beller et al. 2011). These differing stream reaches provided distinct ecological functions, including refugia from drought and flood, support of extensive willow–cottonwood forests in perennial reaches, and support of the now–regionally rare xeric alluvial scrub in intermittent reaches. Although the maintenance of natural spatial patterns of perennial or intermittent flow in summer can be an important component to supporting biodiversity, the duration and timing of low flows should reflect premodified conditions to the extent possible so as to limit stressful habitat conditions. The presence of diverse channel habitat that provides a variety of refugia during low flows is key to supporting native species. Although instream geomorphic diversity is created and maintained by sediment mobility at higher flood flows, instream habitat heterogeneity may be augmented by the addition of large woody debris, riparian vegetation, and other cover features that enhance the diversity of habitat available at low flows.

Interannual variability. Year-to-year variation is a key attribute of functional ecosystems that should be incorporated in all e-flow frameworks. Periodic disturbances from climatically driven high-flow events have been shown to reset successional stages in river systems (Ward 1998) and to regulate river food webs by decreasing the abundance of predator-resistant primary consumers, which supports more diverse food chains (Power et al. 2013). Therefore, the magnitude, timing, and duration of specific flow events should vary within their associated season, depending on the regional climatic conditions, and between years, depending on global climate conditions. When combined with spatial heterogeneity throughout the channel and floodplain, this interannual variability supports diversity in habitat conditions, associated recruitment opportunities and refugia from competition, and subsequent diversity in native species (Naiman et al. 2008, Petts and Gurnell 2013).

Functional flows can accommodate this variability by constituting a suite of hydrographs reflecting different strategies for wet, dry, and normal years (figure 3; Petts 1996). Occasional large-magnitude, long-duration floods should be planned for climatically wet years when water is plentiful, whereas smaller-magnitude, shorter-duration peak flows should occur in drier years. In most western US rivers, climate conditions cycle through periods of wetter and drier years, resulting in a diversity of flow conditions over the long term. Maintenance of this interannual variability in regulated rivers can also help to limit the spread of nonnative species that are less adapted to regional flow variation (Kiernan et al. 2012) and build greater resilience under continued land-use change and changing climate conditions (Viers and Rheinheimer 2011).

Considerations for management

Managing toward the recovery and maintenance of physical processes and connections in highly modified riverscapes requires more than applying simple hydrometric criteria to

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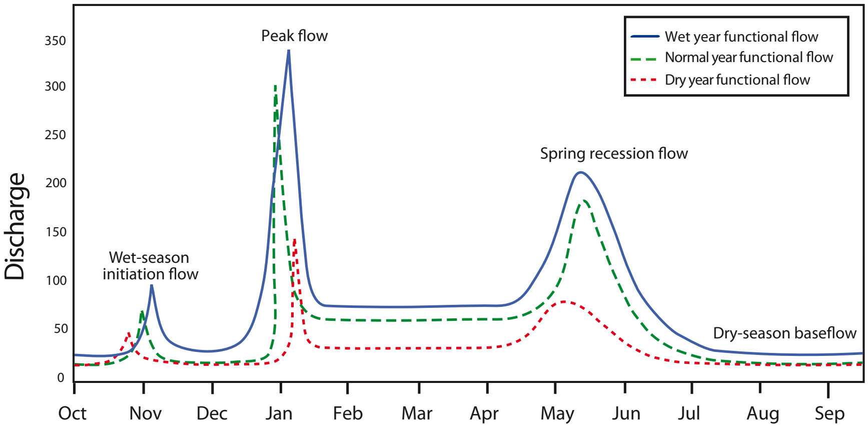

Figure 3. Climatically variable functional flow regimes in a Mediterranean–montane climate, where spring occurs April to June.

mimic the natural flow regime. Considering the interaction of hydrologic, geomorphic, and ecologic processes and the functions they serve is more likely to result in e-flow targets that better support self-sustaining ecosystems that are inherently diverse and adaptive (Florsheim and Mount 2002, Beechie et al. 2010). The specific functional flows presented here support many of the key processes that link riverine dynamics across space and time (see figure 1) and therefore can serve to restore ecological integrity and functionality in highly modified rivers. Resource managers have the opportunity to actively promote restoration by coupling a functional-flows approach with landform reconstruction to encourage connectivity within the riverscape and to initiate natural riverine processes (box 1).

A functional-flows approach focuses on flow and geomorphic components with process-based outcomes. This differentiates it from other e-flow approaches in that flow allocations are made with consideration of how the duration, timing, and rate of change of flows—rather than just the magnitude—are influenced by the geomorphic context and sediment supply conditions. However, functional flows can be readily incorporated into existing e-flow frameworks, such as regional Instream Flow Incremental Methodology (IFIM) approaches (e.g., Denslinger et al. 1998) or the ELOHA framework (Poff et al. 2010), in which consideration of geomorphic context may be mentioned but not developed. In the simplest terms, the IFIM framework is fundamentally a bottom-up approach (adding various flows to a static minimum as needed to achieve a desired outcome) versus ELOHA, which is a top-down approach (starting with the full natural flow regime and removing flow until there are ecological consequences). In both cases, the consideration of key functional flows either allows for specific flows to be added or places limitations on which flows should be removed. Indeed, in the most heavily modified catchments with competition from water users and regulated rivers supported by only a constant baseflow, the restoration of a naturalistic flow regime by the addition of key functional flows at the most ecologically significant times of the year, even if not possible in drought years, may be the best option available at the present time.

Conclusions

Riverscapes are physical systems with a history. Under contemporary climate conditions, a river's physical character and dynamics reflect the interaction of hydrological processes and terrestrial vegetation dynamics superimposed on a valley structure, channel form, and sediment supply inherited from previous climatic conditions. However, centuries of land-use change, urban and industrial development, river impoundment and channelization, and water abstraction have imposed artificial flow regimes on simplified river channels that are isolated from their floodplains and fixed in time. In these highly managed and modified river systems, there is a need for greater sophistication in designing and implementing flows that are optimized for multiple uses, including ecosystem services and functioning, water supply, hydropower generation, recharge of local aquifers, and flood control among others.

We suggest that functional flows, as are described herein, provide the best opportunity to encompass geomorphic and ecologic processes and functions alongside varied human needs when developing flow regimes in regulated river systems. At the simplest level, incorporating specific functional flows in rivers with little geomorphologic diversity and/or highly perturbed sediment regimes can provide some ecological benefits for discrete functions, such as high flows to support migratory pathways for fish or to maintain salinity profiles within the fluvial–estuarine transition. In rivers with some geomorphic diversity in channel width, sinuosity, and local bank variability, functional flows promote in-channel habitat heterogeneity and support a broader species assemblage. When functional flows in these rivers further inundate floodplain and overbank areas, large-scale geomorphic and sediment flux processes occur, enhancing physical and ecological diversity in space and time. Given the room for lateral channel–floodplain connections and the consideration of sediment transport conditions, restoration opportunities exist to transform rivers from the simplest forms with limited functions to more complex riverine mosaics with multiple ecosystem functions and services.

Because of the dependence of societies on developed riverscapes and the implications of climate change, the restoration of highly modified rivers to unimpaired conditions is an unrealistic concept. Managing rivers in a nonstationary world requires management strategies and policies that focus on preserving key functions and processes to sustain the dynamically evolving nature of river ecosystems. The functional-flows approach discussed herein provides a basis for the adaptation of current river regulation policies and the development of new strategies to meet such future needs.

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Box 1. Five principles for management of highly modified rivers.

Guiding principles for management of rivers in highly modified riverscapes.

1. Hydrogeomorphic connections within the riverscape should be maintained or restored in order to achieve optimal ecosystem functionality. This requires peak flows equal to at least the channel-filling discharge that can access overbank areas and are of appropriate duration to move the annually delivered sediment supply. The more space given to a channel and its floodplain, the greater the ecological benefit from flood flows.

2. Transitions in flow between seasons should be retained. High turbidity wet-season initiation flows and spring recession flows have high ecological benefit across a riverscape.

3. Seasonality of baseflows should be retained. Higher baseflows in wet seasons support channel margin habitats and promote groundwater recharge, and lower baseflows in dry seasons create habitat partitioning and limit nonnative species. Variations in baseflows can help limit impacts from prolonged constant flows.

4. Flow regimes should reflect interannual climate variability. Larger peak flows, longer duration recessions, and higher baseflows should occur in wet years, whereas smaller, shorter, lower flows should occur in dry years. Within year variability may be necessarily limited in extreme years, such as prolonged drought or flood.

5. Water management for human uses should consider the seasonality of natural flows. Greater water abstraction, high flow releases to the river from hydropower, or water supply deliveries should occur during wetter months rather than drier months. A few floods should be retained at near full magnitude and duration, whereas others are removed for consumptive uses, rather than reducing all flood magnitudes.

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Appendix 8

Re-managing the Flow

The major rivers and streams of the Sacramento Valley provide essential pathways for spawning salmon and steelhead. Flow agreements to benefit these fish are on every major watercourse in the Sacramento Valley.

Trinity and **Shasta Lakes** are important sources of cold water storage. Timing the release of this cold water into the rivers is vital if spawning fish are to thrive.

Clear Creek

In May and June, water is pulsed into Clear Creek to attract Spring-run salmon from the Sacramento River. From June through October, water released from Whiskeytown Reservoir keeps water temperatures cool.

Sacramento River Tributaries

Various flow agreements benefit spring run salmon.

Feather River

A water quality certification adopted in 2010 provides for specific flow and temperature requirements to accommodate spawning salmon and steelhead.

Sacramento River below Keswick Dam

In 1960, flow objectives were established for the protection of fish and wildlife. In 1990 and 1991 this policy was modified requiring more cold water when warmer temperatures would be harmful to fish.

Yuba River

In 2008, the Yuba River Accord increased the streamflow requirements over previous levels, which benefits fish while insuring sufficient water supplies for irrigation and municipal uses.

Sacramento River at Wilkins Slough

The Rivers and Harbors Act of 1935 mandated a specific flow rate at Wilkins Slough be maintained. The primary goals at that time were navigation and flood control. In 1992, Congress made protection of fish and wildlife a secondary goal and this requirement was updated in 2009.

American River below Nimbus Dam

In 2000, the Flow Management Standard was developed, which established minimum flow standards to improve the conditions for fall-run Chinook salmon and steelhead. Additionally, releases are adjusted to maintain sufficiently low water temperatures for steelhead rearing in summer and Chinook spawning in the fall.

NCWA
Northern California Water Association

For more details visit www.norcalwater.org/efficient-water-management/instream-flows/

Instream Flow Requirements in the Sacramento River Hydrologic Region
Updated: November 2014

This briefing paper describes the existing instream flow requirements for the major rivers and streams in the Sacramento River hydrologic region. These requirements include provisions in State Water Resources Control Board (SWRCB) decisions, biological opinions, streamflow agreements, and other processes. New processes to develop different flow requirements should be aware of, and take into account, these existing flow requirements.

Upper Sacramento River

1. 1960 MOA between Reclamation and DFG

An April 5, 1960, Memorandum of Agreement (MOA) between Reclamation and the DFG originally established flow objectives in the Sacramento River for the protection and preservation of fish and wildlife resources. The agreement provided for minimum releases into the natural channel of the Sacramento River at Keswick Dam for normal and critically dry years (Table 1, below). Since October 1981, Keswick Dam has operated based on a minimum release of 3,250 cfs for normal years from September 1 through the end of February, in accordance with the MOA. This release schedule was included in Order 90-05 (described below), which maintains a minimum release of 3,250 cfs at Keswick Dam and Red Bluff Diversion Dam (RBDD) from September through the end of February in all water years, except critically dry years.

The 1960 MOA provides that releases from Keswick Dam (from September 1 through December 31) are made with minimum water level fluctuation or change to protect salmon to the extent compatible with other operations requirements. Releases from Shasta and Keswick Dams are gradually reduced in September and early October during the transition from meeting Delta export and water quality demands to operating the system for flood control and fishery concerns from October through December.

2. SWRCB Water Rights Order 90-05 and Water Rights Order 91-01

In 1990 and 1991, the SWRCB issued Water Rights Orders 90-05 and 91-01 modifying Reclamation's water rights for the Sacramento River. The orders stated Reclamation shall operate Keswick and Shasta Dams and the Spring Creek Powerplant to meet a daily average water temperature of 56°F as far downstream in the Sacramento River as practicable during periods when higher temperature would be harmful to fisheries. The optimal control point is the RBDD.

Under the orders, the water temperature compliance point may be modified when the objective cannot be met at RBDD. In addition, Order 90-05 modified the minimum flow requirements initially established in the 1960 MOA for the Sacramento River below Keswick Dam. The water right orders also recommended the construction of a Shasta Temperature Control Device (TCD) to improve the management of the limited cold water resources.

Pursuant to SWRCB Orders 90-05 and 91-01, Reclamation configured and implemented the Sacramento-Trinity Water Quality Monitoring Network to monitor temperature and other parameters at key locations in the Sacramento and Trinity Rivers. The SWRCB orders also required Reclamation to establish the Sacramento River Temperature Task Group (SRTTG) to formulate, monitor, and coordinate temperature control plans for the upper Sacramento and Trinity Rivers. This group consists of representatives from Reclamation, SWRCB, NMFS, the Service, DFG, Western, DWR, and the Hoopa Valley Indian Tribe.

Each year, with finite cold water resources and competing demands usually an issue, the SRTTG devises operation plans with the flexibility to provide the best protection consistent with the CVP's temperature control capabilities and considering the annual needs and seasonal spawning distribution monitoring information for winter-run and fall-run Chinook salmon. In every year since the SWRCB issued the orders, those plans have included modifying the RBDD compliance point to make best use of the cold water resources based on the location of spawning Chinook salmon. Reports are submitted periodically to the SWRCB over the temperature control season defining the temperature operation plans. The SWRCB has overall authority to determine if the plan is sufficient to meet water right permit requirements.

3. June 4, 2009 NMFS Biological Opinion

The National Marine Fisheries Service's (NMFS) June 4, 2009, Biological Opinion and Conference Opinion on the Long-Term Operations of the Central Valley Project and State Water Project (NMFS BiOp) contains numerous terms and conditions addressing instream flows on the Upper Sacramento River.

Table 1 below, as excerpted from the NMFS BiOp (at page 254), identifies the aforementioned MOA and SWRCB order requirements, and Reclamation's proposed flow objectives below Keswick that were analyzed in the NMFS BiOp.

Table 1: Minimum flow requirements and objectives (cfs) on the Sacramento River below Keswick Dam

Water year type	MOA	WR 90-5	MOA and WR 90-5	Proposed Flow Objectives below Keswick
Period	Normal	Normal	Critically dry	All
January 1 - February 28(29)	2600	3250	2000	3250
March 1 - March 31	2300	2300	2300	3250
April 1 - April 30	2300	2300	2300	---*
May 1 - August 31	2300	2300	2300	---*
September 1 - September 30	3900	3250	2800	---*
October 1 - November 30	3900	3250	2800	3250
December 1 - December 31	2600	3250	2000	3250
Note: * No regulation.				

The flow related components of the NMFS BiOp related to the Sacramento River Basin are detailed in the Reasonable and Prudent Alternatives (RPA) section of BiOp at pages 587 through 611. The RPA Actions include flow requirements on Clear Creek; release requirements from Whiskeytown Dam for temperature management; cold water pool management of Shasta Reservoir; development of recommended minimum flows at Wilkins Slough; and restoration of floodplain habitat in the lower Sacramento River basin for protection of certain listed species. A selection of the more specific flow-related requirements are described below.

Clear Creek Operations

RPA Action I.1.1 - Clear Creek Spring Attraction Flows

Reclamation shall annually conduct at least two pulse flows in Clear Creek in May and June of at least 600 cfs for at least three days for each pulse, to attract adult spring-run holding in the Sacramento River main stem. This may be done in conjunction with channel-maintenance flows (Action I.1.2).

RPA Action I.1.2. – Clear Creek Channel Maintenance Flows

Reclamation shall re-operate Whiskeytown Glory Hole spills during the winter and spring to produce channel maintenance flows of a minimum of 3,250 cfs mean daily spill from Whiskeytown for one day, to occur seven times in a ten-year period, unless flood control operations provide similar releases. Re-operation of Whiskeytown Dam should be implemented with other project facilities as described in the EWP Pilot Program (Reclamation 2008d).

RPA Action I.1.5. – Clear Creek Thermal Stress Reduction

Reclamation shall manage Whiskeytown releases to meet a daily water temperature of:

(1) 60 deg. F at the Igo gage from June 1 through September 15; and

(2) 56 deg. F at the Igo gage from September 15 to October 31.

Reclamation, in coordination with NMFS, will assess improvements to modeling water temperatures in Clear Creek and identify a schedule for making improvements.

RPA Action I.1.6. - Adaptively Manage to Habitat Suitability/IFIM Study Results on Clear Creek

Reclamation shall operate Whiskeytown Reservoir as described in the Project Description with the modifications described in Action I.1 until September 30, 2012, or until 6 months after current Clear Creek salmonids habitat suitability (*e.g.*, IFIM) studies are completed, whichever occurs later.

When the salmonid habitat suitability studies are completed, Reclamation will, in conjunction with the Clear Creek Technical Working Group (CCTWG), assess whether Clear Creek flows shall be further adapted to reduce adverse impacts on spring-run and CV steelhead, and report their findings and proposed operational flows to NMFS within 6 months of completion of the studies. NMFS will review this report and determine whether the proposed operational flows are sufficient to avoid jeopardizing spring-run and CV steelhead or adversely modifying their critical habitat.

Reclamation shall implement the flows on receipt of NMFS' written concurrence. If NMFS does not concur, NMFS will provide notice of the insufficiencies and alternative flow recommendations. Within 30 days of receipt of non-concurrence by NMFS, Reclamation shall convene the CCTWG to address NMFS' concerns. Reclamation shall implement flows deemed sufficient by NMFS in the next calendar year.

Shasta Operations

RPA Action Suite I.2 – Shasta Operations

This suite of actions is designed to ensure that Reclamation uses maximum discretion to reduce adverse impacts of the projects to winter-run and spring-run in the Sacramento River by maintaining sufficient carryover storage and optimizing use of the cold water pool.

RPA Action I.2.1 – Performance Measures

The following long-term performance measures shall be attained. Reclamation shall track performance and report to NMFS at least every 5 years. If there is significant deviation from these performance measures over a 10-year period, measured as a running average, which is not explained by hydrological cycle factors (*e.g.,* extended drought), then Reclamation shall reinitiate consultation with NMFS.

Performance measures for end-of-season ("EOS") carryover storage at Shasta Reservoir:

- 87 percent of years: Minimum EOS storage of 2.2 MAF
- 82 percent of years: Minimum EOS storage of 2.2 MAF and end-of-April storage of 3.8 MAF in following year (to maintain potential to meet Balls Ferry compliance point)
- 40 percent of years: Minimum EOS storage 3.2 MAF (to maintain potential to meet Jelly's Ferry compliance point in following year)

Measured as a 10-year running average, performance measures for temperature compliance points during summer season shall be:

- Meet Clear Creek Compliance point 95 percent of time
- Meet Balls Ferry Compliance point 85 percent of time
- Meet Jelly's Ferry Compliance point 40 percent of time
- Meet Bend Bridge Compliance point 15 percent of time

RPA Actions I.2.2 through I.2.4 – Keswick Release Schedules

Depending on EOS carryover storage and hydrology, Reclamation is mandated to develop and implement Keswick release schedules, and reduce deliveries and exports, as detailed in RPA Actions I.2.2.A through I.2.2C, I.2.3.A through I.2.3.C, and I.2.4. (See NMFS BiOp at pp. 593-603.)

Required Technical Teams for Adaptive Management

The NMFS BiOp requires actions by various Fisheries and Operations Technical Teams whose function is to make recommendations for adjusting operations to meet contractual obligations for water delivery and minimize adverse effects on listed anadromous fish species. The two teams on the Upper Sacramento River are the SRTTG and the CCTWG. Each group must gather and analyze information, and make recommendations, regarding adjustments to water operations within the range of flexibility prescribed in the implementation procedures for a specific action in their particular geographic area.

4. Wilkins Slough Navigation Flow Requirements Under Federal Law

The NMFS BiOp requires the development of certain recommendations regarding the Wilkins Slough navigation flow requirements. Reclamation's compliance with the Wilkins Slough 5,000 cfs navigation flow standard, however, is not discretionary.

In this regard, Congress initially authorized the construction of certain facilities for the Central Valley Project ("CVP") under the Rivers and Harbors Act of 1935 (the "1935 Act"). (49 Stat. 1028, 1038). The 1935 Act mandated in relevant part that "the following works of improvement of rivers . . . are hereby adopted and authorized . . . in accordance with the plans recommended in the respective reports hereinafter designated and subject to the conditions set forth in such documents . . . Sacramento River, California; Rivers and Harbors Committee Document Numbered 35, Seventy-third Congress . . . ." (50 Stat. 1028, 1038.) As such, the 1935 Act incorporates by reference, and expressly requires the implementation of, the recommendations of the Rivers and Harbors Committee Document Number 35. This document is a 1934 report from the Corps' Chief Engineer recommending to Congress that Kennett Dam (predecessor to Shasta Dam) "shall be operated so as to provide a minimum flow of 5,000 cubic feet per second between Chico Landing and Sacramento." (*See* Central Valley Project Documents, Part I, 544, 548 [Committee Doc. 35, 73rd Cong.].)

Congress re-authorized the CVP under the Rivers and Harbors Act of 1937 (the "1937 Act"). (50 Stat. 844, 850.)[1] This re-authorization mandated in relevant part that "the $12,000,000 recommended for expenditure for a part of the Central Valley project, California, in accordance with the plans set forth in Rivers and Harbors Committee Document Numbered 35, Seventy-third Congress, and adopted and authorized by the provisions of section 1 of the Act of August 30, 1935 (49 Stat. 1028, at 1038) . . . shall, when appropriated, be available for expenditure in accordance with the said plans of the Secretary of Interior instead of the Secretary of War."

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[1] *See also Stockton East Water District, et al. v. United States*, 583 F.3d 1344, 1349 (Fed. Cir. 2009) [citing to the 1935 and 1937 Acts as Congress' initial authorization and reauthorization of the CVP].

(50 Stat. 844, 850.) As such, the 1937 Act also incorporates by reference, and expressly requires the implementation of, the recommended minimum flow of 5,000 cfs between Chico Landing and Sacramento. There has been no subsequent action by Congress that has "discontinued" or otherwise changed this minimum navigation flow requirement.

The 1937 Act also mandates that CVP "dams and reservoirs *shall* be used, *first*, for river regulation, improvement of navigation, and flood control; second, for irrigation and domestic uses; and, third, for power." (50 Stat. 844, 850, emphasis added; *see also United States v. SWRCB* (1986) 182 Cal.App.3d 82, 135.) In 1992, Congress explicitly amended this hierarchy of use by enacting sections 3406(a) and (b) of the Central Valley Project Improvement Act (Pub. L. No. 102-575 (1992)), which make protection of non-ESA listed fish and wildlife co-equal priorities with irrigation. Even with this amendment, however, Reclamation's first priority remains river regulation, navigation and flood control.

On the Sacramento River, all major diversions have positive barrier flat-plate fish screens installed that provide protection to listed fishery species. These screens have been designed with an approach velocity of 0.33 ft/s as required by NMFS and the Department of Fish and Game. During design, the screens, velocities, and diversion rates were based upon the Wilkins Slough Navigational Flow requirement of 5,000 cfs since this requirement under federal law was controlling.

The NMFS BiOp states that flows could be reduced to 3,250 cfs, which is lower than the Wilkins Slough flow requirement. If the Bureau of Reclamation reduced flows below the Wilkins Slough control point requirement and depending on the diversion rate, some screens may not meet the velocity criteria as designed. The agencies should coordinate with the Sacramento River diverters to develop contingency plans and wells as a coordinated operations plan that would benefit the Sacramento River system for fisheries and water users.

Sacramento River Tributaries

1. *Antelope Creek*

2014 Voluntary Agreement with Water Users, National Marine Fisheries Service (NMFS) and California Department of Fish and Wildlife (CDFW)

Spring pulse flows: To meet the needs of out-migrating juvenile spring-run Chinook salmon and for the upstream migration of spring-run Chinook salmon for 2014, a pulse flow was conducted using water volunteered by Los Molinos Mutual Water Company and Mr. Jim Edwards, equal to full natural flow in Antelope Creek. The pulse flow was conducted on May 14-16, 2014 for a 48 hour period.

Fall base flows: Once there is a freshet that doubles the full natural flow (measured at a gage above Edward's Dam) after October 15, but prior to November 1, then a base flow of 35 cfs, or full natural flows (measured at Cone Grove Park), whichever is less, will be maintained through December 31, 2014. If there is not a freshet that doubles the full natural flow, then a base flow of 35 cfs or the full natural flow, whichever is less, will be maintained from November 1 through December 31, 2014.

These were voluntary agreements covering substantially all of the water diverted on Antelope Creek, thus the State Water Resources Control Board emergency regulations did not go into effect.

2. Battle Creek

1998, 2003 and 2006 Agreements with PG&E and the Bureau of Reclamation

For winter-run and spring-run Chinook salmon, the instream flow objective for the North Fork of Battle Creek is 30 cubic feet per second (± 5 cfs). The South Fork of Battle Creek instream flow objective would vary from the Federal Energy Regulatory Commission license condition minimum flow of 5 cfs, to 30 cfs (± 5 cfs). All flows reaching Wildcat Diversion Dam will be released, and no diversion will occur at the main spring collectors at Eagle Canyon. PG&E will block the downstream entrances to fish ladders at the Eagle Canyon and Coleman Diversion Dams unless California Department of Fish and Game, NOAA Fisheries, and US Fish and Wildlife jointly provide PG&E 48 hours advance written notice to open either or both of such downstream entrances.

3. Butte Creek

M&T Ranch and Llano Seco Ranch

In 1997, M&T Ranch and Llano Seco Ranch agreed to dedicate approximately 40 cfs in instream flows from October through June in Butte Creek from Parrott-Phelan diversion to confluence with Sacramento River, for spring-run Chinook and steelhead migration and rearing.

Resource Renewal Institute Court Order

In 1998, the Butte County Superior Court issued an order to change the authorized place of use and point of diversion of 5 cfs of pre-1914 appropriative water rights the Resource Renewal Institute had acquired on Butte Creek, which included the following provisions:

a. The authorized purpose of use in these water rights is now protection of fish and wildlife dependent on instream flows in the portions of Butte Creek that is specified as the place of use;
b. The authorized place of use in these water rights now is Butte Creek between diversion number 54 and the confluence of Butte Creek and Butte Slough (Butte Slough outfall); and,
c. The present authorized point of diversion of these water rights has been eliminated.

4. Deer Creek

<u>2014 Voluntary Agreement with Deer Creek Irrigation District, Grant Leininger, National Marine Fisheries Service (NMFS) and California Department of Fish and Wildlife (CDFW)</u>

For adult spring-run Chinook and juvenile spring-run chinook: From May 30 until June 14, 2014, 50 cubic feet per second (cfs), as measured at the Department of Water Resources (DWR) Gage below Stanford-Vina Ranch Irrigation Company (SVRIC) Diversion Dam, as long as 100 cfs is coming out of the canyon. There will be a proportional reduction in base flow obligation of 1 cfs for each 1 cfs reduction in natural flow below 100 cfs.

June 15 to June 30: 25 cfs, as measured at the DWR Gage below SVRIC Diversion Dam, with Deer Creek Irrigation District (DCID) providing 8.3 cfs during the 25 cfs period.

October 15 to December 31: 50 cfs, as measured at the DWR Gage below the SVIC Diversion Dam, is required for out-migrating yearling juvenile spring-run Chinook and coincidentally Central Valley juvenile and adult steelhead (*Oncorhynchus mykiss*), which are federally listed as Threatened. In the event of a rain freshet, base flows could start on October 1, 2014 if mutually agreed to by NMFS, CDFW and DCID.
Pulse Flows: A minimum of 50 cfs over base flow or full natural flows as recorded at the U.S. Geological Survey (USGS) Stream Gage at the mouth of the canyon above DCID Dam. The duration of the pulse flow in terms of time at which peak flow is maintained will be a minimum of 24 hours but not more than 72 hours. A pulse flow event occurred on May 18-20, 2014 and DCID shall create one more pulse flow event before June 15, 2014. Another pulse flow event may be necessary in June 2014 if monitoring detects fish holding below the SVRIC Diversion Dam.

5. Hat Creek

<u>2002 Federal Energy Regulatory Commission License for the Hat Creek Project</u>

On November 4, 2002, the Federal Energy Regulatory Commission (FERC) issued a new license for the Hat Creek Project. As stipulated in the new license, minimum instream flows in the Hat 1 Bypass Reach were increased from 2 cfs to 8 cfs. In addition, the flow release at the Baum Lake Dam (a minimum of 8 cfs) and accretion flow from the Hat 2 Springs must provide a minimum flow in the lower portion of the Hat 2 Bypass Reach of 43 cfs (measured at the Joerger Diversion Dam).

6. Mill Creek

<u>2014 Voluntary Agreement with Water Users, National Marine Fisheries Service (NMFS) and California Department of Fish and Wildlife (CDFW)</u>

For adult spring-run Chinook and juvenile spring-run Chinook: 50 cubic feet per second (cfs) between April 1 and June 14, 2014, and 25 cfs between June 15 and 30, 2014 for fish passage through the 2.8 miles of stream between the confluence with the Sacramento River and Ward Dam.

If monitoring and evaluations conducted by CDFW determine that fish are not present in lower Mill Creek or water temperatures are not conducive to fish survival during the period of June 15 to 30, 201, and it is mutually agreed to by CDFW and Los Molinos Mutual Water Company (LMMWC), base flows may be reduced below 25 cfs.

For juvenile spring-run Chinook: For the fall period, 50 cfs is required for out-migrating yearling juvenile spring-run Chinook and coincidentally Central Valley juvenile and adult steelhead (*Oncorhynchus mykiss*), which are federally listed as Threatened. In the event of a rain freshet, base flows could start on October 1, 2014 if mutually agreed to by NMFS, CDFW and LMMWC.

Pulse Flows: A minimum of 50 cfs over base flow or full natural flows as recorded at the U.S. Geological Survey (USGS) Stream Gage at the mouth of the canyon above Upper Dam. The duration of the pulse flow in terms of time at which peak flow is maintained will be a minimum of 24 hours but not more than 72 hours. The pulse flows will occur from April 1 through June 30 at a minimum of once every two weeks. If monitoring and evaluations conducted by CDFW determine that fish are not present in lower Mill Creek or water temperatures are not conducive to fish survival during June, and it is mutually agreed to by NMFS, CDFW and LMMWC, pulse flows may cease prior to June 30, 2014.

These were voluntary agreements covering substantially all of the water diverted on Mill Creek, thus the State Water Resources Control Board emergency regulations did not go into effect.

1990, 1996 and 2007 Flow Agreements with Water Users, Department of Water Resources and Department of Fish and Game

The 1990 Agreement: The Department of Water Resources and Fish and Game paid for the construction, operation and maintenance of wells with a capacity of 25 cubic feet per second (the actual well capacity is closer to 10 cfs) for the purpose of increasing flows in Mill Creek for fisheries transportation in the late spring of some years, during the upstream migration of adult spring-run salmon and downstream migration of juvenile salmon and steelhead.

The 1996 Agreement: Los Molinos Mutual Water Company shall provide a minimum of 10 cubic feet per second in addition to the state’s instantaneous capacity (of 10 cfs) for fall-run Chinook immigration and spawning and spring-run Chinook juvenile migration. Los Molinos Mutual Water Company shall release such water upon Fish and Game’s request on or after October 15 and allow such water to continue to flow uninterrupted for the remainder of the calendar year.

The 2007 Agreement: Reaffirms and expands and refines the intent of the earlier agreements to provide spring flows (May 1 through June 15) and fall flows (October 15 through November 30) for spring and fall run Chinook salmon.

Lower American River

The American River provides important fish and wildlife habitat, a high-quality water source, a critical floodway, and a spectacular regional recreational parkway. The Bureau of Reclamation (Reclamation) operates Folsom and Nimbus Dams to provide flood control and water for irrigation, municipal and industrial uses, hydroelectric power, recreation, water quality, and the protection of aquatic resources.

In April of 2000, a diverse group of over 40 local business and agricultural leaders, citizen groups, environmentalists, water managers and local governments ended decades of conflict concerning the American River by signing the Water Forum Agreement (WFA). The foundational elements of the WFA are two coequal objectives: to provide a reliable safe water supply for the region and to preserve fishery, wildlife, recreational, and aesthetic values of the lower American River.

Working in cooperation with Reclamation, California Department of Fish and Game, National Marine Fisheries Service, the U.S. Fish and Wildlife Service, the Water Forum developed the Flow Management Standard (FMS) as an alternative to the standards set by the State Water Resources Control Board in 1958's Decision 893 (the current instream flow requirements on the lower American River). The FMS is intended to improve the condition of aquatic resources in the lower American River, particularly fall-run Chinook salmon and steelhead by improving flow-related habitat and water temperature. In addition, the FMS benefits other fish species, the aquatic environment and the riparian ecosystem of the lower American River Corridor. Designed to achieve these benefits over a wide range of hydrologic conditions, the FMS provides a forum through which biologic and ecologic factors are considered in the river management process, and provides for the analysis of hydrologic and biologic information collected though the monitoring and evaluation component.

The lower American River FMS is designed to allocate flow releases from Folsom and Nimbus Dams in consideration of variable hydrology and cold water pool availability in Folsom Reservoir. The FMS includes: (1) minimum flow requirements; (2) water temperature objectives; (3) implementation criteria; (4) an agency group to address river management and operational actions (the American River Group); and (5) a monitoring and evaluation component.

1. Minimum Flow Requirements

The minimum flow requirements prescribe the flows in the lower American River water to meet fishery needs throughout the entire water year. These minimum flow requirements include minimum release requirements (MRR) measured downstream of Nimbus Dam, and downstream flow requirements (250 cfs from January through mid-September and 500 cfs from mid-September through December) between Nimbus Dam and the mouth of the lower American River. The prescribed flows are minimums only and do not preclude Reclamation from making higher releases.

The MRR varies from 800 to 2,000 cfs throughout the year in response to the hydrology of the Sacramento and American River basins and a set of prescriptive and discretionary adjustments. As such, the specified MRR is higher in wet years and lower in dry years. These adjustments are made in response to specific conditions related to the need for spawning flow progressions, fish protection, and reservoir water conservation. The resultant MRR varies throughout the season as shown in Table 1.

Table 1. Seasonal Variation in the Minimum Release Requirement

Time Period	MRR Range (cfs)	Index	Relevance of Index
October	800 to 1,500	Four Reservoir Index (FRI)	Indicates the amount of upstream storage available during the fall and winter months
November and December	800 to 2,000	FRI	
January and February	800 to 1,750	Sacramento River Index (SRI)	Indicates current multi-basin water availability
March through Labor Day	800 to 1,750	Folsom Inflow Index (IFII)	Forecasts water availability for the American River Basin for the remainder of the current water year
Post-Labor Day through September	800 to 1,500	IFII	

The FMS also includes exceptions to the MRR during extreme dry conditions, including:

- **Conference Years:** Occur when the projected March through November unimpaired inflow to Folsom Reservoir is less than 400,000 AF. A minimum flow of 190 cfs is required downstream of the H Street Bridge.
- **Off-ramp Criteria:** Triggered if Folsom Reservoir storage is forecasted to fall below 200,000 AF in the succeeding 12 months. In this case, downstream flow requirements rather than MRR become the minimum flow requirement throughout the lower American River.

2. Water Temperature Objectives

The water temperature objectives of the FMS have been developed to allocate the available lower American River cold water resources for juvenile steelhead rearing in summer, and fall-run Chinook salmon spawning in fall. These objectives are met through use of an Annual Operations Forecast (Operations Forecast) and Annual Water Temperature Management Plan (Temperature Plan).

The Operations Forecast will be prepared by May 1 of each year to describe forecasted American River operations, including flows and water temperatures for the next 12 months, with implementation of the Minimum Flow Requirements and Water Temperature Objectives.

The Temperature Plan will be developed by May 1 of each year to describe how Reclamation will meet the following water temperature objectives for the lower American River:

- ☐ 65ºF or less from May 15 through October at Watt Avenue for steelhead juvenile rearing. This objective may be relaxed to 68ºF if Temperature Plan analysis indicates that lower temperature targets will prematurely exhaust the available cold water.
- ☐ 60ºF or less as early in October as possible at Hazel Avenue for Chinook salmon spawning and egg incubation.

3. Implementation Criteria

Implementation criteria serve as a tool to determine the conditions by which the FMS Minimum Flow Requirements may be implemented, and to define the method of measuring compliance with the FMS Minimum Flow Requirements. The implementation criteria that are applied for decision-making purposes regarding operational adjustments affecting lower American River flows and water temperatures address the following: (1) end-of-month Folsom Reservoir storage, particularly during May and September; (2) Nimbus Dam releases and flows at the mouth of the lower American River measured over a 5-day averaging period; (3) water conservation adjustments; (4) fish protection adjustments; and (5) other considerations.

4. Lower American River Group

The Lower American River Group (ARG) is an advisory group consisting of agency representatives convened regularly by Reclamation. Through the regularly scheduled ARG meetings, which are open to the public, the ARG provides information to the public and formulates CVP operational recommendations for the protection of fisheries and other in-stream resources consistent with the FMS.

5. Monitoring and Evaluation

Monitoring and evaluation of physical and biological factors are included in the FMS to provide information to support operational decisions and to evaluate operational effects on the aquatic resources of the lower American River including river hydrology, water temperature, salmonid population and downstream movement.

6. Current Status

Sacramento County recently adopted a revised American River Parkway Plan which includes specific policies related to implementing water flows protective of the lower American River ecosystem. The Parkway Plan serves as a guide for other local, state and federal agencies with authority within the American River Parkway under the Wild and Scenic Rivers Act and the Urban American River Parkway Preservation Act. Sacramento County, through the Water Forum, is in the process of preparing a draft environmental impact report to institute the FMS consistent with the American River Parkway Plan and the coequal goals of the Water Forum Agreement by entering into an operations agreement with Reclamation or by seeking to modify Reclamation's Folsom Dam water right permits or other measures.

Reclamation has been operating the Folsom and Nimbus Dams in accordance with the minimum release requirements of the FMS since 2006. In 2009, the National Marine Fisheries Service

(NMFS) included the FMS flow, operational criteria, American River Group, and monitoring requirements in the Reasonable and Prudent Alternatives of the Biological Opinion (BO) for operating the CVP. The NMFS BO also called for an iterative temperature management planning process that is consistent with the water temperature objectives of the FMS.

The Water Forum is currently investigating the potential for an improved Flow Standard for the lower American River that would provide increased protection of salmonid species and improved water supply reliability.

Yuba River

In 2008, the State Water Resources Control Board (the SWRCB) adopted minimum streamflow requirements and related measures proposed by Yuba County Water Agency (YCWA) that implemented the Yuba River Accord Fisheries Agreement, which YCWA developed with the Department of Fish and Game (DFG), the National Marine Fisheries Service (NMFS), the U.S. Fish and Wildlife Service (USFWS) and several conservation groups. The Accord and the SWRCB's related order – Corrected Order WR 2008-14 – resolved 20 years of disputes concerning the Yuba River's minimum streamflows. The Accord streamflow requirements, as implemented by the SWRCB, are depicted in Exhibit A. The SWRCB adopted Corrected Order WR 2008-14, after considering a $6 million environmental impact report that YCWA certified and that was not challenged in court. The Yuba River Accord is summarized below and additional information is available on YCWA's website at http://www.ycwa.com/projects/detail/8.

Disputes concerning the Yuba River's streamflows began in 1988 and continued through a 14-day SWRCB hearing in 1992, a 13-day SWRCB hearing in 2000 and a three-day SWRCB hearing in 2003. In 2003, the SWRCB adopted Revised Water Right Decision 1644 (RD-1644). Many lawsuits, including one by YCWA, were filed to challenge RD-1644.

As an alternative to litigating these disputes to a conclusion, YCWA, DFG, NMFS, USFWS and environmental groups engaged in a collaborative, science-based process to identify and prioritize the key stressors on salmon and steelhead in the lower Yuba River and then to develop streamflow requirements that would address these stressors. The resulting Yuba Accord Fisheries Agreement sets new, substantially-higher streamflow requirements that allocate more water to fishery benefits than RD-1644 would have required. Specifically, the Fisheries Agreement's streamflow schedules include up to more than 174,000 acre-feet of water annually, and more than 100,000 acre-feet in the springtime of about 60% of all years, to fishery benefits than RD-1644 would have required. The Fisheries Agreement allocates these fishery streamflows in a manner that enables YCWA to deliver approximately 350,000 acre-feet of water per year for consumptive use in Yuba County and to transfer water to downstream water users, including Delta-export agencies, for irrigation, municipal and environmental uses.

The Fisheries Agreement is one of four agreements that make up the Yuba River Accord. The other agreements are: (1) Conjunctive Use Agreements with local Yuba County water suppliers; (2) a Water Transfer Agreement with the state Department of Water Resources (DWR); and (3) an agreement with PG&E to allow modified operations at YCWA's New Bullards Bar Reservoir.

Under the Conjunctive Use Agreements, Yuba County water suppliers agreed to pump up to 30,000 acre-feet of groundwater to substitute for surface water deliveries in certain dry years to provide water allocated by the Fisheries Agreement for fishery benefits. Also under the Conjunctive Use Agreements, YCWA agreed to provide funding from its Accord transfer proceeds to assist water suppliers in pumping the necessary groundwater and to monitor local groundwater conditions to ensure that pumping under the Accord does not cause overdrafts. Under the Water Transfer Agreement, YCWA agreed to transfer at least 60,000 acre-feet per year of water to the Environmental Water Account (and successor programs) and potentially 140,000 acre-feet of water in drier years to DWR. In addition to assisting local Yuba County water suppliers in implementing conjunctive use, YCWA has used Accord transfer proceeds to contribute to the funding of setback-levee projects and other flood risk management projects.

The Accord Fisheries Agreement contains several unique elements besides the new streamflow requirements depicted in Exhibit A. The Agreement establishes a River Management Team (RMT), which includes representatives of YCWA, DFG, NMFS, USFWS, PG&E and conservation groups. The RMT may modify flows at certain times for fishery benefits (subject to SWRCB approval). The RMT also is responsible for allocating 50% of the volume of any supplemental surface water transfer by YCWA and up to 20% of the streamflows enabled by implementation of the Accord Conjunctive Use Agreements. The RMT oversees a monitoring and evaluation program that has the goal of determining the efficacy of the Fisheries Agreement's streamflows. That Agreement also establishes a cap on irrigation diversions in extremely dry (1-in-100) "conference years" at about 70% of annual irrigation demands.

Consistent with the Accord agreements, the SWRCB's Corrected Order WR 2008-14 approved water-right permit terms under which, in conference years, YCWA will operate its project to maintain the minimum streamflows required by a 1965 streamflow agreement between YCWA and DFG, but without certain reductions authorized by that agreement and subject to supplemental flow release requirements developed by the RMT's Planning Group under the Fisheries Agreement and approved by the SWRCB's Deputy Director for Water Rights. Under Corrected Order WR 2008-14, if the Planning Group does not make any streamflow recommendations in a conference year by April 1 or if no streamflow requirements are in place by April 11 of such a year, then YCWA must comply with streamflow requirements ordered by the SWRCB after a hearing.

When YCWA operates its facilities, it must comply with the requirements of its existing license for Project No. 2246, which was issued by the Federal Energy Regulatory Commission (FERC). Those FERC license requirements, however, typically are satisfied through implementation of the Accord Fisheries Agreement's streamflow requirements.

The Yuba River Accord has been recognized as a landmark achievement in collaborative water management to achieve water supply reliability and habitat protection. For example, the Accord received the 2008 ACWA Theodore Roosevelt Environmental Award for Excellence in Conservation and Natural Resources Management, the 2009 National Hydropower Association Award for Outstanding Stewards of America's Waters and the 2009 Governor's Environmental and Economic Leadership Award.

EXHIBIT A
Yuba Accord Streamflows, Approved by SWRCB in Corrected Order WR 2008-14

MARYSVILLE GAGE (CFS)

Schedule	OCT		NOV	DEC	JAN	FEB	MAR	APR		MAY		JUN		JUL	AUG	SEP	Total Annual
	1-15	16-31	1-30	1-31	1-31	1-29	1-31	1-15	16-30	1-15	16-31	1-15	16-30	1-31	1-31	1-30	Volume (AF)
1	500	500	500	500	500	500	700	1000	1000	2000	2000	1500	1500	700	600	500	574,200
2	500	500	500	500	500	500	700	700	800	1000	1000	800	500	500	500	500	429,066
3	500	500	500	500	500	500	500	700	700	900	900	500	500	500	500	500	398,722
4	400	400	500	500	500	500	500	600	900	900	600	400	400	400	400	400	361,944
5	400	400	500	500	500	500	500	500	600	600	400	400	400	400	400	400	334,818
6	350	350	350	350	350	350	350	350	500	500	400	300	150	150	150	350	232,155

* Indicated flows represent average volumes for the specified time period. Actual flows may vary from the indicated flows according to established criteria.
* Indicated Schedule 6 flows do not include an additional 30 TAF available from groundwater substitution to be allocated according to established criteria

SMARTVILLE GAGE (CFS)

Schedule	OCT		NOV	DEC	JAN	FEB	MAR	APR		MAY		JUN		JUL	AUG	SEP	Total Annual
	1-15	16-31	1-30	1-31	1-31	1-29	1-31	1-15	16-30	1-15	16-31	1-15	16-30	1-31	1-31	1-30	Volume (AF)
A	700	700	700	700	700	700	700	700	-	-	-	-	-	-	-	700	-
B	600	600	600	550	550	550	550	600	-	-	-	-	-	-	-	500	-

* Schedule A used with Schedules 1, 2, 3 and 4 at Marysville.
* Schedule B used with Schedules 5 and 6 at Marysville.

Feather River

On December 15, 2010, the SWRCB adopted, as Order WQ 2010-0016, a water quality certification for the Oroville Facilities, FERC # 2100, for the relicensing of the Oroville project by DWR. The water quality certification contains instream-flow and temperature-control requirements for the Feather River's reaches downstream of DWR's Oroville Dam.

In general, the streamflow requirements adopted by the SWRCB in the certification are as follows.

For the Low Flow Channel – which is the reach between DWR's Fish Barrier Dam and the outlet of the Thermalito Afterbay – the certification requires that DWR release into that Channel 800 cfs from September 9 to March 31 of each water year to accommodate spawning anadromous fish and 700 cfs the remainder of the time, with both standards subject to possible revision as recommended by resource agencies under a settlement agreement signed by parties to DWR's relicensing proceeding. The SWRCB's Deputy Director for Water Rights would have to approve changes from the indicated streamflows for the Low Flow Channel.

For the High Flow Channel – which is the reach between the Thermalito Afterbay's outlet and the Feather River's confluence with the Sacramento River – the certification applies the following instream-flow requirements, provided that they, along with project operations, are not projected to cause Oroville

Reservoir to be drawn below elevation 733 feet (approximately 1,500,000 acre-feet of storage):

Preceding April through July unimpaired runoff	Minimum Flow in HFC October-February	Minimum Flow in HFC March	Minimum Flow in HFC April-September
Percent of Normal			
55% or greater	1,700 cfs	1,700 cfs	1,000 cfs
Less than 55%	1,200 cfs	1,000 cfs	1,000 cfs

Under the certification, if applying these requirements would be projected to cause Oroville Reservoir to be drawn below elevation 733 feet, then the minimum streamflows in the High Flow Channel could be reduced by the same percentage as State Water Project deliveries for agricultural use, provided that streamflows would not ever be reduced more than 25 percent below the requirements. In addition, if the highest one-hour streamflow between October 15 and November 30 were to exceed 2,500 cfs because of project operations and not a flood flow, then DWR is required to maintain a minimum flow within 500 cfs of the peak flow.

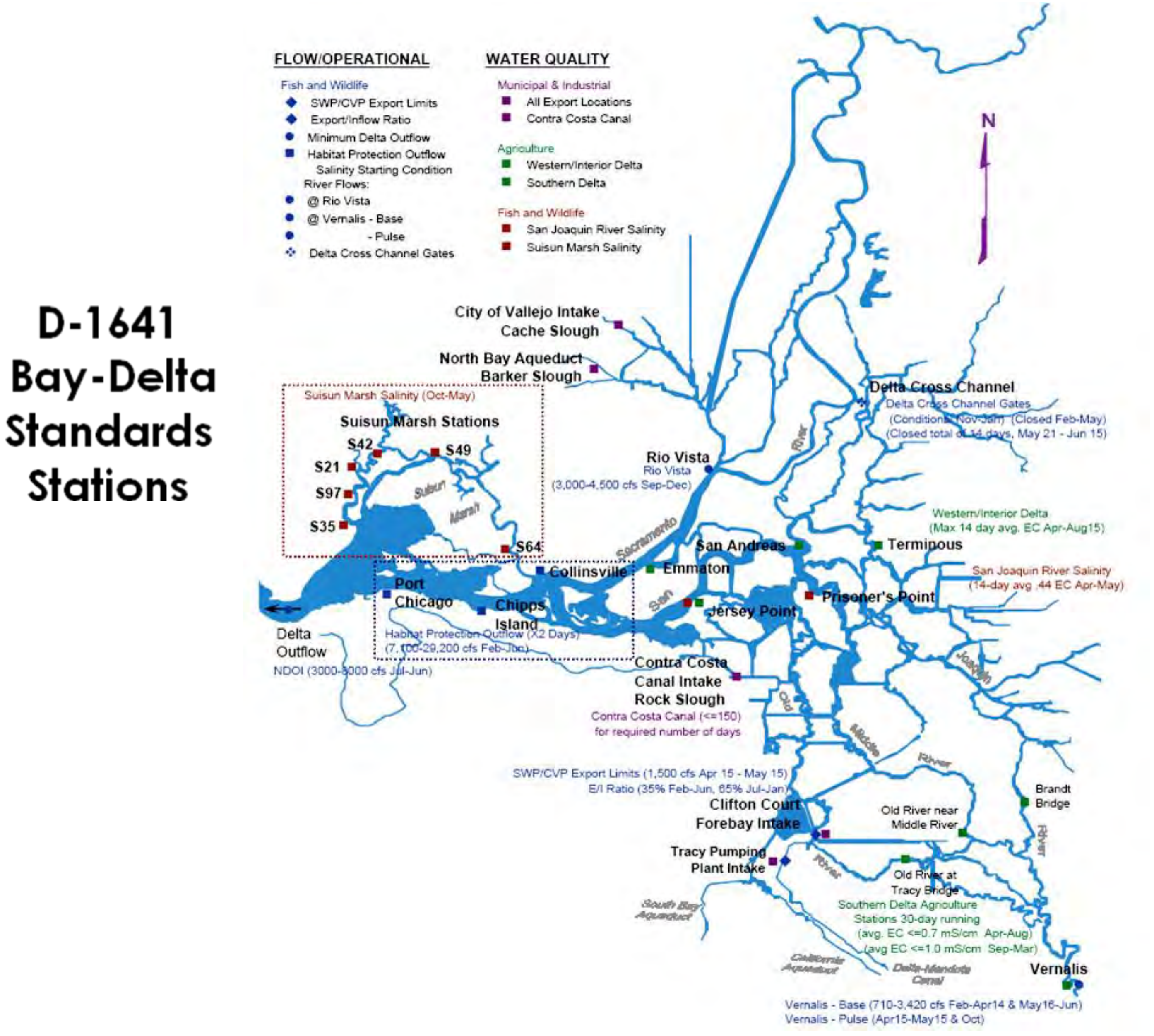
The certification also contains complex terms that require DWR to operate the Oroville project to meet temperature standards in the Low Flow Channel and the High Flow Channel.

For the Low Flow Channel at the Robinson Riffle, the certification sets the following temperature standards: (1) October 1-April 30, 56 degrees F; (2) May 1-15, 56-63 degrees F (as a transition); (3) May 16-August 31, 63 degrees F; (4) September 1-8, 63-58 degrees F (as a transition); and (5) September 9-30, 58 degrees F. If DWR were to demonstrate that it cannot meet these requirements with its current facilities, then the certification would require DWR to submit an interim operations plan to the SWRCB and, within three years of the renewed FERC license's issuance, submit a long-term facility-modification and operations plan to the SWRCB. If after implementing the facility modifications, DWR were to demonstrate that it still cannot meet the above temperature standards, then DWR would be required to propose alternate temperature standards that would provide "reasonable protection of the COLD beneficial use." Upon the approval of the SWRCB's Deputy Director for Water Rights, DWR would be required to operate to the alternate standards.

For the High Flow Channel, DWR is required to operate the project "to protect the COLD beneficial use in [that Channel], as measured in the Feather River at the downstream Project Boundary, to the extent reasonably achievable." Within one year of the renewed FERC license's issuance, DWR would be required to submit an operations plan for the period before facility modifications, which plan would be required to include proposed interim temperature standards and interim measures to reduce temperatures. Within three years of the renewed FERC license's issuance, DWR would be required to submit a long-term facility modification and operations plan, which plan would have to include proposed temperature standards to take effect within 10 years of the renewed license's issuance.

Bay-Delta Standards

The following map shows the existing Bay-Delta standards in SWRCB Decision 1641. Water supplies in the Sacramento Valley are operated to meet these standards.



Appendix 9

Media Contact:
Nancy Vogel, Deputy Secretary for Communications, (916) 653-9402, nancy.vogel@resources.ca.gov

August 31, 2016

New Strategy to Improve Conditions for Delta Smelt Shows Promising Results

Comprehensive Approach Seeks to Reverse Decline in Smelt Population

YOLO BYPASS WILDLIFE AREA – The initial monitoring of a new strategy to improve conditions for the endangered Delta smelt shows significant promise in creating a bloom in the plankton that nourish these imperiled fish. State and federal leaders were joined today by Sacramento Valley farmers and water providers along the banks of the Yolo Bypass to describe the successful experiment and deliver the first update on the State's comprehensive Delta Smelt Resiliency Strategy. The effort is intended to improve ecosystem conditions so more young Delta smelt survive this year and reproduce.

"Acting on a scientific hunch with cooperation that extended deep into the Sacramento Valley, we moved quickly to see if we could boost the Delta smelt food supply in the western Delta in this fifth year of drought," said Charlton H. Bonham, Director of the California Department of Fish and Wildlife. He added, "The results surpassed our expectations and give us hope that in future years we can relatively quickly and easily take advantage of the Yolo Bypass floodplain to improve conditions for a species on the brink of extinction."

State, federal and local water district officials partnered this summer to send water through a wetland and tidal slough corridor of the Sacramento River system and into the Delta where it created a phytoplankton bloom, the critical base of the food web for smelt. The plan was developed based on observations by agency scientists in the fall of 2011 and 2012 following larger-than-normal agricultural drainage flows from the Yolo Bypass. These flows produced an unusual plankton bloom in the Rio Vista area of the lower Sacramento River. Scientists theorized that this production of plankton could be generated in other years if the conditions in the Yolo Bypass could be repeated.

This finding led to a cooperative effort earlier this summer between state and federal governments and various water agencies along the Sacramento River including the Glenn-Colusa Irrigation District, Reclamation District 108, Reclamation 2035, Knaggs Ranch, and Conaway Ranch. The Tehama-Colusa Canal Authority and the U.S. Bureau of Reclamation assisted, along with many other local agricultural partners in the Valley. The result was a redirection of water from the Sacramento River down the Colusa Basin Drain, through the Knights Landing Ridge Cut Slough, past Wallace Weir, through the Yolo Bypass and into the Delta to provide the optimal conditions to create the critical food source for growing Delta smelt. A recent substantial Delta plankton bloom at Rio Vista indicates that this strategy was effective in boosting downstream food web resources for smelt.

“This effort provides a good example of the application of scientific research to address complex management issues,” said Dr. Ted Sommer, lead scientist for the California Department of Water Resources. He added, “The overall strategy of the smelt plan was based on an intensive effort by a multi-agency team to isolate the major factors affecting different life stages of Delta smelt and to identify the habitat, environmental and landscape conditions that could be improved to support better growth, health and reproduction.”

Other actions included in the Delta Smelt Resiliency Strategy include treatment of invasive aquatic weeds in critical smelt habitat in the Delta; generating more brackish water habitat at certain times of the year; studying the potential of re-operating salinity control gates in the Suisun Marsh to attract smelt into high-quality habitat; assessing the feasibility of adding sediment to certain zones in the Delta to create the turbidity smelt need to hide from predators; and studying the feasibility to add sand in certain areas of the Delta which is used by smelt to spawn. In addition, a number of habitat restoration projects that are highly-likely to benefit Delta smelt are planned or underway.

“There is not one simple solution to save the smelt, but a complex set of challenges which must be identified and addressed to secure smelt survival,” said Lewis Bair, general manager, Reclamation District 108. He added, “This is why we are actively working to implement this part of the Delta Smelt Resiliency Strategy in the Sacramento Valley—providing vital nourishment and improving habitat in the Yolo Bypass for smelt to thrive and reproduce. We are very proud of this partnership between state and federal agencies, the environmental community and local water districts because these actions are making a difference for birds, fish and farms.”

The Delta Smelt Resiliency Strategy is being implemented by the California Department of Fish and Wildlife, the California Department of Water Resources, the Division of Boating and Waterways, the U.S. Fish and Wildlife Service and the U.S. Bureau of Reclamation. The smelt food production plan is being executed through a partnership involving local, state and federal agencies teaming up with Sacramento Valley agricultural water users and farmers. This is the latest chapter of cooperation involving a coalition of farmers, water providers, conservationists and regulators who are driven by the mindset to “fix it” rather than “fight it” to improve fish and wildlife habitat throughout the Sacramento River region.

“It is critical – and possible with these partnerships – to improve fish and wildlife habitat through the efficient use of our region’s water resources while managing a productive farm economy,” said David Guy, President of the Northern California Water Association. He added, “The drought has not only impacted smelt, but it has also affected the ability to deliver water for farms, wildlife refuges and recreation throughout the region. Farmers and the rural communities throughout the Sacramento Valley care deeply about our rivers, they understand how the rivers function and they have made significant investments in efforts to preserve and improve fish and wildlife habitat. This cooperation is unique and truly benefits all Californians."

To learn more about California EcoRestore and other habitat restoration projects underway in the Delta, go to http://resources.ca.gov/ecorestore/.

To download video related to the pulse flow and plankton bloom, visit ftp://ftp.wildlife.ca.gov/OCEO/Wallace%20Weir/.

###

Every Californian should conserve water.
Find out how at:

SaveOurWater.com ·· Drought.CA.gov

Delta Smelt Food Web Flow Action

Summer 2016

Increased Keswick Flows

Project Coordination

Delivery of Sac River Flow

Additional pumping

Reoperation of KLOG

Wallace Weir Coordination

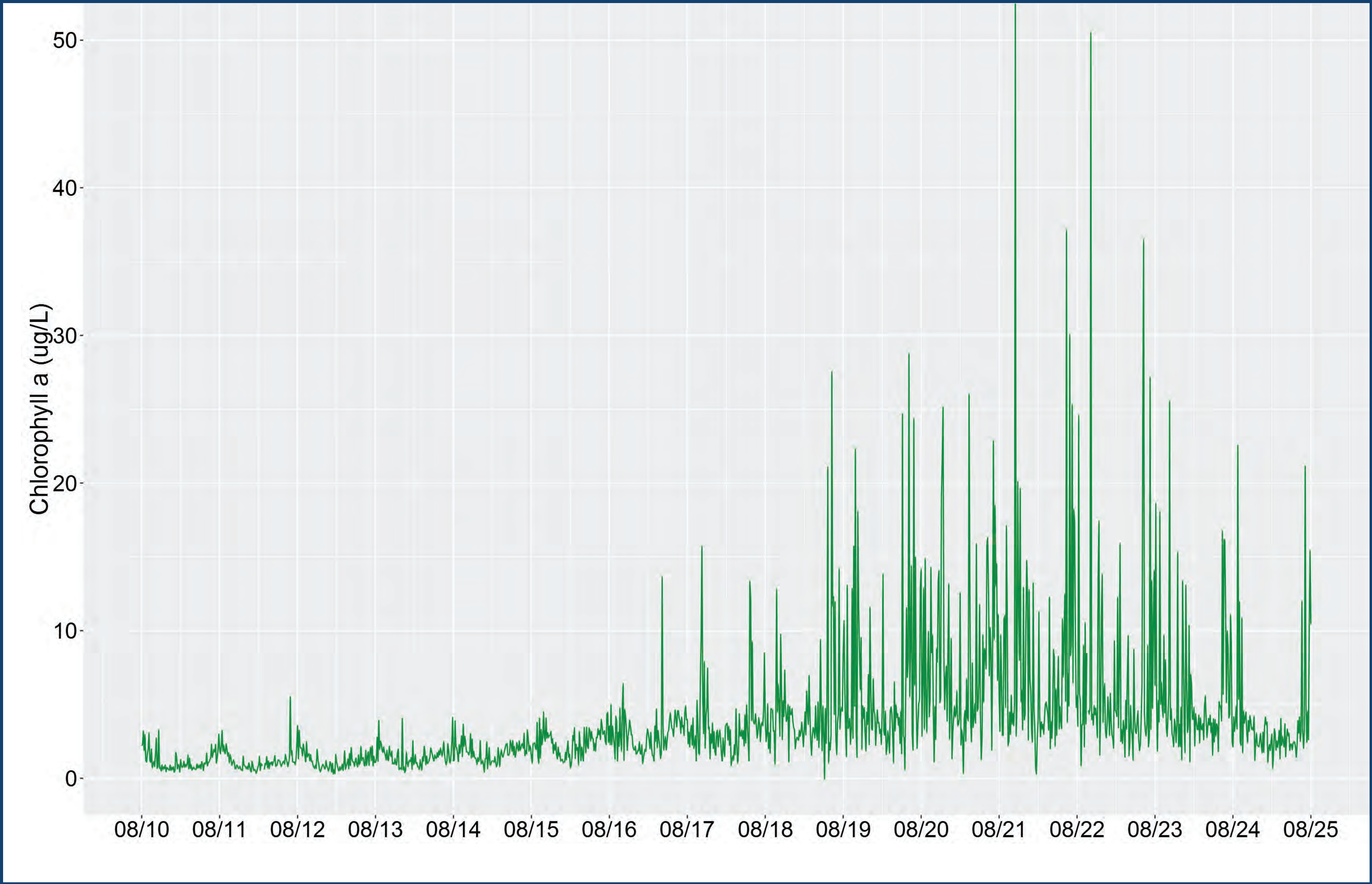
Knaggs Ranch

Additional pumping

Hungry Smelt

Base map courtesy of NOAA Fisheries

Phytoplankton at Rio Vista



2016 North Delta Food Web Action

Who worked on the project?

-Department of Water Resources led the effort as part of the *Delta Smelt Resilience Strategy*.
-The project was major collaboration with action coordinators (Resources Agency, DFW), fisheries agencies (DWR, NMFS, FWS), diverters (GCID, RD108, Conaway Group), funding sources (DFW, USBR, SFCWA), and scientists (USGS, SFSU, UCD).

Why was there an interest in enhancing the food web?

-Loss of plankton is a major factor responsible for the decline of many fishes including the endangered Delta Smelt, whose status affects water supply reliability in the state.

Why was Yolo Bypass a focus?

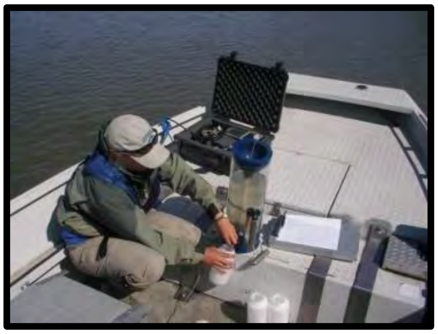
-Yolo Bypass and Cache Slough Complex are known to be relatively richer in plankton than most other parts of the Delta.
-Much of this productivity may not reach the Delta in drier months because local water diversions tend to pull water away from the lower Sacramento River.
-Scientists observed that larger-than-normal fall 2011 and 2012 agricultural flow pulses were followed by downstream Delta plankton blooms. These were the first fall blooms in over 20 years.

What was the basic idea behind the action?

-By routing water through Yolo Bypass instead of the Sacramento River, DWR scientists predicted that a flush of plankton-rich water would provide a "seed" for the downstream Delta, enhancing food resources for Delta Smelt.
-A July 2016 flow pulse was generated with the help of Sacramento Valley water users (See attachment 1).

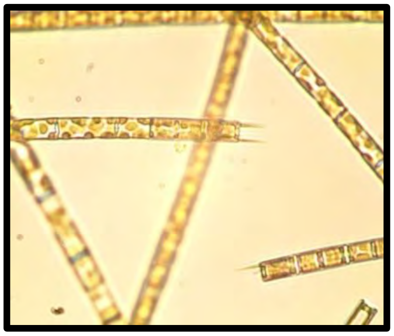
What was measured in the study?

-Water quality, contaminants, plankton, and clams (consumers of plankton) were measured before, during experimental flows at multiple locations.
-Delta Smelt collected during fall will also be analyzed.



2016 North Delta Food Web Action

Did the Action Work?



Aulacoseira granulata

-The action generated a substantial flow pulse (12,700 af) for over two weeks in July. However, the flow was less than the target of 24,000 af.

-As predicted, the flow pulse coincided with a wave of phytoplankton (as measured by chlorophyll *a*) through Yolo Bypass.

-<u>The action generated a major increase in phytoplankton in the Delta at Rio Vista.</u>

-The bloom was dominated by a “good” variety, not a harmful species.

What still needs to be done in 2016?

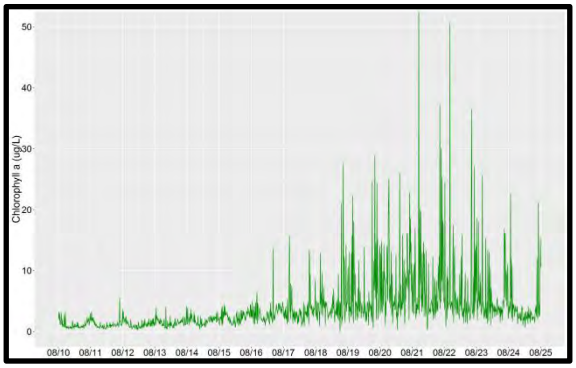
-There are still many samples that need to be analyzed.

-We are still waiting for data from project partners including USGS and SFSU.

-Of particular interest is whether there is a response in zooplankton and Delta Smelt.

-The results will be presented at the upcoming 2016 Bay-Delta Science conference, and written up for scientific peer-review.

Rio Vista Phytoplankton Response



What are future plans?

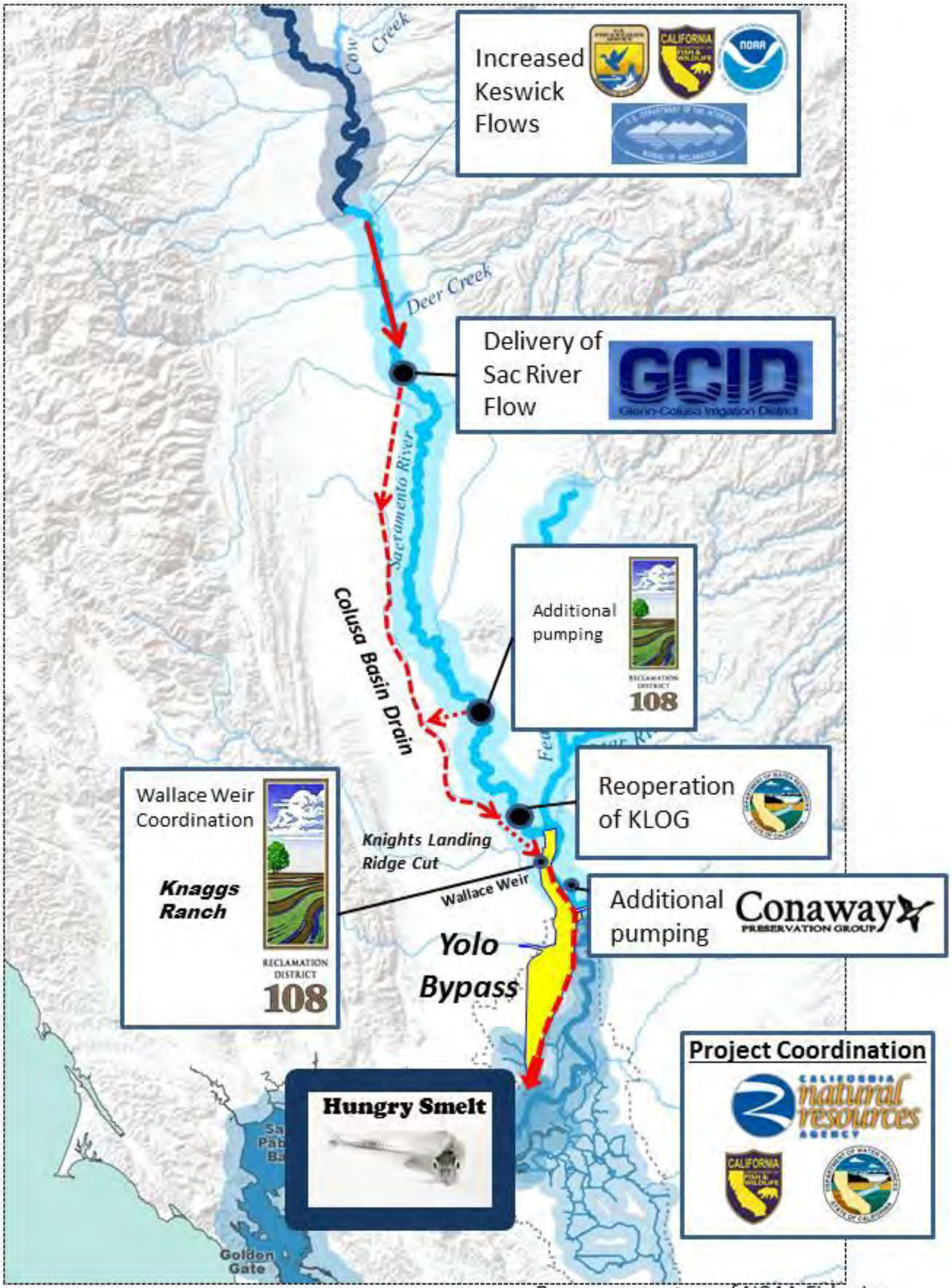
-Funding is available in the Delta Smelt Resilience Strategy for at least two more years.

-A 2017 action could be considered in other months and with more flow, although careful planning may be needed to work around a new Yolo contruction project (“Ag 4 Crossing).

-Long-term improvements to Yolo Bypass including a proposed notch and fish ladder could make this action easier to implement.

-Improved flows in Yolo Bypass will likely help leverage the efficacy of proposed habitat restoration projects in the north Delta.

2016 North Delta Food Web Action



Base map courtesy of NOAA Fisheries

Appendix 10

The Sacramento Valley & Waterfowl

California's **Sacramento Valley** is the single most important wintering area for waterfowl along the Pacific Flyway with 4-5 million waterfowl migrating to the region every fall from as far away as Alaska, Canada, and Siberia. The Sacramento Valley's world-renowned mosaic of natural resources, including farms, wildlife refuges and managed wetlands, cities and rural communities, and meandering rivers work together in concert to support and feed waterfowl, shorebirds, raptors and other species.

As the map on the reverse side shows, diverse land types such as refuges, ricelands, private wetlands, and other farms sustain birds with food and shelter through winter and into spring, acting as surrogate wetlands to defray the loss of 95% of the historic wetland areas in the state.

Each year, between 500,000 and 600,000 acres of rice are planted in the Sacramento Valley, providing habitat for more than 230 species, including many birds. In a typical fall and winter, around 350,000 acres of this rice land is flooded, providing the greatest amount of Pacific Flyway habitat. In addition, more than 40,000 acres of privately managed wetlands and 27,000 acres within the National Wildlife Refuges and State Wildlife Areas also make substantial contributions to the Pacific Flyway habitat in the region.

All of this habitat is reliant upon the ability of Sacramento Valley water districts and companies to divert and deliver surface water resources year-round in accordance with their contracts and water rights. According to the **Central Valley Joint Venture** (CVJV), the combined winter water needs of flooded rice and wetlands in the Sacramento Valley is almost 1.1 million acre-feet per year.*

Currently, the region is experiencing a tenuous balance, providing just enough food for the waterfowl and other birds traveling to the Sacramento Valley in the winter months. Redirecting water to other areas would result in less acres of habitat by shifting the balance, leaving the birds without adequate food.

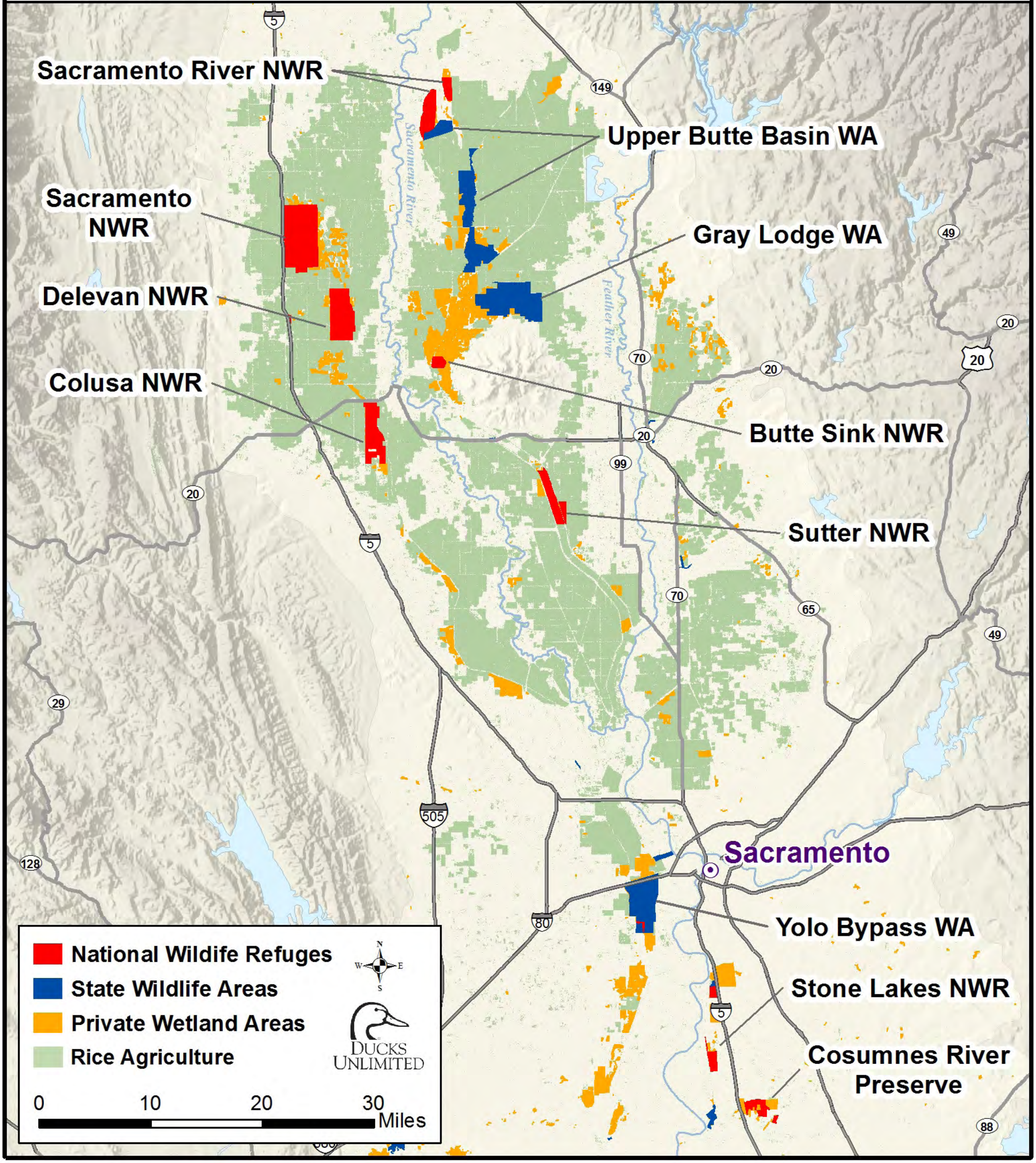
Thanks to the sum of its parts, the Sacramento Valley is an ecological success story where the mosiac of land uses limited water resources to create a modern habitat combination that works for both humans and birds.

**This includes more than 250,000 acre-feet in additional water needed to reach CVJV water supply goals for refuges and privately managed wetlands*

DUCKS UNLIMITED

NCWA
Northern California Water Association

Wetland Areas and Rice Fields in the Sacramento Valley of California



Appendix 11

SWC State Water Contractors Served by the State Water Project Founded in 1982
NCWA Northern California Water Association
TCCA Tehama Colusa Canal Authority
RWA 15 YEARS
San Luis & Delta-Mendota Water Authority

July 19, 2016

Felicia Marcus, Chair
Members of the Board
State Water Resources Control Board
1001 I Street
Sacramento, CA 95814

Re: Integrating Delta Science

Dear Chair Marcus and Members of the Board:

The broad coalition of undersigned public water agencies and water companies serving a significant part of urban and rural California call on the State Water Resources Control Board (State Water Board) to formally engage the Delta Science Program in a robust and rigorous process to both develop and review the scientific basis for Phase II of the Bay-Delta Water Quality Control Plan (WQCP) update. We strongly encourage this engagement prior to the release of a draft or proposed scientific basis report. As we have seen from past experiences, a successful and credible WQCP process will utilize and rely upon the best available data and science that is both developed and peer-reviewed through an independent and scientifically focused entity, such as the Delta Science Program.

The Delta Reform Act of 2009 established the Delta Science Program and the Delta Independent Science Board to formally advance the concept of *One Delta, One Science*. “The mission of the Delta Science Program [is] to provide the best possible unbiased scientific information to inform water and environmental decision making in the Delta. That mission shall be carried out through funding research, synthesizing and communicating scientific information to policymakers and decision-makers, promoting independent scientific peer review, and coordinating with Delta agencies to promote science-based adaptive management. The Delta Science Program shall assist with development and periodic updates of the Delta Plan's adaptive management program.” (Water Code §85280(b)(4).)

The California Water Action Plan (Action Plan) further elaborated that “the administration will direct relevant agencies and departments to work with the Delta Science Program, the Interagency Ecological Program, and others conducting science in the Delta to implement the Delta Science Plan, committing resources and funding for shared science to achieve integrated, collaborative and transparent science to enhance water and natural resource policy and management decisions.” (Page 21.)

The Action Plan also adds that “a coordinated approach to managing the Delta is essential to serve the needs of California’s residents. State agencies will commit to using collaborative processes to achieve water supply, water quality and ecosystem goals. This approach embraces enhanced sharing of data, consistent use of peer-reviewed science, coordinated review under the California Environmental Quality Act, improved integration of related processes, and encouragement of negotiated resolutions.” (Page 20.)

A completely independent process, such as one conducted by the Delta Science Program and envisioned in the Delta Science Plan (*see* e.g., Appendices H and I), is essential for two reasons. First, as the Public Policy Institute of California has noted, the scientific problems presented in the Delta watershed are "wicked" problems, in that they involve the intersection of different bodies of scientific knowledge, areas where there is great uncertainty about the physical and biological processes involved, and areas where conditions are changing rapidly. Adding to the complexity of these questions, California is now squarely confronting the challenge of climate change in trying to weather a 1,200-year drought. The complexities and uncertainties associated with climate change make a difficult problem even harder. For such complicated problems, robust peer review of proposed approaches–even before a draft report is written–is essential to ensure that the best available scientific and commercial information is used as part of the scientific basis report.

Second, robust peer review assures skeptical members of the public that, despite the complexities of the Delta ecosystem, the State of California is committed to analyzing the Delta ecosystem without preconceptions and without ideological or political biases. An honest, straightforward discussion of scientific principles and uncertainties is called for by the Delta Reform Act and the California Water Action Plan. The Delta Science Program, which has the support of various State agencies, is best situated to conduct this intricate and essential review of the scientific basis for the WQCP process.

California needs a progressive approach to science that will empower 21st century water resources management to support a vibrant economy and environment. This type of rigorous and transparent scientific process with independent and objective input and review is critical to build a strong scientific foundation for California to address our water management challenges.

We look forward to discussing this approach envisioned by the Action Plan and the legislation with you in more detail at your earliest convenience.

Sincerely yours,

Terry Erlewine
State Water Contractors

David Guy
Northern California
Water Association

Jason P.
Jason Peltier
San Luis and Delta-Mendota Water Authority

Jeffrey P Sutton
Jeffrey Sutton
Tehama Colusa Canal Authority

John Woodling
Regional Water Authority

cc: Tom Howard
Randy Fiorini
Jay Lund
Jessica Pearson
Michael George

Appendix 12

QUESTIONS FOR INDEPENDENT REVIEWERS OF PHASE 2 DRAFT SCIENTIFIC BASIS REPORT

For each objective intended to protect/benefit fish/wildlife beneficial uses (and, when applicable, the period of time the objective might control):

1. Does the report reflect current scientific information or "lessons learned" from management actions taken within the Bay-Delta?

2. Does the report adequately present the scientific basis in the context of the full species life cycle? If not, what elements of the species life cycle are lacking?

3. Does the report adequately identify the biological mechanism or mechanisms expected to be protected/benefited? Does the report discuss the stressor(s) involved, how the stressor(s) involved affect the biological mechanism(s), and the evidence showing the relationship between the stressor and the mechanism (e.g., in other contexts, a dose-response curve)?

4. Does the report adequately identify the scientific report(s) cited to support the identified biological mechanism or mechanisms? If not, what scientific report(s) should be cited? Does the report identify scientific reports that may contradict the identified biological mechanism or mechanisms?

5. Does the report adequately identify uncertainties in the science (likelihood the benefit of the objective will be realized)? These uncertainties include, but should not be limited to, statistical uncertainties in the predicted response of the species to the required action; uncertainties in whether the identified mechanisms are the true mechanisms; and uncertainties in future environmental conditions. Does the report identify testable conceptual models or hypotheses that would enable investigators to better understand the uncertainties? If not, what are the testable conceptual models or hypotheses that can be identified from the scientific literature?

6. Does the report adequately identify the policy decision needed when applying the science?

7. Does the report identify the anticipated result(s) (both qualitative and quantitative) of each objective? If so, does the report identify the uncertainty in the anticipated results?

8. Does the report adequately analyze or describe potential unintended adverse impacts from the flow recommendations on all life stages for the same and other species?

9. Is there an alternative methodology or approach that would provide similar levels of benefit/protection/uncertainty with less cost to resources (water)?

10. Does the report incorporate adequately the structured decision-making required to support development of adaptive management and necessary monitoring to support adaptive management?

11. Does the report adequately identify the monitoring program needed to evaluate the expected biological mechanism or mechanisms and the expected outcomes in species populations?